PHYSICS IN MANY-SHEETED SPACE-TIME

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Contents

List of Figures

0.1 Background

T(opological) G(eometro)D(ynamics) is one of the many attempts to find a unified description of basic interactions. The development of the basic ideas of TGD to a relatively stable form took time of about half decade [16]. The great challenge is to construct a mathematical theory around these physically very attractive ideas and I have devoted the last twenty-three years for the realization of this dream and this has resulted in seven online books [TGDview, TGDgeom, TGDquant, TGDnumber, TGDclass, TGDpad, TGDfree] about TGD and eight online books about TGD inspired theory of consciousness and of quantum biology [TGDconsc, TGDselforg, TGDware, TGDholo, TGDgeme, TGDeeg, TGDmagn, 15].

Quantum T(opological)D(ynamics) as a classical spinor geometry for infinite-dimensional configuration space, p-adic numbers and quantum TGD, and TGD inspired theory of consciousness have been for last decade of the second millenium the basic three strongly interacting threads in the tapestry of quantum TGD.

For few yeas ago the discussions with Tony Smith generated a fourth thread which deserves the name 'TGD as a generalized number theory'. The work with Riemann hypothesis made time ripe for realization that the notion of infinite primes could provide, not only a reformulation, but a deep generalization of quantum TGD. This led to a thorough and extremely fruitful revision of the basic views about what the final form and physical content of quantum TGD might be.

The fifth thread came with the realization that by quantum classical correspondence TGD predicts an infinite hierarchy of macroscopic quantum systems with increasing sizes, that it is not at all clear whether standard quantum mechanics can accommodate this hierarchy, and that a dynamical quantized Planck constant might be necessary and certainly possible in TGD framework. The identification of hierarchy of Planck constants whose values TGD "predicts" in terms of dark matter hierarchy would be natural. This also led to a solution of a long standing puzzle: what is the proper interpretation of the predicted fractal hierarchy of long ranged classical electro-weak and color gauge fields. Quantum classical correspondences allows only single answer: there is infinite hierarchy of p-adically scaled up variants of standard model physics and for each of them also dark hierarchy. Thus TGD Universe would be fractal in very abstract and deep sense.

TGD forces the generalization of physics to a quantum theory of consciousness, and represent TGD as a generalized number theory vision leads naturally to the emergence of p-adic physics as physics of cognitive representations. The seven online books [TGDview, TGDgeom, TGDquant, TGDnumber, TGDclass, TGDpad, TGDfree] about TGD and eight online books about TGD inspired theory of consciousness and of quantum biology [TGDconsc, TGDselforg, TGDware, TGDholo, TGDgeme, TGDeeg, TGDmagn, 15] are warmly recommended to the interested reader.

0.2 Basic Ideas of TGD

The basic physical picture behind TGD was formed as a fusion of two rather disparate approaches: namely TGD is as a Poincare invariant theory of gravitation and TGD as a generalization of the old-fashioned string model.

0.2.1 TGD as a Poincare invariant theory of gravitation

The first approach was born as an attempt to construct a Poincare invariant theory of gravitation. Space-time, rather than being an abstract manifold endowed with a pseudo-Riemannian structure, is regarded as a surface in the 8-dimensional space $H = M^4_+ \times CP_2$, where M^4_+ denotes the interior of the future light cone of the Minkowski space (to be referred as light cone in the sequel) and $CP_2 = SU(3)/U(2)$ is the complex projective space of two complex dimensions [2, 18, 25, 5]. The identification of the space-time as a submanifold [21, 22] of $M^4 \times CP_2$ leads to an exact Poincare invariance and solves the conceptual difficulties related to the definition of the energy-momentum in General Relativity [Misner-Thorne-Wheeler, Logunov *et al*]. The actual choice $H = M^4_+ \times CP_2$ implies the breaking of the Poincare invariance in the cosmological scales but only at the quantum level. It soon however turned out that submanifold geometry, being considerably richer in structure than the abstract manifold geometry, leads to a geometrization of all basic interactions. First, the geometrization of the elementary particle quantum numbers is achieved. The geometry of CP_2 explains electro-weak and color quantum numbers. The different H-chiralities of H-spinors correspond to the conserved baryon and lepton numbers. Secondly, the geometrization of the field concept results. The projections of the CP_2 spinor connection, Killing vector fields of CP_2 and of H-metric to four-surface define classical electro-weak, color gauge fields and metric in X^4.

0.2.2 TGD as a generalization of the hadronic string model

The second approach was based on the generalization of the mesonic string model describing mesons as strings with quarks attached to the ends of the string. In the 3-dimensional generalization 3-surfaces correspond to free particles and the boundaries of the 3- surface correspond to partons in the sense that the quantum numbers of the elementary particles reside on the boundaries. Various boundary topologies (number of handles) correspond to various fermion families so that one obtains an explanation for the known elementary particle quantum numbers. This approach leads also to a natural topological description of the particle reactions as topology changes: for instance, two-particle decay corresponds to a decay of a 3-surface to two disjoint 3-surfaces.

0.2.3 Fusion of the two approaches via a generalization of the space-time concept

The problem is that the two approaches seem to be mutually exclusive since the orbit of a particle like 3-surface defines 4-dimensional surface, which differs drastically from the topologically trivial macroscopic space-time of General Relativity. The unification of these approaches forces a considerable generalization of the conventional space-time concept. First, the topologically trivial 3-space of General Relativity is replaced with a "topological condensate" containing matter as particle like 3-surfaces "glued" to the topologically trivial background 3-space by connected sum operation. Secondly, the assumption about connectedness of the 3-space is given up. Besides the "topological condensate" there is "vapor phase" that is a "gas" of particle like 3-surfaces (counterpart of the "baby universies" of GRT) and the nonconservation of energy in GRT corresponds to the transfer of energy between the topological condensate and vapor phase.

0.3 The five threads in the development of quantum TGD

The development of TGD has involved four strongly interacting threads: physics as infinite-dimensional geometry; p-adic physics; TGD inspired theory of consciousness and TGD as a generalized number theory. In the following these five threads are briefly described.

0.3.1 Quantum TGD as configuration space spinor geometry

A turning point in the attempts to formulate a mathematical theory was reached after seven years from the birth of TGD. The great insight was "Do not quantize". The basic ingredients to the new approach have served as the basic philosophy for the attempt to construct Quantum TGD since then and are the following ones:

a) Quantum theory for extended particles is free(!), classical(!) field theory for a generalized Schrödinger amplitude in the configuration space CH consisting of all possible 3-surfaces in H. "All possible" means that surfaces with arbitrary many disjoint components and with arbitrary internal topology and also singular surfaces topologically intermediate between two different manifold topologies are included. Particle reactions are identified as topology changes [23, 24, 25]. For instance, the decay of a 3-surface to two 3-surfaces corresponds to the decay $A \rightarrow B + C$. Classically this corresponds to a path of configuration space leading from 1-particle sector to 2-particle sector. At quantum level this corresponds to the dispersion of the generalized Schrödinger amplitude localized to 1-particle sector to two-particle sector. All coupling constants should result as predictions of the theory since no nonlinearities are introduced.

b) Configuration space is endowed with the metric and spinor structure so that one can define various metric related differential operators, say Dirac operator, appearing in the field equations of the theory.

0.3.2 p-Adic TGD

The p-adic thread emerged for roughly ten years ago as a dim hunch that p-adic numbers might be important for TGD. Experimentation with p-adic numbers led to the notion of canonical identification mapping reals to p-adics and vice versa. The breakthrough came with the successful p-adic mass calculations using p-adic thermodynamics for Super-Virasoro representations with the super-Kac-Moody algebra associated with a Lie-group containing standard model gauge group. Although the details of the calculations have varied from year to year, it was clear that p-adic physics reduces not only the ratio of proton and Planck mass, the great mystery number of physics, but all elementary particle mass scales, to number theory if one assumes that primes near prime powers of two are in a physically favored position. Why this is the case, became one of the key puzzless and led to a number of arguments with a common gist: evolution is present already at the elementary particle level and the primes allowed by the p-adic length scale hypothesis are the fittest ones.

It became very soon clear that p-adic topology is not something emerging in Planck length scale as often believed, but that there is an infinite hierarchy of p-adic physics characterized by p-adic length scales varying to even cosmological length scales. The idea about the connection of p-adics with cognition motivated already the first attempts to understand the role of the p-adics and inspired 'Universe as Computer' vision but time was not ripe to develop this idea to anything concrete (p-adic numbers are however in a central role in TGD inspired theory of consciousness). It became however obvious that the p-adic length scale hierarchy somehow corresponds to a hierarchy of intelligences and that p-adic prime serves as a kind of intelligence quotient. Ironically, the almost obvious idea about p-adic regions as cognitive regions of space-time providing cognitive representations for real regions had to wait for almost a decade for the access into my consciousness.

There were many interpretational and technical questions crying for a definite answer. What is the relationship of p-adic non-determinism to the classical non-determinism of the basic field equations of TGD? Are the p-adic space-time region genuinely p-adic or does p-adic topology only serve as an effective topology? If p-adic physics is direct image of real physics, how the mapping relating them is constructed so that it respects various symmetries? Is the basic physics p-adic or real (also real TGD seems to be free of divergences) or both? If it is both, how should one glue the physics in different number field together to get *The Physics*? Should one perform p-adicization also at the level of the configuration space of 3-surfaces? Certainly the p-adicization at the level of super-conformal representation is necessary for the p-adic mass calculations. Perhaps the most basic and most irritating technical problem was how to precisely define p-adic definite integral which is a crucial element of any variational principle based formulation of the field equations. Here the frustration was not due to the lack of solution but due to the too large number of solutions to the problem, a clear symptom for the sad fact that clever inventions rather than real discoveries might be in question.

Despite these frustrating uncertainties, the number of the applications of the poorly defined p-adic physics growed steadily and the applications turned out to be relatively stable so that it was clear that the solution to these problems must exist. It became only gradually clear that the solution of the problems might require going down to a deeper level than that represented by reals and p-adics.

0.3.3 TGD as a generalization of physics to a theory consciousness

General coordinate invariance forces the identification of quantum jump as quantum jump between entire deterministic quantum histories rather than time=constant snapshots of single history. The new view about quantum jump forces a generalization of quantum measurement theory such that observer becomes part of the physical system. Thus a general theory of consciousness is unavoidable outcome. This theory is developed in detail in the books [TGDconsc, TGDselforg, TGDware, TGDholo, TGDgeme, TGDeeg, TGDmagn, 15].

Quantum jump as a moment of consciousness

The identification of quantum jump between deterministic quantum histories (configuration space spinor fields) as a moment of consciousness defines microscopic theory of consciousness. Quantum jump involves the steps

$$\Psi_i \rightarrow U\Psi_i \rightarrow \Psi_f \quad ,$$

where U is informational "time development" operator, which is unitary like the S-matrix characterizing the unitary time evolution of quantum mechanics. U is however only formally analogous to Schrödinger time evolution of infinite duration although there is *no* real time evolution involved. It is not however clear whether one should regard U-matrix and S-matrix as two different things or not: U-matrix is a completely universal object characterizing the dynamics of evolution by self-organization whereas S-matrix is a highly context dependent concept in wave mechanics and in quantum field theories where it at least formally represents unitary time translation operator at the limit of an infinitely long interaction time. The S-matrix understood in the spirit of superstring models is however something very different and could correspond to U-matrix.

The requirement that quantum jump corresponds to a measurement in the sense of quantum field theories implies that each quantum jump involves localization in zero modes which parameterize also the possible choices of the quantization axes. Thus the selection of the quantization axes performed by the Cartesian outsider becomes now a part of quantum theory. Together these requirements imply that the final states of quantum jump correspond to quantum superpositions of space-time surfaces which are macroscopically equivalent. Hence the world of conscious experience looks classical. At least formally quantum jump can be interpreted also as a quantum computation in which matrix U represents unitary quantum computation which is however not identifiable as unitary translation in time direction and cannot be 'engineered'.

The notion of self

The concept of self is absolutely essential for the understanding of the macroscopic and macro-temporal aspects of consciousness. Self corresponds to a subsystem able to remain un-entangled under the sequential informational 'time evolutions' U. Exactly vanishing entanglement is practically impossible in ordinary quantum mechanics and it might be that 'vanishing entanglement' in the condition for self-property should be replaced with 'subcritical entanglement'. On the other hand, if space-time decomposes into p-adic and real regions, and if entanglement between regions representing physics in different number fields vanishes, space-time indeed decomposes into selves in a natural manner.

It is assumed that the experiences of the self after the last 'wake-up' sum up to single average experience. This means that subjective memory is identifiable as conscious, immediate short term memory. Selves form an infinite hierarchy with the entire Universe at the top. Self can be also interpreted as mental images: our mental images are selves having mental images and also we represent mental images of a higher level self. A natural hypothesis is that self S experiences the experiences of its subselves as kind of abstracted experience: the experiences of subselves S_i are not experienced as such but represent kind of averages $\langle S_{ij} \rangle$ of sub-subselves S_{ij}. Entanglement between selves, most naturally realized by the formation of join along boundaries bonds between cognitive or material space-time sheets, provides a possible a mechanism for the fusion of selves to larger selves (for instance, the fusion of the mental images representing separate right and left visual fields to single visual field) and forms wholes from parts at the level of mental images.

Relationship to quantum measurement theory

The third basic element relates TGD inspired theory of consciousness to quantum measurement theory. The assumption that localization occurs in zero modes in each quantum jump implies that the world of conscious experience looks classical. It also implies the state function reduction of the standard quantum measurement theory as the following arguments demonstrate (it took incredibly long time to realize this almost obvious fact!).

a) The standard quantum measurement theory a la von Neumann involves the interaction of brain with the measurement apparatus. If this interaction corresponds to entanglement between microscopic degrees of freedom m with the macroscopic effectively classical degrees of freedom M characterizing the reading of the measurement apparatus coded to brain state, then the reduction of this entanglement in quantum jump reproduces standard quantum measurement theory provide the unitary time evolution operator U acts as flow in zero mode degrees of freedom and correlates completely some orthonormal basis of configuration space spinor fields in non-zero modes with the values of the zero modes. The flow property guarantees that the localization is consistent with unitarity: it also means 1-1 mapping of quantum state basis to classical variables (say, spin direction of the electron to its orbit in the external magnetic field).

b) Since zero modes represent classical information about the geometry of space-time surface (shape, size, classical Kähler field,...), they have interpretation as effectively classical degrees of freedom and are the TGD counterpart of the degrees of freedom M representing the reading of the measurement apparatus. The entanglement between quantum fluctuating non-zero modes and zero modes is the TGD counterpart for the $m-M$ entanglement. Therefore the localization in zero modes is equivalent with a quantum jump leading to a final state where the measurement apparatus gives a definite reading.

This simple prediction is of utmost theoretical importance since the black box of the quantum measurement theory is reduced to a fundamental quantum theory. This reduction is implied by the replacement of the notion of a point like particle with particle as a 3-surface. Also the infinite-dimensionality of the zero mode sector of the configuration space of 3-surfaces is absolutely essential. Therefore the reduction is a triumph for quantum TGD and favors TGD against string models.

Standard quantum measurement theory involves also the notion of state preparation which reduces to the notion of self measurement. Each localization in zero modes is followed by a cascade of self measurements leading to a product state. This process is obviously equivalent with the state preparation process. Self measurement is governed by the so called Negentropy Maximization Principle (NMP) stating that the information content of conscious experience is maximized. In the self measurement the density matrix of some subsystem of a given self localized in zero modes (after ordinary quantum measurement) is measured. The self measurement takes place for that subsystem of self for which the reduction of the entanglement entropy is maximal in the measurement. In p-adic context NMP can be regarded as the variational principle defining the dynamics of cognition. In real context self measurement could be seen as a repair mechanism allowing the system to fight against quantum thermalization by reducing the entanglement for the subsystem for which it is largest (fill the largest hole first in a leaking boat).

Selves self-organize

The fourth basic element is quantum theory of self-organization based on the identification of quantum jump as the basic step of self-organization [I1]. Quantum entanglement gives rise to the generation of long range order and the emergence of longer p-adic length scales corresponds to the emergence of larger and larger coherent dynamical units and generation of a slaving hierarchy. Energy (and quantum entanglement) feed implying entropy feed is a necessary prerequisite for quantum self-organization. Zero modes represent fundamental order parameters and localization in zero modes implies that the sequence of quantum jumps can be regarded as hopping in the zero modes so that Haken's classical theory of self organization applies almost as such. Spin glass analogy is a further important element: self-organization of self leads to some characteristic pattern selected by dissipation as some valley of the "energy" landscape.

Dissipation can be regarded as the ultimate Darwinian selector of both memes and genes. The mathematically ugly irreversible dissipative dynamics obtained by adding phenomenological dissipation terms to the reversible fundamental dynamical equations derivable from an action principle can be understood as a phenomenological description replacing in a well defined sense the series of reversible quantum histories with its envelope.

Classical non-determinism of Kähler action

The fifth basic element are the concepts of association sequence and cognitive space-time sheet. The huge vacuum degeneracy of the Kähler action suggests strongly that the absolute minimum space-time is not always unique. For instance, a sequence of bifurcations can occur so that a given space-time branch can be fixed only by selecting a finite number of 3-surfaces with time like(!) separations on the orbit of 3-surface. Quantum classical correspondence suggest an alternative formulation. Space-time surface decomposes into maximal deterministic regions and their temporal sequences have interpretation a space-time correlate for a sequence of quantum states defined by the initial (or final) states of quantum jumps. This is consistent with the fact that the variational principle selects preferred extremals of Kähler action as generalized Bohr orbits.

In the case that non-determinism is located to a finite time interval and is microscopic, this sequence of 3-surfaces has interpretation as a simulation of a classical history, a geometric correlate for contents of consciousness. When non-determinism has long lasting and macroscopic effect one can identify it as volitional non-determinism associated with our choices. Association sequences relate closely with the cognitive space-time sheets defined as space-time sheets having finite time duration and psychological time can be identified as a temporal center of mass coordinate of the cognitive space-time sheet. The gradual drift of the cognitive space-time sheets to the direction of future force by the geometry of the future light cone explains the arrow of psychological time.

p-Adic physics as physics of cognition and intentionality

The sixth basic element adds a physical theory of cognition to this vision. TGD space-time decomposes into regions obeying real and p-adic topologies labelled by primes $p = 2, 3, 5, ...$ p-Adic regions obey the same field equations as the real regions but are characterized by p-adic non-determinism since the functions having vanishing p-adic derivative are pseudo constants which are piecewise constant functions. Pseudo constants depend on a finite number of positive pinary digits of arguments just like numerical predictions of any theory always involve decimal cutoff. This means that p-adic space-time regions are obtained by gluing together regions for which integration constants are genuine constants. The natural interpretation of the p-adic regions is as cognitive representations of real physics. The freedom of imagination is due to the p-adic non-determinism. p-Adic regions perform mimicry and make possible for the Universe to form cognitive representations about itself. p-Adic physics space-time sheets serve also as correlates for intentional action.

A more more precise formulation of this vision requires a generalization of the number concept obtained by fusing reals and p-adic number fields along common rationals (in the case of algebraic extensions among common algebraic numbers). This picture is discussed in [E1]. The application this notion at the level of the imbedding space implies that imbedding space has a book like structure with various variants of the imbedding space glued together along common rationals (algebraics). The implication is that genuinely p-adic numbers (non-rationals) are strictly infinite as real numbers so that most points of p-adic space-time sheets are at real infinity, outside the cosmos, and that the projection to the real imbedding space is discrete set of rationals (algebraics). Hence cognition and intentionality are almost completely outside the real cosmos and touch it at a discrete set of points only.

This view implies also that purely local p-adic physics codes for the p-adic fractality characterizing long range real physics and provides an explanation for p-adic length scale hypothesis stating that the primes $p \simeq 2^k$, k integer are especially interesting. It also explains the long range correlations and short term chaos characterizing intentional behavior and explains why the physical realizations of cognition are always discrete (say in the case of numerical computations). Furthermore, a concrete quantum model for how intentions are transformed to actions emerges.

The discrete real projections of p-adic space-time sheets serve also space-time correlate for a logical thought. It is very natural to assign to p-adic pinary digits a p-valued logic but as such this kind of logic does not have any reasonable identification. p-Adic length scale hypothesis suggest that the $p = 2^k - n$ pinary digits represent a Boolean logic B^k with k elementary statements (the points of the k-element set in the set theoretic realization) with n taboos which are constrained to be identically true.

0.3.4 TGD as a generalized number theory

Quantum T(opological)D(ynamics) as a classical spinor geometry for infinite-dimensional configuration space, p-adic numbers and quantum TGD, and TGD inspired theory of consciousness, have been for last ten years the basic three strongly interacting threads in the tapestry of quantum TGD. For few yeas ago the discussions with Tony Smith generated a fourth thread which deserves the name 'TGD as a generalized number theory'. It involves three separate threads: the fusion of real and various p-adic physics to a single coherent whole by requiring number theoretic universality discussed already, the formulation of quantum TGD in terms of hyper-counterparts of classical number fields identified as sub-spaces of complexified classical number fields with Minkowskian signature of the metric defined by the complexified inner product, and the notion of infinite prime.

The role of classical number fields

The vision about the physical role of the classical number fields relies on the notion of number theoretic compactifiction stating that space-time surfaces can be regarded as surfaces of either M^8 or $M^4 \times CP_2$.

As surfaces of M^8 identifiable as space of hyper-octonions they are hyper-quaternionic or co-hyper-quaternionic- and thus maximally associative or co-associative. This means that their tangent space is either hyper-quaternionic plane of M^8 or an orthogonal complement of such a plane. These surface can be mapped in natural manner to surfaces in $M^4 \times CP_2$ [E2] provided one can assign to each point of tangent space a hyper-complex plane $M^2(x) \subset M^4$. One can also speak about $M^8 - H$ duality.

This vision has very strong predictive power. It predicts that the extremals of Kähler action correspond to either hyper-quaternionic or co-hyper-quaternionic surfaces such that one can assign to tangent space at each point of space-time surface a hyper-complex plane $M^2(x) \subset M^4$. As a consequence, the M^4 projection of space-time surface at each point contains $M^2(x)$ and its orthogonal complement. These distributions are integrable implying that space-time surface allows dual slicings defined by string world sheets Y^2 and partonic 2-surfaces X^2. The existence of this kind of slicing was earlier deduced from the study of extremals of Kähler action and christened as Hamilton-Jacobi structure. The physical interpretation of $M^2(x)$ is as the space of non-physical polarizations and the plane of local 4-momentum.

One can fairly say, that number theoretical compactification is responsible for most of the understanding of quantum TGD that has emerged during last years. This includes the realization of Equivalence Principle at space-time level, dual formulations of TGD as Minkowskian and Euclidian string model type theories, the precise identification of preferred extremals of Kähler action as extremals for which second variation vanishes (at least for deformations representing dynamical symmetries) and thus providing space-time correlate for quantum criticality, the notion of number theoretic braid implied by the basic dynamics of Kähler action and crucial for precise construction of quantum TGD as almost-topological QFT, the construction of configuration space metric and spinor structure in terms of second quantized induced spinor fields with modified Dirac action defined by Kähler action realizing automatically the notion of finite measurement resolution and a connection with inclusions of hyper-finite factors of type II_1 about which Clifford algebra of configuration space represents an example.

Infinite primes

The discovery of the hierarchy of infinite primes and their correspondence with a hierarchy defined by a repeatedly second quantized arithmetic quantum field theory gave a further boost for the speculations about TGD as a generalized number theory. The work with Riemann hypothesis led to further ideas.

After the realization that infinite primes can be mapped to polynomials representable as surfaces geometrically, it was clear how TGD might be formulated as a generalized number theory with infinite primes forming the bridge between classical and quantum such that real numbers, p-adic numbers, and various generalizations of p-adics emerge dynamically from algebraic physics as various completions of the algebraic extensions of rational (hyper-)quaternions and (hyper-)octonions. Complete algebraic, topological and dimensional democracy would characterize the theory.

What is especially satisfying is that p-adic and real regions of the space-time surface could emerge automatically as solutions of the field equations. In the space-time regions where the solutions of field equations give rise to in-admissible complex values of the imbedding space coordinates, p-adic solution can exist for some values of the p-adic prime. The characteristic non-determinism of the p-adic differential equations suggests strongly that p-adic regions correspond to 'mind stuff', the regions of space-time where cognitive representations reside. This interpretation implies that p-adic physics is physics of cognition. Since Nature is probably extremely brilliant simulator of Nature, the natural idea is to study the p-adic physics of the cognitive representations to derive information about the real physics. This view encouraged by TGD inspired theory of consciousness clarifies difficult interpretational issues and provides a clear interpretation for the predictions of p-adic physics.

0.3.5 Dynamical quantized Planck constant and dark matter hierarchy

By quantum classical correspondence space-time sheets can be identified as quantum coherence regions. Hence the fact that they have all possible size scales more or less unavoidably implies that Planck constant must be quantized and have arbitrarily large values. If one accepts this then also the idea about dark matter as a macroscopic quantum phase characterized by an arbitrarily large value of Planck constant emerges naturally as does also the interpretation for the long ranged classical electro-weak and color fields predicted by TGD. Rather seldom the evolution of ideas follows simple linear logic, and this was the case also now. In any case, this vision represents the fifth, relatively new thread in the evolution of TGD and the ideas involved are still evolving.

Dark matter as large $\hbar$ phase

D. Da Rocha and Laurent Nottale [30] have proposed that Schrödinger equation with Planck constant $\hbar$ replaced with what might be called gravitational Planck constant $\hbar_{gr} = \frac{GmM}{v_0}$ ($\hbar = c = 1$). v_0 is a velocity parameter having the value $v_0 = 144.7 \pm .7$ km/s giving $v_0/c = 4.6 \times 10^{-4}$. This is rather near to the peak orbital velocity of stars in galactic halos. Also subharmonics and harmonics of v_0 seem to appear. The support for the hypothesis coming from empirical data is impressive.

Nottale and Da Rocha believe that their Schrödinger equation results from a fractal hydrodynamics. Many-sheeted space-time however suggests astrophysical systems are not only quantum systems at larger space-time sheets but correspond to a gigantic value of gravitational Planck constant. The gravitational (ordinary) Schrödinger equation would provide a solution of the black hole collapse (IR catastrophe) problem encountered at the classical level. The resolution of the problem inspired by TGD inspired theory of living matter is that it is the dark matter at larger space-time sheets which is quantum coherent in the required time scale [D6].

Already before learning about Nottale's paper I had proposed the possibility that Planck constant is quantized [E9] and the spectrum is given in terms of logarithms of Beraha numbers: the lowest Beraha number B_3 is completely exceptional in that it predicts infinite value of Planck constant. The inverse of the gravitational Planck constant could correspond a gravitational perturbation of this as $1/\hbar_{gr} = v_0/GMm$. The general philosophy would be that when the quantum system would become non-perturbative, a phase transition increasing the value of $\hbar$ occurs to preserve the perturbative character and at the transition $n = 4 \rightarrow 3$ only the small perturbative correction to $1/\hbar(3) = 0$ remains. This would apply to QCD and to atoms with $Z > 137$ as well.

TGD predicts correctly the value of the parameter v_0 assuming that cosmic strings and their decay remnants are responsible for the dark matter. The harmonics of v_0 can be understood as corresponding to perturbations replacing cosmic strings with their n-branched coverings so that tension becomes n^2-fold: much like the replacement of a closed orbit with an orbit closing only after n turns. $1/n$-sub-harmonic would result when a magnetic flux tube split into n disjoint magnetic flux tubes. Also a model for the formation of planetary system as a condensation of ordinary matter around quantum coherent dark matter emerges [D6].

Dark matter as a source of long ranged weak and color fields

Long ranged classical electro-weak and color gauge fields are unavoidable in TGD framework. The smallness of the parity breaking effects in hadronic, nuclear, and atomic length scales does not however seem to allow long ranged electro-weak gauge fields. The problem disappears if long range classical electro-weak gauge fields are identified as space-time correlates for massless gauge fields created by dark matter. Also scaled up variants of ordinary electro-weak particle spectra are possible. The identification explains chiral selection in living matter and unbroken $U(2)_{ew}$ invariance and free color in bio length scales become characteristics of living matter and of bio-chemistry and bio-nuclear physics. An attractive solution of the matter antimatter asymmetry is based on the identification of also antimatter as dark matter.

p-Adic and dark matter hierarchies and hierarchy of moments of consciousness

Dark matter hierarchy assigned to a spectrum of Planck constant having arbitrarily large values brings additional elements to the TGD inspired theory of consciousness.

a) Macroscopic quantum coherence can be understood since a particle with a given mass can in principle appear as arbitrarily large scaled up copies (Compton length scales as $\hbar$). The phase transition to this kind of phase implies that space-time sheets of particles overlap and this makes possible macroscopic quantum coherence.

b) The space-time sheets with large Planck constant can be in thermal equilibrium with ordinary ones without the loss of quantum coherence. For instance, the cyclotron energy scale associated with EEG turns out to be above thermal energy at room temperature for the level of dark matter hierarchy corresponding to magnetic flux quanta of the Earth's magnetic field with the size scale of Earth and a successful quantitative model for EEG results [M3].

Dark matter hierarchy leads to detailed quantitative view about quantum biology with several testable predictions [M3]. The applications to living matter suggests that the basic hierarchy corresponds to a hierarchy of Planck constants coming as $\hbar(k) = \lambda^k(p)\hbar_0$, $\lambda \simeq 2^{11}$ for $p = 2^{127-1}$, $k = 0, 1, 2, ...$ [M3]. Also integer valued sub-harmonics and integer valued sub-harmonics of λ might be possible. Each p-adic length scale corresponds to this kind of hierarchy and number theoretical arguments suggest a general formula for the allowed values of Planck constant λ depending logarithmically on p-adic prime [C6]. Also the value of $\hbar_0$ has spectrum characterized by Beraha numbers $B_n = 4cos^2(\pi/n)$, $n \geq 3$, varying by a factor in the range $n > 3$ [C6]. It must be however emphasized that the relation of this picture to the model of quantized gravitational Planck constant h_{gr} appearing in Nottale's model is not yet completely understood.

The general prediction is that Universe is a kind of inverted Mandelbrot fractal for which each bird's eye of view reveals new structures in long length and time scales representing scaled down copies of standard physics and their dark variants. These structures would correspond to higher levels in self hierarchy. This prediction is consistent with the belief that 75 per cent of matter in the universe is dark.

1. Living matter and dark matter

Living matter as ordinary matter quantum controlled by the dark matter hierarchy has turned out to be a particularly successful idea. The hypothesis has led to models for EEG predicting correctly the band structure and even individual resonance bands and also generalizing the notion of EEG [M3]. Also a generalization of the notion of genetic code emerges resolving the paradoxes related to the standard dogma [L2, M3]. A particularly fascinating implication is the possibility to identify great leaps in evolution as phase transitions in which new higher level of dark matter emerges [M3].

It seems safe to conclude that the dark matter hierarchy with levels labelled by the values of Planck constants explains the macroscopic and macro-temporal quantum coherence naturally. That this explanation is consistent with the explanation based on spin glass degeneracy is suggested by following observations. First, the argument supporting spin glass degeneracy as an explanation of the macro-temporal quantum coherence does not involve the value of $\hbar$ at all. Secondly, the failure of the perturbation theory assumed to lead to the increase of Planck constant and formation of macroscopic quantum phases could be precisely due to the emergence of a large number of new degrees of freedom due to spin glass degeneracy. Thirdly, the phase transition increasing Planck constant has concrete topological interpretation in terms of many-sheeted space-time consistent with the spin glass degeneracy.

2. Dark matter hierarchy and the notion of self

The vision about dark matter hierarchy leads to a more refined view about self hierarchy and hierarchy of moments of consciousness [J6, M3]. The larger the value of Planck constant, the longer the subjectively experienced duration and the average geometric duration $T(k) \propto \lambda^k$ of the quantum jump.

Quantum jumps form also a hierarchy with respect to p-adic and dark hierarchies and the geometric durations of quantum jumps scale like $\hbar$. Dark matter hierarchy suggests also a slight modification of the notion of self. Each self involves a hierarchy of dark matter levels, and one is led to ask whether the highest level in this hierarchy corresponds to single quantum jump rather than a sequence of quantum jumps. The averaging of conscious experience over quantum jumps would occur only for sub-selves at lower levels of dark matter hierarchy and these mental images would be ordered, and single moment of consciousness would be experienced as a history of events. The quantum parallel dissipation at the lower levels would give rise to the experience of flow of time. For instance, hadron as a macro-temporal quantum system in the characteristic time scale of hadron is a dissipating system at quark and gluon level corresponding to shorter p-adic time scales. One can ask whether even entire life cycle could be regarded as a single quantum jump at the highest level so that consciousness would not be completely lost even during deep sleep. This would allow to understand why we seem to know directly that this biological body of mine existed yesterday.

The fact that we can remember phone numbers with 5 to 9 digits supports the view that self corresponds at the highest dark matter level to single moment of consciousness. Self would experience the average over the sequence of moments of consciousness associated with each sub-self but there would be no averaging over the separate mental images of this kind, be their parallel or serial. These mental images correspond to sub-selves having shorter wake-up periods than self and would be experienced as being time ordered. Hence the digits in the phone number are experienced as separate mental images and ordered with respect to experienced time.

3. The time span of long term memories as signature for the level of dark matter hierarchy

The simplest dimensional estimate gives for the average increment τ of geometric time in quantum jump $\tau \sim 10^4$ CP_2 times so that $2^{127}-1 \sim 10^{38}$ quantum jumps are experienced during secondary p-adic time scale $T_2(k=127) \simeq 0.1$ seconds which is the duration of physiological moment and predicted to be fundamental time scale of human consciousness [L1]. A more refined guess is that $\tau_p = \sqrt{p}\tau$ gives the dependence of the duration of quantum jump on p-adic prime p. By multi-p-fractality predicted by TGD and explaining p-adic length scale hypothesis, one expects that at least $p=2$-adic level is also always present. For the higher levels of dark matter hierarchy τ_p is scaled up by $\hbar/\hbar_0$. One can understand evolutionary leaps as the emergence of higher levels at the level of individual organism making possible intentionality and memory in the time scale defined τ [L2].

Higher levels of dark matter hierarchy provide a neat quantitative view about self hierarchy and its evolution. For instance, EEG time scales corresponds to $k=4$ level of hierarchy and a time scale of .1 seconds [J6], and EEG frequencies correspond at this level dark photon energies above the thermal threshold so that thermal noise is not a problem anymore. Various levels of dark matter hierarchy would naturally correspond to higher levels in the hierarchy of consciousness and the typical duration of life cycle would give an idea about the level in question.

The level would determine also the time span of long term memories as discussed in [M3]. $k=7$ would correspond to a duration of moment of conscious of order human lifetime which suggests that $k=7$ corresponds to the highest dark matter level relevant to our consciousness whereas higher levels would in general correspond to transpersonal consciousness. $k=5$ would correspond to time scale of short term memories measured in minutes and $k=6$ to a time scale of memories measured in days.

The emergence of these levels must have meant evolutionary leap since long term memory is also accompanied by ability to anticipate future in the same time scale. This picture would suggest that the basic difference between us and our cousins is not at the level of genome as it is usually understood but at the level of the hierarchy of magnetic bodies [L2, M3]. In fact, higher levels of dark matter hierarchy motivate the introduction of the notions of super-genome and hyper-genome. The genomes of entire organ can join to form super-genome expressing genes coherently. Hyper-genomes would result from the fusion of genomes of different organisms and collective levels of consciousness would express themselves via hyper-genome and make possible social rules and moral.

0.4 Bird's eye of view about the topics of the book

This book is mostly devoted to what might be called classical TGD.

1. In a well-defined sense classical TGD defined as the dynamics of space-time surfaces determining them as kind of generalized Bohr orbits can be regarded as an exact part of quantum theory and assuming quantum classical correspondence has served as an extremely valuable guideline in the attempts to interpret TGD, to form a view about what TGD really predicts, and to to guess what the underlying quantum theory could be and how it deviates from standard quantum theory.

2. The notions of many-sheeted space-time, topological field quantization and the notion of field/magnetic body, follow from simple topological considerations. The observation that space-time sheets can have arbitrarily large sizes and their interpretation as quantum coherence regions forces to conclude that in TGD Universe macroscopic and macro-temporal quantum coherence are possible in arbitrarily long scales. Also long ranged classical color and electro-weak fields are an unavoidable prediction.

3. It took a considerable time to make the obvious conclusion: TGD Universe is fractal containing fractal copies of standard model physics at various space-time sheets and labeled by the collection of p-adic primes assignable to elementary particles and by the level of dark matter hierarchy characterized partially by the value of Planck constant labeling the pages of the book like structure formed by singular covering spaces of the imbedding space $M^4 \times CP_2$ glued together along a four-dimensional back. Particles at different pages are dark relative to each other

since purely local interactions defined in terms of the vertices of Feynman diagram involve only particles at the same page.

4. The new view about energy and time justified by the notion of zero energy ontology means that the sign of inertial energy depends on the time orientation of the space-time sheet and that negative energy space-time sheets serve as correlates for communications to the geometric past. This alone leads to profoundly new views about metabolism, long term memory, and realization of intentional action.

0.4.1 The implications deriving from the topology of space-time surface and from the properties of induced gauge fields

1. The general properties of Kähler action, in particular its vacuum degeneracy and failure of the classical determinism in the conventional sense, have rather far reaching implications. Space-time surfaces as a generalization of Bohr orbit provide not only a representation of quantum states but also sequences of quantum jumps and thus contents of consciousness. Vacuum degeneracy implies spin glass degeneracy in 4-D sense reflecting quantum criticality which is the fundamental characteristic of TGD Universe.

2. The detailed study of the simplest extremals of Kähler action interpreted as correlates for asymptotic self organization patterns provides additional insights [D1]. CP_2 type extremals representing elementary particles, cosmic strings, vacuum extremals, topological light rays ("massless extremal", ME), flux quanta of magnetic and electric fields represent the basic extremals. Pairs of wormhole throats identifiable as parton pairs define a completely new kind of particle carrying only color quantum numbers in ideal case and I have proposed their interpretation as quantum correlates for Boolean cognition. MEs and flux quanta of magnetic and electric fields are of special importance in living matter.

This general picture serves as a cornerstone of also TGD inspired view about cosmology and astrophysics. For obvious reasons the newest ideas developed during last year and still developing (in particular, the vision about dark matter) are not discussed in full depth yet.

0.4.2 Many-sheeted cosmology

The many-sheeted space-time concept, the new view about the relationship between inertial and gravitational four-momenta, the basic properties of the paired cosmic strings, the existence of the limiting temperature, the assumption about the existence of the vapor phase dominated by cosmic strings, and quantum criticality imply a rather detailed picture of the cosmic evolution, which differs from that provided by the standard cosmology in several respects but has also strong resemblances with inflationary scenario.

Basic deviations from standard cosmology

The most important differences between TGD based and standard cosmology are following.

1. Many-sheetedness implies cosmologies inside cosmologies Russian doll like structure with a spectrum of Hubble constants.

2. TGD cosmology is also genuinely quantal: each quantum jump in principle recreates each sub-cosmology in 4-dimensional sense: this makes possible a genuine evolution in cosmological length scales so that the use of anthropic principle to explain why fundamental constants are tuned for life is not necessary.

3. The new view about energy means that inertial energy is negative for space-time sheets with negative time orientation and that the density of inertial energy vanishes in cosmological length scales. Therefore any cosmology is in principle creatable from vacuum and the problem of initial values of cosmology disappears. The density of matter near the initial moment is dominated by cosmic strings approaches to zero so that big bang is transformed to a silent whisper amplified to a relatively big bang.

4. Dark matter hierarchy with dynamical quantized Planck constant implies the presence of dark space-time sheets which differ from non-dark ones in that they define multiple coverings of M^4. Quantum coherence of dark matter in the length scale of space-time sheet involved implies that even in cosmological length scales Universe is more like a living organism than a thermal soup of particles.

5. Sub-critical and over-critical Robertson-Walker cosmologies are fixed completely from the imbeddability requirement apart from a single parameter characterizing the duration of the period after which transition to sub-critical cosmology necessarily occurs. The fluctuations of the microwave background reflect the quantum criticality of the critical period rather than amplification of primordial fluctuations by exponential expansion. This and also the finite size of the space-time sheets predicts deviations from the standard cosmology.

Cosmic strings

Cosmic strings belong to the basic extremals of the Kähler action. The string tension of the cosmic strings is $T \simeq .2 \times 10^{-6}/G$ and slightly smaller than the string tension of the GUT strings and this makes them very interesting cosmologically. Concerning the understanding of cosmic strings a decisive breakthrough came through the identification of gravitational four-momentum as the difference of inertial momenta associated with matter and antimatter and the realization that the net inertial energy of the Universe vanishes. This forced to conclude cosmological constant in TGD Universe is non-vanishing. p-Adic length fractality predicts that Λ scales as $1/L^2(k)$ as a function of the p-adic scale characterizing the space-time sheet. The recent value of the cosmological constant comes out correctly. The gravitational energy density described by the cosmological constant is identifiable as that associated with topologically condensed cosmic strings and of magnetic flux tubes to which they are gradually transformed during cosmological evolution.

p-Adic fractality and simple quantitative observations lead to the hypothesis that pairs of cosmic strings are responsible for the evolution of astrophysical structures in a very wide length scale range. Large voids with size of order 10^8 light years can be seen as structures containing knotted and linked cosmic string pairs wound around the boundaries of the void. Galaxies correspond to same structure with smaller size and linked around the supra-galactic strings. This conforms with the finding that galaxies tend to be grouped along linear structures. Simple quantitative estimates show that even stars and planets could be seen as structures formed around cosmic strings of appropriate size. Thus Universe could be seen as fractal cosmic necklace consisting of cosmic strings linked like pearls around longer cosmic strings linked like...

0.4.3 Dark matter and quantization of gravitational Planck constant

The notion of gravitational Planck constant having gigantic value is perhaps the most radical idea related to the astrophysical applications of TGD. D. Da Rocha and Laurent Nottale have proposed that Schrödinger equation with Planck constant $\hbar$ replaced with what might be called gravitational Planck constant $\hbar_{gr} = \frac{GmM}{v_0}$ $(\hbar = c = 1)$. v_0 is a velocity parameter having the value $v_0 = 144.7 \pm .7$ km/s giving $v_0/c = 4.6 \times 10^{-4}$. This is rather near to the peak orbital velocity of stars in galactic halos. Also subharmonics and harmonics of v_0 seem to appear. The support for the hypothesis coming from empirical data is impressive.

Nottale and Da Rocha believe that their Schrödinger equation results from a fractal hydrodynamics. Many-sheeted space-time however suggests astrophysical systems are not only quantum systems at larger space-time sheets but correspond to a gigantic value of gravitational Planck constant. The gravitational (ordinary) Schrödinger equation would provide a solution of the black hole collapse (IR catastrophe) problem encountered at the classical level. The resolution of the problem inspired by TGD inspired theory of living matter is that it is the dark matter at larger space-time sheets which is quantum coherent in the required time scale.

TGD predicts correctly the value of the parameter v_0 assuming that cosmic strings and their decay remnants are responsible for the dark matter. The harmonics of v_0 can be understood as corresponding to perturbations replacing cosmic strings with their n-branched coverings so that tension becomes n^2-fold: much like the replacement of a closed orbit with an orbit closing only after n turns. $1/n$-sub-harmonic would result when a magnetic flux tube split into n disjoint magnetic flux tubes. An attractive solution of the matter antimatter asymmetry is based on the identification of also antimatter as dark matter.

0.4.4 The topics of the book

The topics of the book are organized as follows.

1. In the first part of the book extremals of Kähler action are discussed and the notions of many-sheeted space-time and topological condensation and evaporation are introduced.

2. In the second part of the book many-sheeted-cosmology and astrophysics are summarized. Cosmic strings and their deformations are basic objects of TGD inspired cosmology and are therefore treated in a separate chapter. p-Adic and dark matter hierarchies imply that TGD inspired cosmology has a kind of Russian doll structure containing cosmologies within cosmologies. In a chapter about TGD inspired cosmology the imbeddings of Robertson-Walker cosmology are studied. Both critical and over-critical cosmology are found to be unique apart from the parameter characterizing its duration.

   The idea about dark matter hierarchy with levels labeled by the values of Planck constant was originally motivated by the observation that planetary orbits could be interpreted as Bohr orbits with enormous value of Planck constant whose value is fixed to a high degree by Equivalence Principle. One ends up to a rather detailed view about macroscopically quantum coherent dark matter in astrophysics and cosmology. In particular, dark matter could be in anyonic phase at light-like 2-surfaces with complex topology and astrophysical size and visible matter would condense around it. Dark matter hierarchy allows to interpret critical cosmologies as correlates for the phase transitions increasing Planck constant and involving a relatively rapid expansion of space-time sheets. The quantum counterpart of the smooth cosmological expansion would be a series of phase transitions increasing the value of Planck constant and these phase transitions are predicted to take place also at planetary level, which provides a new theoretical basis for Expanding Earth hypothesis and suggests totally unexpected connections between biology and geology.

3. The third part of the book includes some old chapters about possible implications of TGD for condensed matter physics written for at least about 15 years ago at least and updated only slightly. The phases of CP_2 complex coordinates could define phases of order parameters of macroscopic quantum phases so that the deviations of induced gauge field concept from the standard one could have direct experimental implications visible for instance in the properties of living matter and even in hydrodynamics. For instance, Z^0 magnetic gauge field could make itself visible in hydrodynamics and also Z^0 magnetic vortices could be involved with super-fluidity.

0.5 The contents of the book

In the first part of the book extremals of Kähler action are discussed and the notions of many-sheeted space-time and topological condensation and evaporation are introduced. In the second part many-sheeted-cosmology and astrophysics are summarized. The third part of the book includes some old chapters about possible implications of TGD for condensed matter physics written for at least about 15 years ago at least and updated only slightly. There is a lot of material about applications of classical TGD in its recent form to say living matter but its inclusion would have led to an explosion: this material can from seven online books about TGD [TGDview, TGDgeom, TGDquant, TGDnumber, TGDclass, TGDpad, TGDfree] and eight online books about TGD inspired theory of consciousness and quantum biology [TGDconsc, TGDselforg, TGDware, TGDholo, TGDgeme, TGDeeg, TGDmagn, 15] are warmly recommended for the reader willing to get overall view about what is involved.

0.5.1 PART I: The notion of many-sheeted space-time

Basic extremals of the Kähler action

In this chapter the classical field equations associated with the Kähler action are studied. The study of the extremals of the Kähler action has turned out to be extremely useful for the development of TGD.

Towards the end of year 2003 quite dramatic progress occurred in the understanding of field equations and it seems that field equations might be in well-defined sense exactly solvable. The progress made during next five years led to a detailed understanding of quantum TGD at the fundamental parton level and this provides considerable additional insights concerning the interpretation of field equations.

1. General considerations

The vanishing of Lorentz 4-force for the induced Kähler field means that the vacuum 4-currents are in a mechanical equilibrium. Lorentz 4-force vanishes for all known solutions of field equations which inspires the hypothesis that all extremals or at least the absolute minima of Kähler action satisfy the condition. The vanishing of the Lorentz 4-force in turn implies local conservation of the ordinary energy momentum tensor. The corresponding condition is implied by Einstein's equations in General Relativity. The hypothesis would mean that the solutions of field equations are what might be called generalized Beltrami fields. The condition implies that vacuum currents can be non-vanishing only provided the dimension D_{CP_2} of the CP_2 projection of the space-time surface is less than four so that in the regions with $D_{CP_2} = 4$, Maxwell's vacuum equations are satisfied.

The hypothesis that Kähler current is proportional to a product of an arbitrary function ψ of CP_2 coordinates and of the instanton current generalizes Beltrami condition and reduces to it when electric field vanishes. Kähler current has vanishing divergence for $D_{CP_2} < 4$, and Lorentz 4-force indeed vanishes. The remaining task would be the explicit construction of the imbeddings of these fields and the demonstration that field equations can be satisfied.

Under additional conditions magnetic field reduces to what is known as Beltrami field. Beltrami fields are known to be extremely complex but highly organized structures. The natural conjecture is that topologically quantized many-sheeted magnetic and Z^0 magnetic Beltrami fields and their generalizations serve as templates for the helical molecules populating living matter, and explain both chirality selection, the complex linking and knotting of DNA and protein molecules, and even the extremely complex and self-organized dynamics of biological systems at the molecular level.

Field equations can be reduced to algebraic conditions stating that energy momentum tensor and second fundamental form have no common components (this occurs also for minimal surfaces in string models) and only the conditions stating that Kähler current vanishes, is light-like, or proportional to instanton current, remain and define the remaining field equations. The conditions guaranteing topologization to instanton current can be solved explicitly. Solutions can be found also in the more general case when Kähler current is not proportional to instanton current. On basis of these findings there are strong reasons to believe that classical TGD is exactly solvable.

2. In what sense field equations mimic dissipative dynamics?

By quantum classical correspondence the non-deterministic space-time dynamics should mimic the dissipative dynamics of the quantum jump sequence. The nontrivial question is what this means in TGD framework.

1. Beltrami fields appear in physical applications as asymptotic self organization patterns for which Lorentz force and dissipation vanish. This suggests that absolute minima of Kähler action correspond to space-time sheets which asymptotically satisfy generalized Beltrami conditions so that one can indeed assign to the final (rather than initial!) 3-surface a unique 4-surface apart from effects related to non-determinism. Absolute minimization of Kähler action abstracted to purely algebraic generalized Beltrami conditions would make sense also in the p-adic context. Also the equivalence of absolute minimization with the second law strongly suggests itself. Of course, one must keep mind open for the possibility that it is the second law of thermodynamics which replaces absolute minimization as the fundamental principle.

2. A more radical view inspired by zero energy ontology is that the light-like 3-surfaces and corresponding space-time regions with Euclidian signature defining generalized Feynman diagrams provide a space-time representation of dissipative dynamics just as they provide this representation in quantum field theory. Minkowskian regions would represent empty space so that the vanishing of Lorentz 4-force and absence of dissipation would be natural. This would mean very precise particle field duality and the topological pattern associated with the generalized Feynman diagram would represent dissipation.

3. The dimension of CP_2 projection as classifier for the fundamental phases of matter

The dimension D_{CP_2} of CP_2 projection of the space-time sheet encountered already in p-adic mass calculations classifies the fundamental phases of matter. For $D_{CP_2} = 4$ empty space Maxwell equations hold true. This phase is chaotic and analogous to de-magnetized phase. $D_{CP_2} = 2$ phase is analogous to ferromagnetic phase: highly ordered and relatively simple. $D_{CP_2} = 3$ is the analog of spin glass and liquid crystal phases, extremely complex but highly organized by the properties of the generalized Beltrami fields. This phase is the boundary between chaos and order and corresponds to life emerging in the interaction of magnetic bodies with bio-matter. It is possible only in a finite temperature interval (note however the p-adic hierarchy of critical temperatures) and characterized by chirality just like life.

4. Specific extremals of Kähler action

The study of extremals of Kähler action represents more than decade old layer in the development of TGD.

1. The huge vacuum degeneracy is the most characteristic feature of Kähler action (any 4-surface having CP_2 projection which is Legendre sub-manifold is vacuum extremal, Legendre sub-manifolds of CP_2 are in general 2-dimensional). This vacuum degeneracy is behind the spin glass analogy and leads to the p-adic TGD. As found in the second part of the book, various particle like vacuum extremals also play an important role in the understanding of the quantum TGD.

2. The so called CP_2 type vacuum extremals have finite, negative action and are therefore an excellent candidate for real particles whereas vacuum extremals with vanishing Kähler action are candidates for the virtual particles. These extremals have one dimensional M^4 projection, which is light like curve but not necessarily geodesic and locally the metric of the extremal is that of CP_2: the quantization of this motion leads to Virasoro algebra. Space-times with topology $CP_2\#CP_2\#...CP_2$ are identified as the generalized Feynmann diagrams with lines thickened to 4-manifolds of "thickness" of the order of CP_2 radius. The quantization of the random motion with light velocity associated with the CP_2 type extremals in fact led to the discovery of Super Virasoro invariance, which through the construction of the configuration space geometry, becomes a basic symmetry of quantum TGD.

3. There are also various non-vacuum extremals.

   (a) String like objects, with string tension of same order of magnitude as possessed by the cosmic strings of GUTs, have a crucial role in TGD inspired model for the galaxy formation and in the TGD based cosmology.

   (b) The so called massless extremals describe non-linear plane waves propagating with the velocity of light such that the polarization is fixed in given point of the space-time surface. The purely TGD:eish feature is the light like Kähler current: in the ordinary Maxwell theory vacuum gauge currents are not possible. This current serves as a source of coherent photons, which might play an important role in the quantum model of bio-system as a macroscopic quantum system.

   (c) In the so called Maxwell's phase, ordinary Maxwell equations for the induced Kähler field are satisfied in an excellent approximation. A special case is provided by a radially symmetric extremal having an interpretation as the space-time exterior to a topologically condensed particle. The sign of the gravitational mass correlates with that of the Kähler charge and one can understand the generation of the matter antimatter asymmetry from the basic properties of this extremal. The possibility to understand the generation of the matter antimatter asymmetry directly from the basic equations of the theory gives strong support in favor of TGD in comparison to the ordinary EYM theories, where the generation of the matter antimatter asymmetry is still poorly understood.

General View About Physics in Many-Sheeted Space-Time: Part I

This chapter is first part of the discussion devoted to the notion of many-sheeted space-time. The notion of many-sheeted space-time used is roughly that as it was around 1990 and text only refers to the recent picture when needed. Topological condensation and somewhat questionable notion of topological evaporation represent the basic new concepts of TGD and an attempt to formulate a general qualitative theory of the topological condensation and evaporation and TGD based space-time concept is made.

The fusion of real and various p-adic physics to single coherent whole by generalizing the notion of number, the generalization of the notion of the imbedding space to allow a mathematical representation of dark matter hierarchy based on dynamical and quantized Planck constant, parton level formulation of TGD using light-like 3-surfaces as basic dynamical objects, and so called zero energy ontology force to generalizes considerably the view about space-time. These developments are discussed in the next chapter.

The topics to be discussed in the sequel will be following.

1. The general structure of topological condensate

The question what 3-space looks like in various scales and end up to a purely topological description for the generation of structures. Topological arguments imply a finite size for non-vacuum 3-surfaces and the conservation of the gauge and gravitational fluxes requires that 3-surface feeds these fluxes to a larger 3-surface via # contacts situated near the boundaries of the 3-surface. Renormalization group invariance (RGI) hypothesis suggests that 3-surfaces with all sizes are important in the functional integral and this leads to the idea of the many-sheeted space-time with hierarchical, fractal like structure such that each level of the hierarchy corresponds to a characteristic length scale.

2. Topological field quantization

The general space-time picture suggested by RGI hypothesis can be justified mathematically. Due to the compactness of CP_2, a general space-time surface representable as a map $M^4 \rightarrow CP_2$ decomposes into regions, "topological field quanta", characterized by certain vacuum quantum numbers and 3-surface is in general unstable against the decay to disjoint components along the boundaries of the field quanta.

Topological field quanta have finite size depending on the values of the vacuum quantum numbers: the size increases as the values of the vacuum quantum numbers increase. Topological field quantum is therefore a good candidate for a quantum coherent system provided some Bose Einstein condensate or quantum coherent state is available. The BE condensate or coherent state of the light # contacts (wormhole contacts) near the boundaries of the topological field quantum is a good candidate in this respect.

The requirement of the gauge charge conservation in implies the hierarchical structure of the topological condensate: gauge fluxes must go somewhere from the outer boundaries of the topological field quantum with finite size and this 'somewhere' must be a larger topological field quantum, which in turn feeds its gauge fluxes to a larger topological field quantum,.... Of course, the nonlinearity of the theory could allow vacuum charge densities which can cancel the net charge near boundaries. The recent view about quantum TGD however supports the conclusion that vacuum currents are light-like and do not contribute to charge renormalization. This provides a justification for the notion of p-adic coupling constant evolution.

Topological field quanta allow discrete scalings as a dynamical symmetry. p-Adic length scale hypothesis states that the allowed scaling factors correspond to powers of $\sqrt{p}$, where the prime p satisfies $p \simeq 2^k$, k integer with prime values favored. p-Adic fractality (actually multi-p-fractality) can be justified more rigorously by a precise formulation for the fusion of real and various p-adic physics based on the generalization of the notion of number.

3. General physical consequences of new view about space-time

The physical consequences of the new space-time picture are nontrivial at all length scales.

1. A natural interpretation for the hierarchical structure is in terms of bound state formation. Quarks condense to form hadrons, nucleons condense to form atomic nuclei, nuclei and electrons condense to form atoms, how atoms condense to form molecules, and so on. One ends up with a general picture for the topology of 3-space associated with, say, solid state and with the idea that even the macroscopic bodies of the everyday world correspond to topologically condensed 3-surfaces.

2. The join of 3-surfaces along their boundaries defines a new kind of interaction, which has in fact has been used in phenomenological modelling of chemical reactions. Usually chemical bond is believed to result from Schrödinger equation. At the macroscopic level this interaction is rather familiar to us since it means that two macroscopic bodies just touch each other.

3. In TGD context there are purely topological necessary conditions for quantum coherence and a topological description for dissipative phenomena. The formation of the join along boundaries bonds plays a decisive role in the description and this process provides a universal manner to generate macroscopic quantum systems. There is also a topological description for the formation of the supra phases and the phase of the order parameter of the supra phase ground state contains information about the homotopy of the join along boundaries condensate.

4. Gauge bosons and Higgs boson as wormhole contacts

The proper understanding of the concepts of gauge charges and fluxes and their gravitational counterparts in TGD space-time has taken a lot of efforts.

1. Wormhole (#-) contact is the key notion. Wormhole contacts can be regarded as particles carrying classical charges defined by the gauge fluxes but behaving as extremely tiny dipoles quantum mechanically in the case that gauge charge is conserved. Gauge fluxes and gauge charges assignable to light-like 3-D surfaces (wormhole throats, elementary particle horizons, causal determinants) surrounding a topologically condensed CP_2 type extremals can be identified as the quantum numbers assignable to fermionic oscillator operators generating the state associated with horizon (wormhole throat) identifiable as a parton.

2. Quantum classical correspondence requires that commuting classical gauge charges are quantized and this is expected to be true by the generalized Bohr orbit property of the space-time surface.

3. Both gauge bosons and Higgs boson must be identified as wormhole contacts whereas elementary fermions correspond to wormhole throats associated with topologically condensed CP_2 type vacuum extremals. Gravitons in turn correspond to string like objects formed by pairs of wormhole contacts connected by a flux tube.

5. The interpretation of long range weak and color gauge fields

In TGD gravitational fields are accompanied by long ranged electro-weak and color gauge fields. The only possible interpretation is that there exists a p-adic hierarchy of color and electro-weak physics such that weak bosons are massless below the p-adic length scale determining the mass scale of weak bosons. By quantum classical correspondence classical long ranged gauge fields serve as space-time correlates for gauge bosons below the p-adic length scale in question.

The unavoidable long ranged electro-weak and color gauge fields are created by dark matter and dark particles can screen dark nuclear electro-weak charges below the weak scale. Above this scale vacuum screening occurs as for ordinary weak interactions. Dark gauge bosons are massless below the appropriate p-adic length scale but massive above it and $U(2)_{ew}$ is broken only in the fermionic sector. For dark copies of ordinary fermions masses are essentially identical with those of ordinary fermions.

This interpretation is consistent with the standard elementary particle physics for visible matter apart from predictions such as the possibility of p-adically scaled up versions of ordinary quarks predicted to appear already in ordinary low energy hadron physics. The most interesting implications are seen in longer length scales. Dark variants of ordinary valence quarks and gluons and a scaled up copy of ordinary quarks and gluons are predicted to emerge already in ordinary nuclear physics. Chiral selection in living matter suggests that dark matter is an essential component of living systems so that non-broken $U(2)_{ew}$ symmetry and and free color in bio length scales become characteristics of living matter and of bio-chemistry and bio-nuclear physics. An attractive solution of the matter antimatter asymmetry is based on the identification of also antimatter as dark matter.

In this chapter the above vision is discussed in detail. As an application a simple model of color confinement is discussed using the general properties of the induced (classical) color gauge field, in particular the fact that its holonomy group is Abelian.

0.5.2 General View About Physics in Many-Sheeted Space-Time: Part II

This chapter, which is second part of a summary about the recent view about many-sheeted space-time, provides a summary of the developments in TGD that have occurred during last few years (the year I am writing this is 2007). The most important steps of progress are following ones.

1. Parton level formulation of quantum TGD

The formulation of quantum TGD at partonic level identifying fundamental objects as light-like 3-surfaces having also interpretation as random light-like orbits of 2-D partons having arbitrarily large size. This picture reduces quantum TGD to an almost-topological quantum field theory and leads to a dramatic understanding of S-matrix. A generalization of Feynman diagrams emerges obtained by replacing lines of Feynman diagram with light-like 3-surfaces meeting along their ends at vertices. This picture is different from that of string models and means also a generalization of the view about space-time and 3-surface since these surfaces cannot be assumed to be a smooth manifold anymore.

2. Zero energy ontology

In zero energy ontology physical states are creatable from vacuum and have vanishing net quantum numbers, in particular energy. Zero energy states can be decomposed to positive and negative energy parts with definite geometro-temporal separation, call it T, and having interpretation in terms of initial and final states of particle reactions. Zero energy ontology is consistent with ordinary positive energy ontology at the limit when the time scale of the perception of observer is much shorter than T.

Zero energy ontology leads to the view about S-matrix as a characterizer of time-like entanglement associated with the zero energy state and a generalization of S-matrix to what might be called M-matrix emerges. M-matrix is complex square root of density matrix expressible as a product of real valued "modulus" and unitary matrix representing phase and can be seen as a matrix valued generalization of Schrödinger amplitude. Also thermodynamics becomes an inherent element of quantum theory in this approach.

3. Fusion of real and p-adic physics to single one

The fusion of p-adic physics and real physics to single coherent whole requires generalization of the number concept obtained by gluing reals and various p-adic number fields along common algebraic numbers. This leads to a new vision about how cognition and intentionality make themselves visible in real physics via long range correlations realized via the effective p-adicity of real physics. The success of the p-adic length scale hypothesis and p-adic mass calculations suggest that cognition and intentionality are present already at elementary particle level. This picture leads naturally to an effective discretization of the real physics at the level of S-matrix and relying on the notion of umber theoretic braid.

4. Dark matter hierarchy and hierarchy of Planck constants

Dark matter revolution with levels of the hierarchy labeled by values of Planck constant forces a further generalization of the notion of imbedding space and thus of space-time. One can say, that imbedding space is a book like structure obtained by gluing together infinite number of copies of the imbedding space like pages of a book: two copies characterized by singular discrete bundle structure are glued together along 4-dimensional set of common points. These points have physical interpretation in terms of quantum criticality. Particle states belonging to different sectors (pages of the book) can interact via field bodies representing space-time sheets which have parts belonging to two pages of this book.

5. Equivalence Principle and evolution of gravitational constant

Before saying anything about evolution of gravitational constant one must understand whether it is a fundamental constant or prediction of quantum TGD. Also one should understand whether Equivalence Principle holds true and if so, in what sense. Also the identification of gravitational and inertial masses seems to be necessary.

1. The coset construction for super-symplectic and super Kac-Moody algebras implies Equivalence Principle in the sense that four-momenta assignable to the Super Virasoro generators of the two algebras are identical. The challenge is to understand this result in more concrete terms.

2. The progress made in the understanding of number theoretical compactification led to a dramatic progress in the construction of configuration space geometry and spinor structure in terms of the modified Dirac operator associated with light-like 3-surfaces appearing in the slicing of the preferred extremal $X^(X_l^3)$ of Kähler action to light-like 3-surfaces Y_l^3 "parallel" to X_l^3. Even more the M^4 projection is predicted to have a slicing into 2-dimensional stringy worldsheets having $M^2(x) \subset M^4$ as a tangent space at point x.

3. By dimensional reduction one can assign to any stringy slice Y^2 a stringy action obtained by integrating Kähler action over the transversal degrees of freedom labeling the copies of Y^2. One can assign length scale evolution to the string tension $T(x)$, which in principle can depend on the point of the string world sheet and thus evolves. $T(x)$ is not identifiable as inverse of gravitational constant but by general arguments proportional to $1/L_p^2$, where L_p is p-adic length scale.

4. Gravitational constant can be understood as a product of L_p^2 with the exponential of the Kähler action for the two pieces of CP_2 type vacuum extremals representing wormhole contacts assignable to graviton connected by the string world sheets. The volume of the typical CP_2 type extremal associated with the graviton increases with L_p so that the exponential factor decreases reducing the growth due to the increase of L_p. Hence G could be RG invariant in p-adic coupling constant evolution. It does not make sense to formulate evolution of gravitational constant at space-time level and gravitational constant characterizes given CD.

5. Gravitational mass is assigned to the stringy world sheet and should be identical with the inertial mass identified as Noether charge assignable to the preferred extremal. By construction there are good hopes that for a proper choice of G gravitational and inertial masses are identical.

6. Renormalization group equations for gauge couplings at space-time level

Renormalization group evolution equations for gauge couplings at given space-time sheet are discussed using quantum classical correspondence. For known extremals of Kähler action gauge couplings are RG invariants inside single space-time sheet, which supports the view that discrete p-adic coupling constant evolution replaces the ordinary coupling constant evolution.

7. Quantitative predictions for the values of coupling constants

The latest progress in the understanding of p-adic coupling constant evolution comes from a formula for Kähler coupling strength α_K in terms of Dirac determinant of the modified Dirac operator associated with Kähler action.

The formula for α_K fixes its number theoretic anatomy and also that of other coupling strengths. The assumption that simple rationals (p-adicization) are involved can be combined with the input from p-adic mass calculations and with an old conjecture for the formula of gravitational constant allowing to express it in terms of CP_2 length scale and Kähler action of topologically condensed CP_2 type vacuum extremal. The prediction is that α_K is renormalization group invariant and equals to the value of fine structure constant at electron length scale characterized by M_{127}. Although Newton's constant is proportional to p-adic length scale squared it can be RG invariant thanks to exponential reduction due to the presence of the exponent of Kähler action associated with the two CP_2 type vacuum extremals representing the wormhole contacts associated with graviton. The number theoretic anatomy of R^2/G allows to consider two options. For the first one only M_{127} gravitons are possible number theoretically. For the second option gravitons corresponding to $p \simeq 2^k$ are possible.

A relationship between electromagnetic and color coupling constant evolutions based on the formula $1/\alpha_{em} + 1/\alpha_s = 1/\alpha_K$ is suggested by the induced gauge field concept, and would mean that the otherwise hard-to-calculate evolution of color coupling strength is fixed completely. The predicted value of α_s at intermediate boson length scale is correct.

In this chapter the above topics are discussed in detail. Also the possible role of so called super-symplectic gauge bosons in the understanding of non-perturbative phase of QCD and black-hole physics is discussed.

0.5.3 PART II: Many-Sheeted Cosmology, and Astrophysics

The Relationship Between TGD and GRT

In this chapter the recent view about TGD as Poincare invariant theory of gravitation is discussed. Radically new views about ontology were necessary before it was possible to see what had been there all the time. Zero energy ontology states that all physical states have vanishing net quantum numbers. The hierarchy of dark matter identified as macroscopic quantum phases labeled by arbitrarily large values of Planck constant is second aspect of the new ontology.

1. Is Equivalence Principle satisfied in TGD?

Whether or not Equivalence Principle holds true in TGD Universe has been a long standing issue. The source of problems was the attempt to deduce the formulation of Equivalence Principle in the framework provided by General Relativity framework rather than in string model like context. There were several steps in the enlightment process.

1. First came the conviction that coset representation for super-symplectic and super Kac-Moody algebras provides extremely general formulation of Equivalence Principle in which inertial and gravitational four-momenta are replaced with Super Virasoro generators of two algebras whose differences annihilate physical states. This idea came for years before becoming aware of its importance and I simply forgot it.

2. Next came the realization of the fundamental role of number theoretical compactification providing a number theoretical interpretation of $M^4 \times CP_2$ and thus also of standard model quantum numbers. This lead to the identification of the preferred extremals of Kähler action and to the formulation of quantum TGD in terms of second quantized induced spinors fields. One of conclusion was that dimensional reduction for preferred extremals of Kähler action- if they have the properties required by theoretic compactification- leads to string model with string tension which is however not proportional to the inverse of Newton's constant but to L_p^2, p-adic length scale squared and thus gigantic. The connection between gravitational constant and L_p^2 comes from an old argument that I discovered about two decades ago and which allowed to predict the value of Kähler coupling strength by using as input electron mass and p-adic mass calculations. In this framework the role of Planck length as a fundamental length scale is taken by CP_2 size so that Planck length scale loses its magic role as a length scale in which usual views about space-time geometry cease to hold true.

3. The next step was the realization that zero energy ontology allows to avoid the paradox implied in positive energy ontology by the fact that gravitational energy is not conserved but inertial energy identified as Noether charge is. Energy conservation is always in some length scale in zero energy ontology.

4. As a matter fact, there was still one step. I had to become fully aware that the identification of gravitational four-momentum in terms of Einstein tensor makes sense only in long length scales. This is of course trivial but for some reason I did not realize that this fact resolves the paradoxes associated with objects like cosmic strings.

To sum up, the understanding of Equivalence Principle in TGD context required quite many discoveries of mostly mathematical character: the understanding of the super-conformal symmetries of quantum TGD, the discovery of zero energy ontology, the identification of preferred extremals of Kähler action by requiring number theoretical compactification, and the discovery that dimensional reduction allows to formulate quantum in terms of slicing of space-time surface by stringy word sheets.

2. The problem of cosmological constant

A further implication of dark matter hierarchy is that astrophysical systems correspond to stationary states analogous to atoms and do not participate to cosmic expansion in a continuous manner but via discrete quantum phase transitions in which gravitational Planck constant increases. By quantum criticality of these phase transitions critical cosmologies are excellent candidates for the modeling of these transitions. Imbeddable critical (and also over-critical) cosmologies are unique apart from a parameter determining their duration and represent accelerating cosmic expansion so that there is no need to introduce cosmological constant.

It indeed turns out possible to understand these critical phases in terms of quantum phase transition increasing the size of large modeled in terms of cosmic strings. A possible mechanism driving the strings to the boundaries of large voids could be repulsive interaction due to net charges of strings. Also repulsive gravitational acceleration could do this. In this framework cosmological constant like parameter does not characterize the density of dark energy but that of dark matter identifiable as quantum phases with large Planck constant.

A further problem is that the naive estimate for the cosmological constant is predicted to be by a factor 10^{120} larger than its value deduced from the accelerated expansion of the Universe. In TGD framework the resolution of the problem comes naturally from the fact that large voids are quantum systems which follow the cosmic expansion only during the quantum critical phases.

p-Adic fractality predicting that cosmological constant is reduced by a power of 2 in phase transitions occurring at times $T(k) \propto 2^{k/2}$, which correspond to p-adic time scales. These phase transitions would naturally correspond to quantum phase transitions increasing the size of the large voids during which critical cosmology predicting accelerated expansion naturally applies. On the average $\Lambda(k)$ behaves as $1/a^2$, where a is the light-cone proper time. This predicts correctly the order of magnitude for observed value of Λ.

3. Topics of the chapter

The topics discussed in the chapter are following.

1. The basic principles of GRT (General Coordinate Invariance, Equivalence Principle, and Machian Principle) are discussed from TGD point of view.

2. The theory is applied to the vacuum extremal embeddings of Reissner-Nordström and Schwartschild metric.

3. A model for the final state of a star, which indicates that Z^0 force, presumably created by dark matter, might have an important role in the dynamics of the compact objects. During year 2003, more than decade after the formulation of the model, the discovery of the connection between supernovas and gamma ray bursts provided strong support for the predicted axial magnetic and Z^0 magnetic flux tube structures predicted by the model for the final state of a rotating star. Two years later the interpretation of the predicted long range weak forces as being caused by dark matter emerged.

   The progress in understanding of hadronic mass calculations has led to the identification of so called super-symplectic bosons and their super-counterparts as basic building blocks of hadrons. This notion leads also to a microscopic description of neutron stars and black-holes in terms of highly entangled string like objects in Hagedorn temperature and in very precise sense analogous to gigantic hadrons.

4. A brief summary about cosmic strings, which form a corner stone of TGD inspired cosmology, is given.

5. Allais effect is interpreted as interference effect made possible by gigantic value of gravitational Planck constant assignable to space-time sheets mediating gravitational interaction. There is experimental evidence for gravimagnetic fields in rotating superconductors which are by 20 orders of magnitudes stronger than predicted by general relativity. A TGD based explanation of these observations is proposed. Also the predicted anomalous time dilation due to warping of space-time sheet and possible even for gravitational vacua is discussed.

Cosmic strings

This forces the updating of the more than decade old rough vision about topologically condensed cosmic strings and about gamma ray bursts described in this chapter. According to the updated model, cosmic strings transform in topological condensation to magnetic flux tubes about which they represent a limiting case. Primordial magnetic flux tubes forming ferro-magnet like structures become seeds for gravitational condensation leading to the formation of stars and galaxies. The TGD based model for the asymptotic state of a rotating star as dynamo leads to the identification of the predicted magnetic flux tube at the rotation axis of the star as Z^0 magnetic flux tube of primordial origin. Besides Z^0 magnetic flux tube structure also magnetic flux tube structure exists at different space-time sheet but is in general not parallel to the Z^0 magnetic structure. This structure cannot have primordial origin (the magnetic field of star can even flip its polarity).

The flow of matter along Z^0 magnetic (rotation) axis generates synchrotron radiation, which escapes as a precisely targeted beam along magnetic axis and leaves the star. The identification is as the rotating light beam associated with ordinary neutron stars. During the core collapse leading to the supernova this beam becomes gamma ray burst. The mechanism is very much analogous to the squeezing of the tooth paste from the tube. The fact that all nuclei are fully ionized Z^0 ions, the Z^0 charge unbalance caused by the ejection of neutrinos, and the radial compression make the effect extremely strong so that there are hopes to understand the observed incredibly high polarization of 80 ± 20 per cent.

TGD suggests the identification of particles of mass $m \simeq 2m_e$ accompanying dark matter as lepto-pions formed by color excited leptons, and topologically condensed at magnetic flux tubes having thickness of about lepto-pion Compton length. Lepto-pions would serve as signatures of dark matter whereas dark matter itself would correspond to the magnetic energy of topologically condensed cosmic strings transformed to magnetic flux tubes.

TGD inspired cosmology

A proposal for what might be called TGD inspired cosmology is made. The basic ingredient of this cosmology is the TGD counter part of the cosmic string. It is found that many-sheeted space-time concept, the new view about the relationship between inertial and gravitational four-momenta, the basic properties of the cosmic strings, zero energy ontology, the hierarchy of dark matter with levels labeled by arbitrarily large values of Planck constant: the existence of the limiting temperature (as in string model, too), the assumption about the existence of the vapor phase dominated by cosmic strings, and quantum criticality imply a rather detailed picture of the cosmic evolution, which differs from that provided by the standard cosmology in several respects but has also strong resemblances with inflationary scenario.

TGD inspired cosmology in its recent form relies on an ontology differing dramatically from that of GRT based cosmologies. Zero energy ontology states that all physical states have vanishing net quantum numbers so that all matter is creatable from vacuum. The hierarchy of dark matter identified as macroscopic quantum phases labeled by arbitrarily large values of Planck constant is second aspect of the new ontology. The values of the gravitational Planck constant assignable to space-time sheets mediating gravitational interaction are gigantic. This implies that TGD inspired late cosmology might decompose into stationary phases corresponding to stationary quantum states in cosmological scales and critical cosmologies corresponding to quantum transitions changing the value of the gravitational Planck constant and inducing an accelerated cosmic expansion.

1. Zero energy ontology

The construction of quantum theory leads naturally to zero energy ontology stating that everything is creatable from vacuum. Zero energy states decompose into positive and negative energy parts having identification as initial and final states of particle reaction in time scales of perception longer than the geometro-temporal separation T of positive and negative energy parts of the state. If the time scale of perception is smaller than T, the usual positive energy ontology applies.

In zero energy ontology inertial four-momentum is a quantity depending on the temporal time scale T used and in time scales longer than T the contribution of zero energy states with parameter $T_1 < T$ to four-momentum vanishes. This scale dependence alone implies that it does not make sense to speak about conservation of inertial four-momentum in cosmological scales. Hence it would be in principle possible to identify inertial and gravitational four-momenta and achieve strong form of Equivalence Principle. It however seems that this is not the correct approach to follow.

2. Dark matter hierarchy and hierarchy of Planck constants

Dark matter revolution with levels of the hierarchy labeled by values of Planck constant forces a further generalization of the notion of imbedding space and thus of space-time. One can say, that imbedding space is a book like structure obtained by gluing together infinite number of copies of the imbedding space like pages of a book: two copies characterized by singular discrete bundle structure are glued together along 4-dimensional set of common points. These points have physical interpretation in terms of quantum criticality. Particle states belonging to different sectors (pages of the book) can interact via field bodies representing space-time sheets which have parts belonging to two pages of this book.

3. Quantum criticality

TGD Universe is quantum counterpart of a statistical system at critical temperature. As a consequence, topological condensate is expected to possess hierarchical, fractal like structure containing topologically condensed 3-surfaces with all possible sizes. Both Kähler magnetized and Kähler electric 3-surfaces ought to be important and string like objects indeed provide a good example of Kähler magnetic structures important in TGD inspired cosmology. In particular space-time is expected to be many-sheeted even at cosmological scales and ordinary cosmology must be replaced with many-sheeted cosmology. The presence of vapor phase consisting of free cosmic strings containing topologically condensed fermions is second crucial aspect of TGD inspired cosmology.

Quantum criticality of TGD Universe, which corresponds to the vanishing of second variation of Kähler action for preferred extremals - at least of the variations related to dynamical symmetries-supports the view that many-sheeted cosmology is in some sense critical. Criticality in turn suggests fractality. Phase transitions, in particular the topological phase transitions giving rise to new space-time sheets, are (quantum) critical phenomena involving no scales. If the curvature of the 3-space does not vanish, it defines scale: hence the flatness of the cosmic time=constant section of the cosmology implied by the criticality is consistent with the scale invariance of the critical phenomena. This motivates the assumption that the new space-time sheets created in topological phase transitions are in good approximation modelable as critical Robertson-Walker cosmologies for some period of time at least.

These phase transitions are between stationary quantum states having stationary cosmologies as space-time correlates: also these cosmologies are determined uniquely apart from single parameter.

4. Only sub-critical cosmologies are globally imbeddable

TGD allows global imbedding of subcritical cosmologies. A partial imbedding of one-parameter families of critical and overcritical cosmologies is possible. The infinite size of the horizon for the imbeddable critical cosmologies is in accordance with the presence of arbitrarily long range fluctuations at criticality and guarantees the average isotropy of the cosmology. Imbedding is possible for some critical duration of time. The parameter labeling these cosmologies is scale factor characterizing the duration of the critical period. These cosmologies have the same optical properties as inflationary cosmologies. Critical cosmology can be regarded as a 'Silent Whisper amplified to Bang' rather than 'Big Bang' and transformed to hyperbolic cosmology before its imbedding fails. Split strings decay to elementary particles in this transition and give rise to seeds of galaxies. In some later stage the hyperbolic cosmology can decompose to disjoint 3-surfaces. Thus each sub-cosmology is analogous to biological growth process leading eventually to death.

5. Fractal many-sheeted cosmology

The critical cosmologies can be used as a building blocks of a fractal cosmology containing cosmologies containing ... cosmologies. p-Adic length scale hypothesis allows a quantitative formulation of the fractality. Fractal cosmology predicts cosmos to have essentially same optic properties as inflationary scenario but avoids the prediction of unknown vacuum energy density. Fractal cosmology explains the paradoxical result that the observed density of the matter is much lower than the critical density associated with the largest space-time sheet of the fractal cosmology. Also the observation that some astrophysical objects seem to be older than the Universe, finds a nice explanation.

6. Cosmic strings as basic building blocks of TGD inspired cosmology

Cosmic strings are the basic building blocks of TGD inspired cosmology and all structures including large voids, galaxies, stars, and even planets can be seen as pearls in a cosmic fractal necklaces consisting of cosmic strings containing smaller cosmic strings linked around them containing... During cosmological evolution the cosmic strings are transformed to magnetic flux tubes with smaller Kähler string tension and these structures are also key players in TGD inspired quantum biology.

The observed large voids would contain galactic cosmic strings at their boundaries. These voids would participate cosmic expansion only in average sense. During stationary periods the quantum states would be modelable using stationary cosmologies and during phase transitions increasing gravitational Planck constant and thus size of the large void they critical cosmologies would be the appropriate description. The acceleration of cosmic expansion predicted by critical cosmologies can be naturally assigned with these periods. Classically the quantum phase transition would be induced when galactic strings are driven to the boundary of the large void. The mechanism forcing the phase transition could be repulsive Coulomb energy associated with dark matter at strings if cosmic strings generate net em charge as a consequence of CP breaking (antimatter could reside inside cosmic strings) or a repulsive gravitational acceleration. The large values of Planck constant are crucial for understanding of living matter so that gravitation would play fundamental role also in the evolution of life and intelligence.

Many-sheeted fractal cosmology containing both hyperbolic and critical space-time sheets based on cosmic strings suggests an explanation for several puzzles of GRT based cosmology such as dark matter problem, origin of matter antimatter asymmetry, the problem of cosmological constant and mechanism of accelerated expansion, the problem of several Hubble constants, and the existence of stars apparently older than the Universe. Under natural assumptions TGD predicts same optical properties of the large scale Universe as inflationary scenario does. The recent balloon experiments however favor TGD inspired cosmology.

TGD and Astrophysics

In this chapter some applications of TGD based view about cosmology and astrophysics are discussed.

1. p-Adic length scale hypothesis can be applied in astrophysical length scales, too and some examples of possible applications are discussed. One of the most interesting implications of p-adicity is the possibility of series of phase transitions changing the value of cosmological constant behaving as $\Lambda \propto 1/L^2(k)$ as a function of p-adic length scale characterizing the size of the space-time sheet.

2. A model for the solar magnetic field as a bundle of topological magnetic flux tubes is constructed and a model of Sunspot cycle is proposed. This model is also shown to explain the mysteriously high temperature of solar corona and also some other mysterious phenomena related to the solar atmosphere. A direct connection with the TGD based explanation of the dark energy as magnetic and Z^0 magnetic energy of the magnetic flux tubes containing dark matter as ordinary matter, emerges. The matter in the solar corona is simply dark matter leaked from the highly curved portions of the magnetic flux tubes to the space-time sheets where it becomes visible. The generation of anomalous Z^0 charge caused by the runoff of dark neutrinos in Super Nova could provide a first principle explanation for the avoidance of collapse to black-hole in Super Nova explosion.

3. D. Da Rocha and Laurent Nottale have proposed that Schrödinger equation with Planck constant $\hbar$ replaced with what might be called gravitational Planck constant $\hbar_{gr} = \frac{GmM}{v_0}$ ($\hbar = c = 1$). v_0 is a velocity parameter having the value $v_0 = 144.7 \pm .7$ km/s giving $v_0/c = 4.6 \times 10^{-4}$. This is rather near to the peak orbital velocity of stars in galactic halos. Also subharmonics and harmonics of v_0 seem to appear. The support for the hypothesis coming from empirical data is impressive.

   Nottale and Da Rocha believe that their Schrödinger equation results from a fractal hydrodynamics. Many-sheeted space-time however suggests astrophysical systems are not only quantum systems at larger space-time sheets but correspond to a gigantic value of gravitational Planck constant. The gravitational (ordinary) Schrödinger equation would provide a solution of the black hole collapse (IR catastrophe) problem encountered at the classical level. The resolution of the problem inspired by TGD inspired theory of living matter is that it is the dark matter at larger space-time sheets which is quantum coherent in the required time scale.

   I have proposed already earlier the possibility that Planck constant is quantized.

   (a) The spectrum would given in terms of integers n characterizing the quantum phases $q = exp(i\pi/n)$. The Planck constants associated with M^4 and CP_2 degrees of freedom are predicted to be different in general and arbitrarily large values of Planck constants are possible so that $\hbar_{gr} = GMm/v_0$ can be understood in this framework. The general philosophy would be that when the quantum system would become non-perturbative, a phase transition increasing the value of $\hbar$ occurs to preserve the perturbative character. This would apply to QCD and to atoms with $Z > 137$ as well.

(b) The model explaining Nottale's findings led later to the generalization of the notion of imbedding space involving a book like structure in both M^4 and CP_2 degrees of freedom. The particles at different pages of the book cannot appear in the same vertex of Feynman diagram. This might be called relative darkness. Interactions via classical fields and exchange of particles leaking between pages are however possible. This distinguishes between TGD based model and more conventional models of dark matter.

(c) The integers n which correspond to polygons constructible using ruler and compass are number theoretically preferred. This gives very strong constraints on planetary masses, their general mass scale, and also on the value of v_0. The constraints are satisfied with accuracy better than 10 per cent.

(d) TGD predicts correctly the value of the parameter v_0 assuming that cosmic strings and their decay remnants are responsible for the dark matter. The harmonics of v_0 can be understood as corresponding to perturbations replacing cosmic strings with their n-branched coverings so that tension becomes n^2-fold: much like the replacement of a closed orbit with an orbit closing only after n turns. $1/n$-sub-harmonic would result when a magnetic flux tube split into n disjoint magnetic flux tubes.

4. Long ranged classical electro-weak and color gauge fields are unavoidable in TGD framework. The smallness of the parity breaking effects in hadronic, nuclear, and atomic length scales does not however seem to allow long ranged electro-weak gauge fields. The problem disappears if long range classical electro-weak gauge fields are identified as space-time correlates for massless gauge fields created by dark matter. The identification explains chiral selection in living matter and unbroken $U(2)_{ew}$ invariance and free color in bio length scales become characteristics of living matter and of bio-chemistry and bio-nuclear physics. An attractive solution of the matter antimatter asymmetry is based on the identification of also antimatter as dark matter.

5. The last section of the chapter is devoted to some astrophysical and cosmological anomalies such as the apparent shrinking of solar system observed by Masreliez, Pioneer anomaly and Flyby anomaly.

Quantum Astrophysics

The vision that the quantum dynamics for dark matter is behind the formation of the visible structures suggests that the formation of the astrophysical structures could be understood as a consequence of gravitational Bohr rules. The origin of these rules has remained a little bit mysterious until the discovery that the hierarchy of Planck constants relates very closely to anyons and fractionization of quantum numbers.

1. Key element is the notion of partonic 2-surface, which for large values of Planck constant can have astrophysical size. This surface contains dark matter in anyonic many particle state if it surrounds the tip of so called causal diamond (the intersection of future and past directed light-cones). Also flux tubes surrounding the orbits of planets and other astrophysical objects containing dark matter would be connected by radial flux tubes to central anyonic 2-surface so that the entire system would be anyonic and quantum coherent in astrophysical scale. Visible matter is condensed around these dark matter structures.

2. Since space-times are 4-surfaces in $H = M^4 \times CP_2$ (or rather, its generalization to a book like structure), gravitational Bohr rules can be formulated in a manner which is general coordinate invariant and Lorentz invariant.

3. The value of the parameter v_0 appearing in gravitational Planck constant varies and this leads to a weakened form of Equivalence Principle stating that v_0 is same for given connected anyonic 2-surface, which can have very complex topology. In the case of solar system inner planets would be connected to an anyonic surface assignable to Sun and outer planets with different value of v_0 to an anyonic surface assignable to Sun and inner planets as a whole. If one accepts

ruler-and-compass hypothesis for allowed values of Planck constant very powerful predictions follow.

This general conceptual framework is applied to build simple models in some concrete examples.

1. Concerning Bohr orbitology in astrophysical length scales, the basic observation is that in the case of a straight cosmic string creating a gravitational potential of form v_1^2/ρ Bohr quantization does not pose any conditions on the radii of the circular orbits so that a continuous mass distribution is possible. This situation is obviously exceptional. If one however accepts the TGD based vision that the very early cosmology was cosmic string dominated and that elementary particles were generated in the decay of cosmic strings, this situation might have prevailed at very early times. If so, the differentiation of a continuous density of ordinary matter to form the observed astrophysical structures would correspond to an approach to a stationary situation governed by Bohr rules for dark matter and in the first approximation one could neglect the intermediate stages.

2. This general picture is applied by considering some simple models for astrophysical systems involving planar structures. There are several universal predictions. Velocity spectrum is universal and only the Bohr radii depend on the choice of mass distribution. The inclusion of cosmic string implies that the system associated with the central mass is finite. Quite generally dark parts of astrophysical objects have shell like structure like atoms as do also ring like structures.

3. p-Adic length scale hypothesis provides a manner to obtain a realistic model for the central objects meaning a structure consisting of shells coming as half octaves of the basic radius: this obviously relates to Titius-Bode law. Also a simple model for planetary rings is obtained. Bohr orbits do not follow cosmic expansion which is obtained only in the average sense if phase transitions reducing the value of basic parameter v_0 occur at preferred values of cosmic time. This explains why v_0 has different values and also the decomposition of planetary system to outer and inner planets with different values of v_0.

TGD Universe is quantum critical and quantum criticality corresponds very naturally to what has been identified as the transition region to quantum chaos.

1. The basic formulation of quantum TGD is consistent with what has been learned from the properties of quantum chaotic systems and quantum chaotic scattering. Wave functions are concentrated around Bohr orbits in the limit of quantum chaos, which is just what dark matter picture assumes.

2. The model for the emission and detection of dark gravitons allows to conclude that the transition to chaos via generation of sub-harmonics of fundamental frequency spoiling the original exact periodicity corresponds to a sequence of phase transitions in which Planck constant transforms from integer to a rational number whose denominator increases as chaos is approached. This gives a precise characterization for the phase transitions leading to quantum chaos in general.

3. In this framework the chaotic motion of astrophysical object becomes the counterpart of quantum chaotic scattering and the description in terms of classical chaos is predicted to fail. By Equivalence Principle the value of the mass of the object does not matter at all so that the motion of sufficiently light objects in solar system might be understandable only as quantum chaotic scattering. The motion of gravitationally unbound comets and rings of Saturn and Jupiter and the collisions of galactic structures known to exhibit the presence of cart-wheel like structures define possible applications.

The description of gravitational radiation provides a stringent test for the idea about dark matter hierarchy with arbitrary large values of Planck constants. In accordance with quantum classical correspondence, one can take the consistency with classical formulas as a constraint allowing to deduce information about how dark gravitons interact with ordinary matter. The standard facts about gravitational radiation are discussed first and then TGD based view about the situation is sketched.

0.5.4 PART III: Topological field quantization

Topological field quantization is perhaps the most important signature differentiating between Maxwellian and TGD based gauge field concepts. What happens that space-time surface decomposes into regions characterized by a handful of vacuum quantum numbers. These quantum numbers partially characterize the coordinate dependence of the two phase angles Ψ and Φ associated the two complex coordinates of CP_2.

Topological field quanta have in general outer boundary and renormalization group invariance suggests that all sizes are possible so that 3-space should have a hierarchical, fractal like, structure containing 3-surfaces condensed on each other. Not only atoms and molecules but also macroscopic bodies correspond to 3-surfaces with outer boundary so that the visible world of the everyday life can be interpreted in completely new manner: instead of topologically trivial space E^3 with mysterious material objects we see empty but topologically extremely rich 3-space: the outer boundaries of the material objects correspond to the boundaries of this 3-space. Topological field quanta can be partially joined together along their boundaries (join along boundaries bond). At the level of chemistry this means the formation of chemical bond, at macroscopic level macroscopic bodies touch each other. An exciting possibility is that the formation of macroscopic quantum systems from smaller units is possible by the formation of the joing along boundaries bonds.

All this suggests that topological field quantization might provide the first principle explanation for the generation of both spatial and temporal structures so that CP_2 geometry would manifest itself in all length scales, in particular at the visible structures of the everyday world and the last part of the book is devoted to some more detailed applications of these ideas.

Hydrodynamics and CP_2 geometry

The chapter begins with a brief summary of the basic notions related to many-sheeted space-time. A generalization of hydrodynamics to a p-adic hierarchy of hydrodynamics is performed and a mechanism of energy transfer between condensate levels is identified. Mary Selvam has found a fascinating connection between the distribution of primes and the distribution of vortex radii in turbulent flow in atmosphere. These observations provide new insights into p-adic length scale hypothesis and suggest that TGD based generalization of Hawking-Bekenstein law holds even in macroscopic length scales and that hydrodynamical vortices behave in some aspects like elementary particles. TGD leads to a formulation of a general theory of phase transitions: the new element is the presence of several condensate levels.

A topological model for the generation of the hydrodynamical turbulence is proposed. The basic idea is that hydrodynamical turbulence can be regarded as a spontaneous Kähler magnetization leading to the increase the value of Kähler function and therefore of the probability of the configuration. Kähler magnetization is achieved through the formation of a vortex cascade via the decay of the mother vortex by the emission of smaller daughter vortices. Vortices with various values of the fractal quantum number and with sizes related by a discrete scaling transformation appear in the cascade. The decay of the vortices takes place via the so called phase slippage process.

An encouraging result is the prediction for the size distribution of the vortices: the prediction is practically identical with that obtained from the model of Heisenberg but on rather different physical grounds. The model is rather insensitive to the p-adic scaling of vortices in the transition as long as it is smaller than $\lambda = 2^{-5}$. The model is also consistent with the assumption that the decay of a vortex to smaller vortices corresponds to a phase transition from a given level of dark matter hierarchy to a lower level so that the value of $\hbar$ is reduced by a factor $\lambda = v_0/n \simeq 2^{-11}/n$, $n = 1, 2, ...$ so that Compton length scales as well as sizes of vortices are reduced by this factor.

Macroscopic quantum phenomena and CP_2 geometry

A TGD inspired description of super conductivity, super fluidity and quantum Hall effect is suggested. Contrary to the original expectation, it is found that TGD based ideas should provide new insights also to the description of less exotic condensed matter phenomena: say the description of the conductors, di-electrics and magnetism, too.

1. The basic assumption is that supra phases correspond to the small vacuum quantum number limit of TGD. At this limit the sizes of the topological field quanta becomes small (typically of

the size of the coherence length of the supra phase: $\xi = 10^{-8}-10^{-7}$ meters for super conductors). Supra phase corresponds to a phase obtained by gluing these field quanta together by join along boundaries bonds to form a macroscopic quantum system: the presence of these bonds (or rather bridges) makes possible dissipation free flow.

2. The generation of the vacuum Kähler and Z^0 fields suggests a possible unification for the classical descriptions of the super fluidity and super conductivity: the role of the magnetic field is taken by the Z^0 magnetic field in the super fluidity.

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Part I

THE NOTION OF MANY-SHEETED SPACE-TIME

Chapter 1

Basic Extremals of the Kähler Action

1.1 Introduction

The physical interpretation of the Kähler function and the TGD based space-time concept are the basic themes in the third part of the book. The aim is to develop what might be called classical TGD at fundamental level. The strategy is simple: try to guess the general physical consequences of the configuration space geometry and of the TGD based gauge field concept and study the simplest extremals of Kähler action and try to abstract general truths from their properties.

The fundamental underlying assumptions are the following:

1. The 4-surface associated with given 3-surface defined by Kähler function K as an absolute minimum or some more general preferred extremal of the Kähler action is identifiable as a classical space-time. In [E2] it was proposed that absolute value of Kähler action inside regions where the action density has definite sign is minimized or maximized. Number theoretically these extremals would correspond to Kähler calibrations and their duals having representation has hyper-quaternionic or co-hyper-quaternionic surfaces of hyper-octonionic imbedding space. . . Hence the notion of space-time would not not completely objective: similar situation is encountered in M-theory (mirror symmetry [17]).

   Due to the preferred extremal property classical space-time can be also regarded as a generalized Bohr orbit so that the quantization of the various parameters associated with a typical extremal of the Kähler action is expected to take place in general. In TGD quantum states corresponds to quantum superpositions of these classical space-times so that this classical space-time is certainly not some kind of effective quantum average space-time.

   It must be emphasized that absolute minimization could be replaced by any other principle allowing to select a unique extremal going through X^3 belonging to 7-D light-like causal determinant determined as the boundary of the union of future or past directed light cones $M^4_\pm \times CP_2$. Indeed, the number theoretical considerations of [E2] favor the separate minimization of magnitudes of positive and contributions to the Kähler action. This option seems to be also more physical since it reduces to the minimization of the energy and thus to fixing of time derivatives of imbedding space coordinates at X^3. Since the considerations of this chapter do to depend on the detailed form of the variational principle, I leave it for the reader to replace "absolute minimization" by some more general phrase everywhere.

2. The bosonic vacuum functional of the theory is the exponent of the Kähler function $\Omega_B = exp(K)$. This assumption is the only assumption about the dynamics of the theory and is necessitated by the requirement of divergence cancellation.

3. Renormalization group invariance and spin glass analogy. The value of the Kähler coupling strength is such that the vacuum functional $exp(K)$ is analogous to the exponent $exp(H/T)$ defining the partition function of a statistical system at critical temperature. This allows Kähler coupling strength to depend on zero modes of the configuration space metric and as already

found there is very attractive hypothesis determining completely the dependence of the Kähler coupling strength on the zero modes based on p-adic considerations motivated by the spin glass analogy.

4. In spin degrees of freedom the massless Dirac equation for the induced spinor fields with modified Dirac action defines classical theory: this is in complete accordance with the proposed definition of the configuration space spinor structure.

In the case that absolute minimization is taken as the fundamental principle, the assumption about the form of the vacuum functional leads to principle, which we shall call "Yin-Yang" principle in what follows.

1. Kähler function is essentially a Maxwell action and as such not positive definite: the generation of the Kähler electric fields gives negative contribution to the Kähler action. Therefore the absolute minima of the Kähler action are expected to have in general non-positive Kähler action and to correspond to space-times carrying Kähler- electric fields. This tendency of the Kähler function to become negative corresponds to the "Yin"-aspect of our principle.

2. Vacuum functional favors 3-surfaces with the property that the value of the Kähler function is positive. This tendency is the "Yang" aspect of the principle. Together these tendencies stabilize the theory since they imply that for very large systems the average Kähler action per volume is essentially zero to guarantee that vacuum amplitude is non-vanishing: in particular vacuum functional doesn't diverge for any configurations.

If preferred extrema correspond to Kähler calibrations or their duals [E2], Yin-Yang principle is modified to a local principle. For Kähler calibrations (their duals) the absolute value of action in given region is minimized (maximized). A given region with positive (negative sign) of action density favors Kähler electric (magnetic) fields. In long length scales the average density of Kähler action per four-volume tends to vanish so that Kähler function of the entire universe is expected to be very nearly zero. This regularizes the theory automatically but positive values of Kähler function are of course favored.

The geometrization of the classical gauge fields in terms of the induced gauge field concept is also important concerning the physical interpretation. Electro-weak gauge potentials correspond to the space-time projections of the spinor connection of CP_2, gluonic gauge potentials to the projections of the Killing vector fields of CP_2 and gravitational field to the induced metric. The topics to be discussed in this part of the book are summarized briefly in the following.

What the selection of preferred extremals of Kähler action might mean has remained a longstanding problem and real progress occurred only quite recently (I am writing this towards the end of year 2003).

1. The vanishing of Lorentz 4-force for the induced Kähler field means that the vacuum 4-currents are in a mechanical equilibrium. Lorentz 4-force vanishes for all known solutions of field equations which inspires the hypothesis that all preferred extremals of Kähler action satisfy the condition. The vanishing of the Lorentz 4-force in turn implies local conservation of the ordinary energy momentum tensor. The corresponding condition is implied by Einstein's equations in General Relativity. The hypothesis would mean that the solutions of field equations are what might be called generalized Beltrami fields. The condition implies that vacuum currents can be non-vanishing only provided the dimension D_{CP_2} of the CP_2 projection of the space-time surface is less than four so that in the regions with $D_{CP_2} = 4$, Maxwell's vacuum equations are satisfied.

2. The hypothesis that Kähler current is proportional to a product of an arbitrary function ψ of CP_2 coordinates and of the instanton current generalizes Beltrami condition and reduces to it when electric field vanishes. Kähler current has vanishing divergence for $D_{CP_2} < 4$, and Lorentz 4-force indeed vanishes. The remaining task would be the explicit construction of the imbeddings of these fields and the demonstration that field equations can be satisfied.

3. By quantum classical correspondence the non-deterministic space-time dynamics should mimic the dissipative dynamics of the quantum jump sequence. Beltrami fields appear in physical applications as asymptotic self organization patterns for which Lorentz force and dissipation vanish. This suggests that absolute minima of Kähler action correspond to space-time sheets

which asymptotically satisfy generalized Beltrami conditions so that one can indeed assign to the final 3-surface a unique 4-surface apart from effects related to non-determinism. Preferred extremal property abstracted to purely algebraic generalized Beltrami conditions makes sense also in the p-adic context.

This chapter is mainly devoted to the study of the basic extremals of the Kähler action besides the detailed arguments supporting the view that the preferred extrema satisfy generalized Beltrami conditions asymptotically. It is perhaps good to emphasize that only extremals rather than preferred extremals are in question. These extremals can however form building blocks of genuine absolute minima or space-time surface satisfying an action principle reducing to extremization of absolute value of Kähler action in regions where action density has definite sign, and are therefore interesting. Also the small deformations of them, say vacuum extremals, are expected to be important physically. Extremals decompose in a natural manner to vacuum and non-vacuum extremals and both kinds of extremals are studied.

1.2 General considerations

The solution families of field equations studied in this chapter were found already during eighties. The physical interpretation turned out to be the the really tough problem. What is the principle selecting preferred extremals of Kähler action as analogs of Bohr orbits assigning to 3-surface X^3 a unique space-time surface $X^4(X^3)$? Does Equivalence Principle hold true and if so, in what sense? These have been the key questions. The realization that light-like 3-surfaces X^3_l associated with the light-like wormhole throats at which the signature of the induced metric changes from Minkowskian to Euclidian led to the formulation of quantum TGD in terms of second quantized induced spinor fields at these surfaces. Together with the notion of number theoretical compactification this approach allowed to identify the conditions characterizing the preferred extremals. What is remarkable that these conditions are consistent with what is known about extremals. Also a connection with string models and understanding of the space-time realization of Equivalence Principle emerged. In this section the theoretical background behind field equations is briefly summarized. I will not repeat the discussion of previous two chapters [D2, D3] summarizing the general vision about many-sheeted space-time, and consideration will be restricted to those aspects of vision leading to direct predictions about the properties of preferred extremals of Kähler action.

1.2.1 Number theoretical compactification and $M^8 - H$ duality

The notion of hyper-quaternionic and octonionic manifold makes sense but it not plausible that $H = M^4 \times CP_2$ could be endowed with a hyper-octonionic manifold structure. Situation changes if H is replaced with hyper-octonionic M^8. Suppose that $X^4 \subset M^8$ consists of hyper-quaternionic and co-hyper-quaternionic regions. The basic observation is that the hyper-quaternionic sub-spaces of M^8 with a fixed hyper-complex structure (containing in their tangent space a fixed hyper-complex subspace M^2 or at least one of the light-like lines of M^2) are labeled by points of CP_2. Hence each hyper-quaternionic and co-hyper-quaternionic four-surface of M^8 defines a 4-surface of $M^4 \times CP_2$. One can loosely say that the number-theoretic analog of spontaneous compactification occurs: this of course has nothing to do with dynamics.

This picture was still too naive and it became clear that not all known extremals of Kähler action contain fixed $M^2 \subset M^4$ or light-like line of M^2 in their tangent space.

1. The first option represents the minimal form of number theoretical compactification. M^8 is interpreted as the tangent space of H. Only the 4-D tangent spaces of light-like 3-surfaces X^3_l (wormhole throats or boundaries) are assumed to be hyper-quaternionic or co-hyper-quaternionic and contain fixed M^2 or its light-like line in their tangent space. Hyper-quaternionic regions would naturally correspond to space-time regions with Minkowskian signature of the induced metric and their co-counterparts to the regions for which the signature is Euclidian. What is of special importance is that this assumption solves the problem of identifying the boundary conditions fixing the preferred extremals of Kähler action since in the generic case the intersection of M^2 with the 3-D tangent space of X^3_l is 1-dimensional. The surfaces $X^4(X^3_l) \subset M^8$ would

be hyper-quaternionic or co-hyper-quaternionic but would not allow a local mapping between the 4-surfaces of M^8 and H.

2. One can also consider a more local map of $X^4(X_l^3) \subset H$ to $X^4(X_l^3) \subset M^8$. The idea is to allow $M^2 \subset M^4 \subset M^8$ to vary from point to point so that $S^2 = SO(3)/SO(2)$ characterizes the local choice of M^2 in the interior of X^4. This leads to a quite nice view about strong geometric form of $M^8 - H$ duality in which M^8 is interpreted as tangent space of H and $X^4(X_l^3) \subset M^8$ has interpretation as tangent for a curve defined by light-like 3-surfaces at X_l^3 and represented by $X^4(X_l^3) \subset H$. Space-time surfaces $X^4(X_l^3) \subset M^8$ consisting of hyper-quaternionic and co-hyper-quaternionic regions would naturally represent a preferred extremal of E^4 Kähler action. The value of the action would be same as CP_2 Kähler action. $M^8 - H$ duality would apply also at the induced spinor field and at the level of configuration space. The possibility to assign $M^2(x) \subset M^4$ to each point of M^4 projection $P_{M^4}(X^4(X_l^3))$ is consistent with what is known about extremals of Kähler action with only one exception: CP_2 type vacuum extremals. In this case M^2 can be assigned to the normal space.

3. Strong form of $M^8 - H$ duality satisfies all the needed constraints if it represents Kähler isometry between $X^4(X_l^3) \subset M^8$ and $X^4(X_l^3) \subset H$. This implies that light-like 3-surface is mapped to light-like 3-surface and induced metrics and Kähler forms are identical so that also Kähler action and field equations are identical. The only differences appear at the level of induced spinor fields at the light-like boundaries since due to the fact that gauge potentials are not identical.

4. The map of $X_l^3 \subset H \rightarrow X_l^3 \subset M^8$ would be crucial for the realization of the number theoretical universality. $M^8 = M^4 \times E^4$ allows linear coordinates as those preferred coordinates in which the points of imbedding space are rational/algebraic. Thus the point of $X^4 \subset H$ is algebraic if it is mapped to algebraic point of M^8 in number theoretic compactification. This of course restricts the symmetry groups to their rational/algebraic variants but this does not have practical meaning. Number theoretical compactication could thus be motivated by the number theoretical universality.

5. The possibility to use either M^8 or H picture might be extremely useful for calculational purposes. In particular, M^8 picture based on $SO(4)$ gluons rather than $SU(3)$ gluons could perturbative description of low energy hadron physics. The strong $SO(4)$ symmetry of low energy hadron physics can be indeed seen direct experimental support for the $M^8 - H$ duality.

Number theoretical compactification has quite deep implications for quantum TGD and is actually responsible for most of the progress in the understanding of the mathematical structure of quantum TGD. A very powerful prediction is that preferred extremals should allow slicings to either stringy world sheets or dual partonic 2-surfaces as well as slicing by light-like 3-surfaces. Both predictions are consistent with what is known about extremals.

1. If the distribution of planes $M^2(x)$ is integrable, it is possible to slice $X^4(X^3)$ to a union of 2-dimensional surfaces having interpretation as string world sheets and dual 2-dimensional copies of partonic surfaces X^2. This decomposition defining 2+2 Kaluza-Klein type structure realizes quantum gravitational holography and allows to understand Equivalence Principle at space-time level in the sense that dimensional reduction defined by the integral of Kähler action over the 2-dimensional space labeling stringy world sheets gives rise to the analog of stringy action and one obtains string model like description of quantum TGD as dual for a description based on light-like partonic 3-surfaces. String tension is not however equal to the inverse of gravitational constant as one might naively expect but the connection is more delicate.

2. Second implication is the slicing of $X^4(X_l^3)$ to light-like 3-surfaces Y_l^3 "parallel" to X_l^3. Also this slicing realizes quantum gravitational holography if one requires General Coordinate Invariance in the sense that the Dirac determinant defined by the generalized eigenvalues of the transverse part $D_K(X^2)$ of D_K is differs for two 3-surfaces Y_l^3 in the slicing only by an exponent of a real part of a holomorphic function of configuration space complex coordinates giving no contribution to the Kähler metric. The requirement that the zero modes of the 4-D modified Dirac operators D_K reduce to the analogs of 3-D shock waves for all 3-surfaces Y_l^3 in the slicing requires that Noether currents are parallel to Y_l^3. Clearly, 3+1 type Kaluza-Klein structure is in question.

This slicing allows to realize RG flow at space-time level using the light-like coordinate associated with the slicing as RG parameter [D3]. The prediction is RG invariance of couplings for a causal diamond (CD) in given p-adic length scale meaning a justification of the hypothesis that coupling constant evolution reduces to a discrete p-adic coupling constant evolution with p-adic length scales coming as half octaves. This prediction follows if the known properties of extremals of Kähler action hold true quite generally.

3. The assumption that Kähler current and other gauge currents flow along the slices Y_l^3 of the slicing of $X^4(X_l^3)$ is enough for the renormalization group invariance of gauge couplings inside CD guaranteing p-adic coupling constant evolution [D3]. The current could thus have also a component parallel to the transverse cross section in which case the current would be space-like. Space-likeness brings in mind the Euclidian signature of the effective metric defined by the modified gamma matrices $\hat{\Gamma}^\alpha = (\partial L_K/\partial h^k_\alpha)\gamma^k$ necessary for the Higgs mechanism. Dissipation would be absent but Lorentz force would be non-vanishing. The general solution ansatz for the field equations allows besides light-like Kähler currents also space-like gauge currents, which can be regarded as topological currents. The gluing of CP_2 type vacuum extremals to the known extremals with light-like gauge currents could generate the transversal part of the currents and increase the dimension D_{CP_2} of the CP_2 projection to at least $D_{CP_2} = 3$.

1.2.2 The exponent of Kähler function as Dirac determinant for the modified Dirac action

Although quantum criticality in principle predicts the possible values of Kähler coupling strength, one might hope that there exists even more fundamental approach involving no coupling constants and predicting even quantum criticality and realizing quantum gravitational holography.

The identification of the light-like partonic 3-surfaces as carriers of elementary particle quantum numbers inspired by the TGD based quantum measurement theory suggests the identification of the modified Dirac action as that associated with the Chern-Simons action for the induced Kähler gauge potential. It however turned out that it is 4-D modified Dirac action associated with Kähler action, which is the correct choice. The point is that only the solutions of D_K which are effectively 3-dimensional by generalized super-conformal gauge invariance are physical. The effective metric defined by the modified gamma matrices is non-singular even for light-like 3-surfaces Y_l^3, and this allows to develop a well-defined theory involving also metric degrees of freedom. In this framework $C-S$ action emerges as a phase factor of quantum states for phases with non-standard value of Planck constant and is related to anyons and charge fractionization.

Absolutely essential role is played by number theoretical compactification predicted that space-time sheets have dual slicings to string world sheets and partonic 2-surfaces. This prediction is supported by the properties of known extremals of Kähler action. This allows the decompositions $D_K = D_K(Y^2) + D_K(X^2)$ generalized eigenvalues can be associated associated with $D_K(X^2)$ for zero modes of D_K.

1. The Dirac determinant defined by the product of Dirac determinants associated with the light-like partonic 3-surfaces X_l^3 associated with a given space-time sheet X^4 is the simplest candidate for vacuum functional identifiable as the exponent of the Kähler function. One can of course worry about the finiteness of the Dirac determinant. p-Adicization requires that the eigenvalues belong to a given algebraic extension of rationals. This restriction would imply a hierarchy of physics corresponding to different extensions and could automatically imply the finiteness and algebraic number property of the Dirac determinants if only finite number of eigenvalues would contribute. The regularization would be performed by physics itself if this were the case.

2.

3. The basic problem has been how to feed in the information about the preferred extremal of Kähler action to the eigenvalue spectrum $D_K(X^2)$ at light-like 3-surface X_l^3. The identification of the preferred extremal came possible via boundary conditions at X_l^3 dictated by number theoretical compactification. The basic observation is that the Dirac equation associated with the 4-D Dirac operator D_K defined by Kähler action can be seen as a conservation law for a super current. By restricting the super current to flow along X_l^3 by requiring that its normal

component vanishes, one obtains a singular solution of 4-D modified Dirac equation restricted to X_l^3. The "energy" spectrum to the spectrum of eigenvalues for $D_K(X^2)$ and the product of the eigenvalues defines the Dirac determinant in standard manner. Since the eigenmodes are restricted to those localized to regions of non-vanishing induced Kähler form, the number of eigen modes is finite and therefore also Dirac determinant is finite. The eigenvalues can be also algebraic numbers.

4. It remains to be proven that the product of eigenvalues gives rise to the exponent of Kähler action for the preferred extremal of Kähler action. At this moment the only justification for the conjecture is that this the only thing that one can imagine.

5. An additional bonus is precise definition of quantum criticality. The Noether currents associated with the modified Dirac action are conserved if its variation with respect to H-coordinates vanishes. This means that the second variation of Kähler action varies. One can consider also a weaker form of quantum criticality in which case only the variations with respect to deformations defining the conserved currents are vanishing. This would give to a hierarchy of criticalities defined by the second variations of Kähler action. The vacuum degeneracy of Kähler action would be essential for the realization of quantum criticality and could correspond to a hierarchy of dynamical gauge symmetries characterizing finite measurement resolution suggested by the hierarchy of Jones inclusions [A9].

6. A long-standing conjecture has been that the zeros of Riemann Zeta are somehow relevant for quantum TGD. Rieman zeta is however naturally replaced Dirac zeta defined by the eigenvalues of $D_K(X^2)$ and closely related to Riemann Zeta since the spectrum consists essentially for the cyclotron energy spectra for localized solutions region of non-vanishing induced Kähler magnetic field and hence is in good approximation integer valued up to some cutoff integer. In zero energy ontology the Dirac zeta function associated with these eigenvalues defines "square root" of thermodynamics assuming that the energy levels of the system in question are expressible as logarithms of the eigenvalues of the modified Dirac operator defining kind of fundamental constants. Critical points correspond to approximate zeros of Dirac zeta and if Kähler function vanishes at criticality as it ineed should, the thermal energies at critical points are in first order approximation proportional to zeros themselves so that a connection between quantum criticality and approximate zeros of Dirac zeta emerges.

7. The discretization induced by the number theoretic braids reduces the world of classical worlds to effectively finite-dimensional space and configuration space Clifford algebra reduces to a finite-dimensional algebra. The interpretation is in terms of finite measurement resolution represented in terms of Jones inclusion $\mathcal{M} \subset \mathcal{N}$ of HFFs with $\mathcal{M}$ taking the role of complex numbers. The finite-D quantum Clifford algebra spanned by fermionic oscillator operators is identified as a representation for the coset space $\mathcal{N}/\mathcal{M}$ describing physical states modulo measurement resolution. In the sectors of generalized imbedding space corresponding to non-standard values of Planck constant quantum version of Clifford algebra is in question.

Concerning the understanding of preferred extremals, the basic prediction (assuming that Kähler gauge potential has no gauge part in M^4) is that the CP_2 projection of the light-like 3-surfaces is 3-dimensional for non-vacuum partons. One implication is that a very general family of cosmic string type solutions with 2-D CP_2 projection cannot correspond to preferred extremals. If ideal cosmic strings were preferred extremals, the most general realization for the hierarchy of Planck constants in terms of a book like structure of the imbedding space would not be possible [A9]. Also massless extremals have 2-D CP_2 projection and are excluded as preferred extremals. The interpretation is that the preferred extremals must be deformations of these extremals containing topologically condensed CP_2 type vacuum extremals representing elementary particles and that these extremals provide only smoothed out representation of the actual physics. The general principle would be that matter is present only if light-like 3-surfaces at which the signature of the induced metric changes (light-like boundary components cannot be excluded but in this case gauge charges would vanish). That the interaction with a larger Minkowskian space-time sheet creates matter could be seen as a variant of Mach Principle.

1.2.3 Preferred extremal property as classical correlate for quantum criticality, holography, and quantum classical correspondence

The Noether currents assignable to the modified Dirac equation are conserved only if the first variation of the modified Dirac operator D_K defined by Kähler action vanishes. This is equivalent with the vanishing of the second variation of Kähler action -at least for the variations corresponding to dynamical symmetries having interpretation as dynamical degrees of freedom which are below measurement resolution and therefore effectively gauge symmetries. The weaker condition would mean that the inner product defined by the integral of $D_\alpha \partial L_K/\partial h^k_\alpha \delta h^k$ over the space-time surface vanishes for the deformations defining dynamical symmetries but the field equations are not satisfied completely generally. The weaker condition would mean that the inner product defined by the integral of $D_\alpha \partial L_K/\partial h^k_\alpha \delta h^k$ over the space-time surface vanishes for the deformations defining dynamical symmetries but the field equations are not satisfied completely generally.

The vanishing of the second variation in interior of $X^4(X^3_l)$ is what corresponds exactly to quantum criticality so that the basic vision about quantum dynamics of quantum TGD would lead directly to a precise identification of the preferred extremals. Something which I should have noticed for more than decade ago! The question whether these extremals correspond to absolute minima remains however open.

The vanishing of second variations of preferred extremals -at least for deformations representing dynamical symmetries, suggests a generalization of catastrophe theory of Thom, where the rank of the matrix defined by the second derivatives of potential function defines a hierarchy of criticalities with the tip of bifurcation set of the catastrophe representing the complete vanishing of this matrix. In the recent case this theory would be generalized to infinite-dimensional context. There are three kind of variables now but quantum classical correspondence (holography) allows to reduce the types of variables to two.

1. The variations of $X^4(X^3_l)$ vanishing at the intersections of $X^4(X^3_l)$ wth the light-like boundaries of causal diamonds CD would represent behavior variables. At least the vacuum extremals of Kähler action would represent extremals for which the second variation vanishes identically (the "tip" of the multi-furcation set).

2. The zero modes of Kähler function would define the control variables interpreted as classical degrees of freedom necessary in quantum measurement theory. By effective 2-dimensionality (or holography or quantum classical correspondence) meaning that the configuration space metric is determined by the data coming from partonic 2-surfaces X^2 at intersections of X^3_l with boundaries of CD, the interiors of 3-surfaces X^3 at the boundaries of CDs in rough sense correspond to zero modes so that there is indeed huge number of them. Also the variables characterizing 2-surface, which cannot be complexified and thus cannot contribute to the Kähler metric of configuration space represent zero modes. Fixing the interior of the 3-surface would mean fixing of control variables. Extremum property would fix the 4-surface and behavior variables if boundary conditions are fixed to sufficient degree.

3. The complex variables characterizing X^2 would represent third kind of variables identified as quantum fluctuating degrees of freedom contributing to the configuration space metric. Quantum classical correspondence requires 1-1 correspondence between zero modes and these variables. This would be essentially holography stating that the 2-D "causal boundary" X^2 of $X^3(X^2)$ codes for the interior. Preferred extremal property identified as criticality condition would realize the holography by fixing the values of zero modes once X^2 is known and give rise to the holographic correspondence $X^2 \to X^3(X^2)$. The values of behavior variables determined by extremization would fix then the space-time surface $X^4(X^3_l)$ as a preferred extremal.

4. Clearly, the presence of zero modes would be absolutely essential element of the picture. Quantum criticality, quantum classical correspondence, holography, and preferred extremal property would all represent more or less the same thing. One must of course be very cautious since the boundary conditions at X^3_l involve normal derivative and might bring in delicacies forcing to modify the simplest heuristic picture.

The basic question is whether number theoretic view about preferred extremals imply absolute minimization or something analogous to it.

1. The number theoretic conditions defining preferred extremals are purely algebraic and make sense also p-adically and this is enough since p-adic variants of field equations make sense although the notion of Kähler action does not make sense as integral. Despite this the identification of the vacuum functional as exponent of Kähler function as Dirac determinant allows to define the exponent of Kähler function as a p-adic number [B4].

2. The general objection against all extremization principles is that they do not make sense p-adically since p-adic numbers are not well-ordered.

3. These observations do not encourage the idea about equivalence of the two approaches. On the other hand, real and p-adic sectors are related by algebraic continuation and it could be quite enough if the equivalence were true in real context alone.

The finite-dimensional analogy allows to compare absolute minimization and criticality with each other.

1. Absolute minimization would select the branch of Thom's catastrophe surface with the smallest value of potential function for given values of control variables. In general this value would not correspond to criticality since absolute minimization says nothing about the values of control variables (zero modes).

2. Criticality forces the space-time surface to belong to the bifurcation set and thus fixes the values of control variables, that is the interior of 3-surface assignable to the partonic 2-surface, and realized holography. If the catastrophe has more than $N = 3$ sheets, several preferred extremals are possible for given values of control variables fixing $X^3(X^2)$ unless one assumes that absolute minimization or some other criterion is applied in the bifurcation set. In this sense absolute minimization might make sense in the real context and if the selection is between finite number of alternatives is in question, it should be possible carry out the selection in number theoretically universal manner.

1.2.4 Can one determine experimentally the shape of the space-time surface?

The question 'Can one determine experimentally the shape of the space-time surface?' does not relate directly to the topic of this chapter in technical sense, and the only excuse for its inclusion is the title of this section plus the fact that the general conceptual framework behind quantum TGD assumes an affirmative answer to this question. If physics were purely classical physics, operationalism in the strong sense of the word would require that one can experimentally determine the shape of the space-time as a surface of the imbedding space with arbitrary accuracy by measuring suitable classical observables. In quantum physics situation is considerably more complex and quantum effects are both a blessing and a curse.

Measuring classically the shape of the space-time surface

Consider first the purely classical situation to see what is involved.

1. All classical gauge fields are expressible in terms of CP_2 coordinates and their space-time gradients so that the measurement of four field quantities with some finite resolution in some space-time volume could in principle give enough information to deduce the remaining field quantities. The requirement that space-time surface corresponds to an extremal of Kähler action gives a further strong consistency constraint and one can in principle test whether this constraint is satisfied. A highly over-determined system is in question.

2. The freedom to choose the space-time coordinates freely causes complications and it seems that one must be able to determine also the distances between the points at which the field quantities are determined. At purely classical Riemannian level this boils down to the measurement of the induced metric defining classical gravitational field. In macroscopic length scales one could base the approach to iterative procedure in which one starts from the assumption that the coordinates used are Minkowski coordinates and gravitational corrections are very weak.

3. The measurement of induced Kähler form in some space-time volume determines space-time surface only modulo canonical transformations of CP_2 and isometries of the imbedding space. If one measures classical electromagnetic field, which is not canonical invariant in general case, with some precision, one can determine to what kind of surface space-time region corresponds apart from the action of the isometries of H.

Quantum measurement of the shape of the space-time surface

In practice the measurement of the shape of the space-time surface is necessarily a bootstrap procedure based on the model for space-time region and on the requirement of internal consistency. Many-sheeted space-time and quantum phenomena produce considerable complications but also provide universal measurement standards.

Consider first how quantum effects could help to measure classical fields and distances.

1. The measurement of distances by measuring first induced metric at each point of space-time sheet is rather unpractical procedure. Many-sheeted space-time however comes in rescue here. p-Adic length scale hypothesis provides a hierarchy of natural length scales and one can use p-adic length and time scales as natural units of length and time: space-time sheets serve as meter sticks. For instance, length measurement reduces in principle to a finite number of operations using various space-time sheets with standardized lengths given by p-adic length scales. Also various transition frequencies and corresponding wavelengths provide universal time and length units. Atomic clock provides a standard example of this kind of time unit. A highly nontrivial implication is the possibility to deduce the composition of distant star from its spectral lines. Without p-adic length scale hypothesis the scales for the mass spectra of the elementary particles would be variable and atomic spectra would vary from point to point in TGD universe.

   Do the p-adic length scales correspond to the length units of the induced metric or of M^4_+ metric? If the topological condensation a meter stick space-time sheet at a larger space-time sheet does not stretch the meter stick but only bends it, the length topologically condensed meter stick in the induced metric equals to its original length measured using M^4_+ metric.

2. If superconducting order parameters are expressible in terms of the CP_2 coordinates (there is evidence for this, see the chapter "Macroscopic quantum phenomena and CP_2 geometry"), one might determine directly the CP_2 coordinates as functions of Minkowski coordinates and this would allow to estimate all classical fields directly and thus to deduce strong consistency constraints.

3. At quantum level only the fluxes of the classical fields through surface areas with some minimum size determined by the length scale resolution can be measured. In case of magnetic fields the quantization of the magnetic flux simplifies the situation dramatically. Topological field quantization quite generally modifies the measurement of continuous field variables to the measurement of fluxes. Interestingly, the construction of the configuration space geometry uses as configuration space coordinates various electric and magnetic fluxes over 2-dimensional cross sections of 3-surface.

Quantum effects introduce also difficulties and restrictions.

1. Canonical transformations localized with respect to the boundary of the light cone or more general light like surfaces act as isometries of the configuration space and one can determine the space-time surface only modulo these isometries. Even more, only the values of the non-quantum fluctuating zero modes characterizing the shape and size of the space-time surface are measurable with arbitrary precision in quantum theory. At the level of conscious experience quantum fluctuating degrees of freedom correspond to sensory qualia like color having no classical geometric content.

2. Space-time surface is replaced by a new one in each quantum jump (or rather the superposition of perceptively equivalent space-time surfaces). Only in the approximation that the change of the space-time region in single quantum jump is negligible, the measurement of the shape of space-time surface makes sense. The physical criterion for this is that dissipation is negligible. The change of the space-time region in single quantum jump can indeed be negligible if the measurement is performed with a finite resolution.

3. Conscious experience of self is an average over quantum jumps defining moments of consciousness. In particular, only the average increment of the zero modes is experienced and this means that one cannot fix the space-time surface apart from canonical transformation affecting the zero modes. Again the notion of measurement resolution comes in rescue.

4. The possibility of coherent states of photons and gravitons brings in a further quantum complication since the effective classical em and gravitational fields are superpositions of classical field and the order parameter describing the coherent state. In principle the extremely strong constraints between the classical field quantities allow to measure both the order parameters of the coherent phases and classical fields.

Quantum holography and the shape of the space-time surface

If the Dirac determinant associated with the generalized eigenvalue spectrum of the modified Dirac operator $D_K(X^2)$ indeed codes for Kähler action of a preferred extremal, it is fair to say that a lot of information about the shape of the space-time surface is coded to physical observables, which eigenvalues indeed represent. Quantum gravitational holography due to the Bohr orbit like character of space-time surface reduces the amount of information needed. Only a finite number of eigenvalues is involved and the eigen modes are associated with the 3-D light-like wormhole throats rather than with the space-time surface itself. If the eigenvalues were known or could be measured with infinite accuracy, one could in principle fix the boundary conditions at X_l^3 and solve field equations determining the preferred extremal of Kähler action.

What is of course needed is the complete knowledge of the light-like 3-surfaces X_l^3. Needless to say, in practice a complete knowledge of X_l^3 is impossible since measurement resolution is finite. The notion number theoretic braid provides a precise realization for the finite measurement accuracy at space-time level. At the level of configuration space spinors fields (world of classical worlds) just the fact that the number of eigenvalues is finite is correlate for the finite measurement accuracy. Furthermore, quantum states are actually quantum superpositions of 3-surfaces, which means that one can only speak about quantum average space-time surface for which the phase factors coding for the quantum numbers of elementary particles assigned to the strands of number theoretic braids are stationary so that correlation of classical gauge charges with quantum gauge charges is obtained.

1.3 General view about field equations

In this section field equations are deduced and discussed in general level. The fact that the divergence of the energy momentum tensor, Lorentz 4-force, does not vanish in general, in principle makes possible the mimicry of even dissipation and of the second law. For asymptotic self organization patterns for which dissipation is absent the Lorentz 4-force must vanish. This condition is guaranteed if Kähler current is proportional to the instanton current in the case that CP_2 projection of the space-time sheet is smaller than four and vanishes otherwise. An attractive identification for the vanishing of Lorentz 4-force is as a condition equivalent with the selection of preferred extremal of Kähler action. If preferred extremals correspond to absolute minima this principle would be essentially equivalent with the second law of thermodynamics.

1.3.1 Field equations

The requirement that Kähler action is stationary leads to the following field equations in the interior of the four-surface

$$\begin{aligned} D_\beta(T^{\alpha\beta}h^k_\alpha) &- j^\alpha J^k{}_l\partial_\alpha h^l = 0 \ , \\ T^{\alpha\beta} &= J^{\nu\alpha}J_\nu{}^\beta - \frac{1}{4}g^{\alpha\beta}J^{\mu\nu}J_{\mu\nu} \ . \end{aligned} \tag{1.3.1}$$

Here $T^{\alpha\beta}$ denotes the traceless canonical energy momentum tensor associated with the Kähler action. An equivalent form for the first equation is

$$\begin{aligned} T^{\alpha\beta}H^k_{\alpha\beta} &- j^\alpha(J_\alpha{}^\beta h^k{}_\beta + J^k{}_l\partial_\alpha h^l) = 0 \ . \\ H^k_{\alpha\beta} &= D_\beta\partial_\alpha h^k \ . \end{aligned} \tag{1.3.2}$$

$H^k_{\alpha\beta}$ denotes the components of the second fundamental form and $j^\alpha = D_\beta J^{\alpha\beta}$ is the gauge current associated with the Kähler field.

On the boundaries of X^4 and at wormhole throats the field equations are given by the expression

$$\frac{\partial L_K}{\partial_n h^k} = T^{n\beta}\partial_\beta h^k - J^{n\alpha}(J_\alpha{}^\beta\partial_\beta h^k + J^k_l)\partial_\alpha h^k) = 0 \ . \tag{1.3.3}$$

At wormhole throats problems are caused by the vanishing of metric determinant implying that contravariant metric is singular.

For M^4 coordinates boundary conditions are satisfied if one assumes

$$T^{n\beta} = 0 \tag{1.3.4}$$

stating that there is no flow of four-momentum through the boundary component or wormhole throat. This means that there is no energy exchange between Euclidian and Minkowskian regions so that Euclidian regions provide representations for particles as autonomous units. This is in accordance with the general picture [D3]. Note that momentum transfer with external world necessarily involves generalized Feynman diagrams also at classical level.

For CP_2 coordinates the boundary conditions are more delicate. The construction of configuration space spinor structure [B4] led to the conditions

$$g_{ni} = 0 \ , \ J_{ni} = 0 \ . \tag{1.3.5}$$

$J^{ni} = 0$ does not and should not follow from this condition since contravariant metric is singular. It seems that limiting procedure is necessary in order to see what comes out.

The condition that Kähler electric charge defined as a gauge flux is non-vanishing would require that the quantity $J^{nr}\sqrt{g}$ is finite (here r refers to the light-like coordinate of X^3_l). Also $g^{nr}\sqrt{g_4}$ which is analogous to gravitational flux if n is interpreted as time coordinate could be non-vanishing. These conditions are consistent with the above condition if one has

$$\begin{aligned} &J_{ni} = 0 \ , && g_{ni} = 0 \ , && J_{ir} = 0 \ , && g_{ir} = 0 \ , \\ &J^{nk} = 0 \ \ k \neq r \ , && g^{nk} = 0 \ \ k \neq r \ , && J^{nr}\sqrt{g_4} \neq 0 \ , && g^{nr}\sqrt{g_4} \neq 0 \ . \end{aligned} \tag{1.3.6}$$

The interpretation of this conditions is rather transparent.

1. The first two conditions state that covariant form of the induced Kähler electric field is in direction normal to X^3_l and metric separate into direct sum of normal and tangential contributions. Fifth and sixth condition state the same in contravariant form for $k \neq n$.

2. Third and fourth condition state that the induced Kähler field at X^3_l is purely magnetic and that the metric of x^3_l reduces to a block diagonal form. The reduction to purely magnetic field is of obvious importance as far as the understanding of the generalized eigen modes of the modified Dirac operator is considered [B4].

3. The last two conditions must be understood as a limit and $\neq$ means only the possibility of non-vanishing Kähler gauge flux or analog of gravitational flux through X^3_l.

4. The vision inspired by number theoretical compactification allows to identify r and n in terms of the light-like coordinates assignable to an integrable distribution of planes $M^2(x)$ assumed to be assignable to M^4 projection of $X^4(X^3_l)$. Later it will be found that Hamilton-Jacobi structure assignable to the extremals indeed means the existence of this kind of distribution meaning slicing of $X^4(X^3_l)$ both by string world sheets and dual partonic 2-surfaces as well as by light-like 3-surfaces Y^3_l.

5. The physical analogy for the situation is the surface of an ideal conductor. It would not be surprising that these conditions are satisfied by all induced gauge fields.

1.3.2 Topologization and light-likeness of the Kähler current as alternative manners to guarantee vanishing of Lorentz 4-force

The general solution of 4-dimensional Einstein-Yang Mills equations in Euclidian 4-metric relies on self-duality of the gauge field, which topologizes gauge charge. This topologization can be achieved by a weaker condition, which can be regarded as a dynamical generalization of the Beltrami condition. An alternative manner to achieve vanishing of the Lorentz 4-force is light-likeness of the Kähler 4-current. This does not require topologization.

Topologization of the Kähler current for $D_{CP_2} = 3$: covariant formulation

The condition states that Kähler 4-current is proportional to the instanton current whose divergence is instanton density and vanishes when the dimension of CP_2 projection is smaller than four: $D_{CP_2} < 4$. For $D_{CP_2} = 2$ the instanton 4-current vanishes identically and topologization is equivalent with the vanishing of the Kähler current.

If the simplest vision about light-like 3-surfaces as basic dynamical objects is accepted $D_{CP_2} = 2$, corresponds to a non-physical situation and only the deformations of these surfaces - most naturally resulting by gluing of CP_2 type vacuum extremals on them - can represent preferred extremals of Kähler action. One can however speak about $D_{CP_2} = 2$ phase if 4-surfaces are obtained are obtained in this manner.

$$j^\alpha \equiv D_\beta J^{\alpha\beta} = \psi \times j_I^\alpha = \psi \times \epsilon^{\alpha\beta\gamma\delta} J_{\beta\gamma} A_\delta \ . \tag{1.3.7}$$

Here the function ψ is an arbitrary function $\psi(s^k)$ of CP_2 coordinates s^k regarded as functions of space-time coordinates. It is essential that ψ depends on the space-time coordinates through the CP_2 coordinates only. Hence the representation as an imbedded gauge field is crucial element of the solution ansatz.

The field equations state the vanishing of the divergence of the 4-current. This is trivially true for instanton current for $D_{CP_2} < 4$. Also the contraction of $\nabla\psi$ (depending on space-time coordinates through CP_2 coordinates only) with the instanton current is proportional to the winding number density and therefore vanishes for $D_{CP_2} < 4$.

The topologization of the Kähler current guarantees the vanishing of the Lorentz 4-force. Indeed, using the self-duality condition for the current, the expression for the Lorentz 4-force reduces to a term proportional to the instanton density:

$$\begin{aligned} j^\alpha J_{\alpha\beta} &= \psi \times j_I^\alpha J_{\alpha\beta} \\ &= \psi \times \epsilon^{\alpha\mu\nu\delta} J_{\mu\nu} A_\delta J_{\alpha\beta} \ . \end{aligned} \tag{1.3.8}$$

Since all vector quantities appearing in the contraction with the four-dimensional permutation tensor are proportional to the gradients of CP_2 coordinates, the expression is proportional to the instanton density, and thus winding number density, and vanishes for $D_{CP_2} < 4$.

Remarkably, the topologization of the Kähler current guarantees also the vanishing of the term $j^\alpha J^{k_l} \partial_\alpha s^k$ in the field equations for CP_2 coordinates. This means that field equations reduce in both M^4_+ and CP_2 degrees of freedom to

$$T^{\alpha\beta} H^k_{\alpha\beta} = 0 \ . \tag{1.3.9}$$

These equations differ from the equations of minimal surface only by the replacement of the metric tensor with energy momentum tensor. The earlier proposal that quaternion conformal invariance in a suitable sense might provide a general solution of the field equations could be seen as a generalization of the ordinary conformal invariance of string models. If the topologization of the Kähler current implying effective dimensional reduction in CP_2 degrees of freedom is consistent with quaternion conformal invariance, the quaternion conformal structures must differ for the different dimensions of CP_2 projection.

Topologization of the Kähler current for $D_{CP_2} = 3$: non-covariant formulation

In order to gain a concrete understanding about what is involved it is useful to repeat these arguments using the 3-dimensional notation. The components of the instanton 4-current read in three-dimensional notation as

$$\overline{j}_I = \overline{E} \times \overline{A} + \phi \overline{B} \ , \quad \rho_I = \overline{B} \cdot \overline{A} \ . \tag{1.3.10}$$

The self duality conditions for the current can be written explicitly using 3-dimensional notation and read

$$\begin{aligned} \nabla \times \overline{B} - \partial_t \overline{E} &= \overline{j} = \psi \overline{j}_I = \psi \left(\phi \overline{B} + \overline{E} \times \overline{A} \right) \ , \\ \nabla \cdot E &= \rho = \psi \rho_I \ . \end{aligned} \tag{1.3.11}$$

For a vanishing electric field the self-duality condition for Kähler current reduces to the Beltrami condition

$$\nabla \times \overline{B} = \alpha \overline{B} \ , \quad \alpha = \psi \phi \ . \tag{1.3.12}$$

The vanishing of the divergence of the magnetic field implies that α is constant along the field lines of the flow. When ϕ is constant and $\overline{A}$ is time independent, the condition reduces to the Beltrami condition with $\alpha = \phi = constant$, which allows an explicit solution [20].

One can check also the vanishing of the Lorentz 4-force by using 3-dimensional notation. Lorentz 3-force can be written as

$$\rho_I \overline{E} + \overline{j} \times \overline{B} = \psi \overline{B} \cdot \overline{AE} + \psi \left(\overline{E} \times \overline{A} + \phi \overline{B} \right) \times \overline{B} = 0 \ . \tag{1.3.13}$$

The fourth component of the Lorentz force reads as

$$\overline{j} \cdot \overline{E} = \psi \overline{B} \cdot \overline{E} + \psi \left(\overline{E} \times \overline{A} + \phi \overline{B} \right) \cdot \overline{E} = 0 \ . \tag{1.3.14}$$

The remaining conditions come from the induction law of Faraday and could be guaranteed by expressing $\overline{E}$ and $\overline{B}$ in terms of scalar and vector potentials.

The density of the Kähler electric charge of the vacuum is proportional to the the helicity density of the so called helicity charge $\rho = \psi \rho_I = \psi B \cdot A$. This charge is topological charge in the sense that it does not depend on the induced metric at all. Note the presence of arbitrary function ψ of CP_2 coordinates.

Further conditions on the functions appearing in the solution ansatz come from the 3 independent field equations for CP_2 coordinates. What is remarkable that the generalized self-duality condition for the Kähler current allows to understand the general features of the solution ansatz to very high degree without any detailed knowledge about the detailed solution. The question whether field equations allow solutions consistent with the self duality conditions of the current will be dealt later. The optimistic guess is that the field equations and topologization of the Kähler current relate to each other very intimately.

Vanishing or light likeness of the Kähler current guarantees vanishing of the Lorentz 4-force for $D_{CP_2} = 2$

For $D_{CP_2} = 2$ one can always take two CP_2 coordinates as space-time coordinates and from this it is clear that instanton current vanishes so that topologization gives a vanishing Kähler current. In particular, the Beltrami condition $\nabla \times \overline{B} = \alpha \overline{B}$ is not consistent with the topologization of the instanton current for $D_{CP_2} = 2$.

$D_{CP_2} = 2$ case can be treated in a coordinate invariant manner by using the two coordinates of CP_2 projection as space-time coordinates so that only a magnetic or electric field is present depending on whether the gauge current is time-like or space-like. Light-likeness of the gauge current provides a second manner to achieve the vanishing of the Lorentz force and is realized in case of massless extremals having $D_{CP_2} = 2$: this current is in the direction of propagation whereas magnetic and electric fields are orthogonal to it so that Beltrami conditions is certainly not satisfied.

Under what conditions topologization of Kähler current yields Beltrami conditions?

Topologization of the Kähler 4-current gives rise to magnetic Beltrami fields if either of the following conditions is satisfied.

1. The $\overline{E} \times \overline{A}$ term contributing besides $\phi\overline{B}$ term to the topological current vanishes. This requires that $\overline{E}$ and $\overline{A}$ are parallel to each other

$$\overline{E} = \nabla\Phi - \partial_t\overline{A} = \beta\overline{A} \tag{1.3.15}$$

   This condition is analogous to the Beltrami condition. Now only the 3-space has as its coordinates time coordinate and two spatial coordinates and and $\overline{B}$ is replaced with $\overline{A}$. Since E and B are orthogonal, this condition implies $\overline{B}\cdot\overline{A} = 0$ so that Kähler charge density is vanishing.

2. The vector $\overline{E} \times \overline{A}$ is parallel to $\overline{B}$.

$$\overline{E} \times \overline{A} = \beta\overline{B} \tag{1.3.16}$$

   The condition is consistent with the orthogonality of $\overline{E}$ and $\overline{B}$ but implies the orthogonality of $\overline{A}$ and $\overline{B}$ so that electric charge density vanishes

In both cases vector potential fails to define a contact structure since $B\cdot A$ vanishes (contact structures are discussed briefly below), and there exists a global coordinate along the field lines of $\overline{A}$ and the full contact structure is lost again. Note however that the Beltrami condition for magnetic field means that magnetic field defines a contact structure irrespective of whether $\overline{B}\cdot\overline{A}$ vanishes or not. The transition from the general case to Beltrami field would thus involve the replacement

$$(\overline{A},\overline{B}) \rightarrow_{\nabla\times} (\overline{B},\overline{j})$$

induced by the rotor.

One must of course take these considerations somewhat cautiously since the inner product depends on the induced 4-metric and it might be that induced metric could allow small vacuum charge density and make possible genuine contact structure.

Hydrodynamic analogy

The field equations of TGD are basically hydrodynamic equations stating the local conservation of the currents associated with the isometries of the imbedding space. Therefore it is intriguing that Beltrami fields appear also as solutions of ideal magnetohydrodynamics equations and as steady solutions of non-viscous incompressible flow described by Euler equations [21].

In hydrodynamics the role of the magnetic field is taken by the velocity field. TGD based models for nuclei [F6] and condensed matter [F9] involve in an essential manner valence quarks having large $\hbar$ and exotic quarks giving nucleons anomalous color and weak charges creating long ranged color and weak forces. Weak forces have a range of order atomic radius and could be responsible for the repulsive core in van der Waals potential.

This raises the idea that the incompressible flow could occur along the field lines of the Z^0 magnetic field so that the velocity field would be proportional to the Z^0 magnetic field and the Beltrami condition for the velocity field would reduce to that for Z^0 magnetic field. Thus the flow lines of hydrodynamic flow would directly correspond to those of Z^0 magnetic field. The generalized Beltrami flow based on the topologization of the Z^0 current would allow to model also the non-stationary incompressible non-viscous hydrodynamical flows.

It would seem that one cannot describe viscous flows using flows satisfying generalized Beltrami conditions since the vanishing of the Lorentz 4-force says that there is no local dissipation of the classical field energy. One might claim that this is not a problem since in TGD framework viscous flow could be seen as a practical description of a quantum jump sequence by replacing the corresponding sequence of space-time surfaces with a single space-time surface.

One the other hand, quantum classical correspondence requires that also dissipative effects have space-time correlates. Kähler fields, which are dissipative, and thus correspond to a non-vanishing Lorentz 4-force, represent one candidate for correlates of this kind. If this is the case, then the fields satisfying the generalized Beltrami condition provide space-time correlates only for the asymptotic self organization patterns for which the viscous effects are negligible, and also the solutions of field equations describing effects of viscosity should be possible.

One must however take this argument with a grain of salt. Dissipation, that is the transfer of conserved quantities to degrees of freedom corresponding to shorter scales, could correspond to a transfer of these quantities between different space-time sheets of the many-sheeted space-time. Here the opponent could however argue that larger space-time sheets mimic the dissipative dynamics in shorter scales and that classical currents represent "symbolically" averaged currents in shorter length scales, and that the local non-conservation of energy momentum tensor consistent with local conservation of isometry currents provides a unique manner to mimic the dissipative dynamics. This view will be developed in more detail below.

The stability of generalized Beltrami fields

The stability of generalized Beltrami fields is of high interest since unstable points of space-time sheets are those around which macroscopic changes induced by quantum jumps are expected to be localized.

1. Contact forms and contact structures

The stability of Beltrami flows has been studied using the theory of contact forms in three-dimensional Riemann manifolds [22]. Contact form is a one-form A (that is covariant vector field A_α) with the property $A \wedge dA \neq 0$. In the recent case the induced Kähler gauge potential A_α and corresponding induced Kähler form $J_{\alpha\beta}$ for any 3-sub-manifold of space-time surface define a contact form so that the vector field $A^\alpha = g^{\alpha\beta} A_\beta$ is not orthogonal with the magnetic field $B^\alpha = \epsilon^{\alpha\beta\delta} J_{\beta\gamma}$. This requires that magnetic field has a helical structure. Induced metric in turn defines the Riemann structure.

If the vector potential defines a contact form, the charge density associated with the topologized Kähler current must be non-vanishing. This can be seen as follows.

1. The requirement that the flow lines of a one-form X_μ defined by the vector field X^μ as its dual allows to define a global coordinate x varying along the flow lines implies that there is an integrating factor ϕ such that $\phi X = dx$ and therefore $d(\phi X) = 0$. This implies $dlog(\phi) \wedge X = -dX$. From this the necessary condition for the existence of the coordinate x is $X \wedge dX = 0$. In the three-dimensional case this gives $\overline{X} \cdot (\nabla \times \overline{X}) = 0$.

2. This condition is by definition not satisfied by the vector potential defining a contact form so that one cannot identify a global coordinate varying along the flow lines of the vector potential. The condition $\overline{B} \cdot \overline{A} \neq 0$ states that the charge density for the topologized Kähler current is non-vanishing. The condition that the field lines of the magnetic field allow a global coordinate requires $\overline{B} \cdot \nabla \times \overline{B} = 0$. The condition is not satisfied by Beltrami fields with $\alpha \neq 0$. Note that in this case magnetic field defines a contact structure.

Contact structure requires the existence of a vector ξ satisfying the condition $A(\xi) = 0$. The vector field ξ defines a plane field, which is orthogonal to the vector field A^α. Reeb field in turn is a vector field for which $A(X) = 1$ and $dA(X;) = 0$ hold true. The latter condition states the vanishing of the cross product $X \times B$ so that X is parallel to the Kähler magnetic field B^α and has unit projection in the direction of the vector field A^α. Any Beltrami field defines a Reeb field irrespective of the Riemannian structure.

2. Stability of the Beltrami flow and contact structures

Contact structures are used in the study of the topology and stability of the hydrodynamical flows [22], and one might expect that the notion of contact structure and its proper generalization to the four-dimensional context could be useful in TGD framework also. An example giving some idea about the complexity of the flows defined by Beltrami fields is the Beltrami field in R^3 possessing closed orbits with all possible knot and link types simultaneously [22]!

Beltrami flows associated with Euler equations are known to be unstable [22]. Since the flow is volume preserving, the stationary points of the Beltrami flow are saddle points at which also vorticity vanishes and linear instabilities of Navier-Stokes equations can develop. From the point of view of biology it is interesting that the flow is stabilized by vorticity which implies also helical structures. The stationary points of the Beltrami flow correspond in TGD framework to points at which the induced Kähler magnetic field vanishes. They can be unstable by the vacuum degeneracy of Kähler action implying classical non-determinism. For generalized Beltrami fields velocity and vorticity (both divergence free) are replaced by Kähler current and instanton current.

More generally, the points at which the Kähler 4-current vanishes are expected to represent potential instabilities. The instanton current is linear in Kähler field and can vanish in a gauge invariant manner only if the induced Kähler field vanishes so that the instability would be due to the vacuum degeneracy also now. Note that the vanishing of the Kähler current allows also the generation of region with $D_{CP_2} = 4$. The instability of the points at which induce Kähler field vanish is manifested in quantum jumps replacing the generalized Beltrami field with a new one such that something new is generated around unstable points. Thus the regions in which induced Kähler field becomes weak are the most interesting ones. For example, unwinding of DNA could be initiated by an instability of this kind.

1.3.3 How to satisfy field equations?

The topologization of the Kähler current guarantees also the vanishing of the term $j^\alpha J^{k_l}\partial_\alpha s^k$ in the field equations for CP_2 coordinates. This means that field equations reduce in both M^4_+ and CP_2 degrees of freedom to

$$T^{\alpha\beta}H^k_{\alpha\beta} = 0 \ . \tag{1.3.17}$$

These equations differ from the equations of minimal surface only by the replacement of the metric tensor with energy momentum tensor. The following approach utilizes the properties of Hamilton Jacobi structures of M^4_+ introduced in the study of massless extremals and contact structures of CP_2 emerging naturally in the case of generalized Beltrami fields.

String model as a starting point

String model serves as a starting point.

1. In the case of Minkowskian minimal surfaces representing string orbit the field equations reduce to purely algebraic conditions in light cone coordinates (u, v) since the induced metric has only the component g_{uv}, whereas the second fundamental form has only diagonal components H^k_{uu} and H^k_{vv}.

2. For Euclidian minimal surfaces (u, v) is replaced by complex coordinates $(w, \overline{w})$ and field equations are satisfied because the metric has only the component $g^{w\overline{w}}$ and second fundamental form has only components of type H^k_{ww} and $H^{\overline{k}}_{\overline{w}\overline{w}}$. The mechanism should generalize to the recent case.

The general form of energy momentum tensor as a guideline for the choice of coordinates

Any 3-dimensional Riemann manifold allows always a orthogonal coordinate system for which the metric is diagonal. Any 4-dimensional Riemann manifold in turn allows a coordinate system for which 3-metric is diagonal and the only non-diagonal components of the metric are of form g^{ti}. This kind of coordinates might be natural also now. When $\overline{E}$ and $\overline{B}$ are orthogonal, energy momentum tensor has the form

$$T = \begin{pmatrix} \frac{E^2+B^2}{2} & 0 & 0 & EB \\ 0 & \frac{E^2+B^2}{2} & 0 & 0 \\ 0 & 0 & \frac{-E^2+B^2}{2} & 0 \\ EB & 0 & 0 & \frac{E^2-B^2}{2} \end{pmatrix} \qquad (1.3.18)$$

in the tangent space basis defined by time direction and longitudinal direction $\overline{E}\times\overline{B}$, and transversal directions $\overline{E}$ and $\overline{B}$. Note that T is traceless.

The optimistic guess would be that the directions defined by these vectors integrate to three orthogonal coordinates of X^4 and together with time coordinate define a coordinate system containing only g^{ti} as non-diagonal components of the metric. This however requires that the fields in question allow an integrating factor and, as already found, this requires $\nabla \times X \cdot X = 0$ and this is not the case in general.

Physical intuition suggests however that X^4 coordinates allow a decomposition into longitudinal and transversal degrees freedom. This would mean the existence of a time coordinate t and longitudinal coordinate z the plane defined by time coordinate and vector $\overline{E}\times\overline{B}$ such that the coordinates $u = t-z$ and $v = t+z$ are light like coordinates so that the induced metric would have only the component g^{uv} whereas g^{vv} and g^{uu} would vanish in these coordinates. In the transversal space-time directions complex space-time coordinate coordinate w could be introduced. Metric could have also non-diagonal components besides the components $g^{w\overline{w}}$ and g^{uv}.

Hamilton Jacobi structures in M^4_+

Hamilton Jacobi structure in M^4_+ can understood as a generalized complex structure combing transversal complex structure and longitudinal hyper-complex structure so that notion of holomorphy and Kähler structure generalize.

1. Denote by m^i the linear Minkowski coordinates of M^4. Let (S^+, S^-, E^1, E^2) denote local coordinates of M^4_+ defining a *local* decomposition of the tangent space M^4 of M^4_+ into a direct, not necessarily orthogonal, sum $M^4 = M^2 \oplus E^2$ of spaces M^2 and E^2. This decomposition has an interpretation in terms of the longitudinal and transversal degrees of freedom defined by local light-like four-velocities $v_\pm = \nabla S_\pm$ and polarization vectors $\epsilon_i = \nabla E^i$ assignable to light ray. Assume that E^2 allows complex coordinates $w = E^1 + iE^2$ and $\overline{w} = E^1 - iE^2$. The simplest decomposition of this kind corresponds to the decomposition $(S^+ \equiv u = t+z, S^- \equiv v = t-z, w = x+iy, \overline{w} = x-iy)$.

2. In accordance with this physical picture, S^+ and S^- define light-like curves which are normals to light-like surfaces and thus satisfy the equation:

   $$(\nabla S_\pm)^2 = 0 \quad .$$

   The gradients of $S_\pm$ are obviously analogous to local light like velocity vectors $v = (1, \overline{v})$ and $\tilde{v} = (1, -\overline{v})$. These equations are also obtained in geometric optics from Hamilton Jacobi equation by replacing photon's four-velocity with the gradient ∇S: this is consistent with the interpretation of massless extremals as Bohr orbits of em field. $S_\pm = constant$ surfaces can be interpreted as expanding light fronts. The interpretation of $S_\pm$ as Hamilton Jacobi functions justifies the term Hamilton Jacobi structure.

   The simplest surfaces of this kind correspond to $t = z$ and $t = -z$ light fronts which are planes. They are dual to each other by hyper complex conjugation $u = t - z \to v = t + z$. One should somehow generalize this conjugation operation. The simplest candidate for the conjugation $S^+ \to S^-$ is as a conjugation induced by the conjugation for the arguments: $S^+(t-z, t+z, x, y) \to S^-(t-z, t+z, x, y) = S^+(t+z, t-z, x, -y)$ so that a dual pair is mapped to a dual pair. In transversal degrees of freedom complex conjugation would be involved.

3. The coordinates $(S_\pm, w, \overline{w})$ define local light cone coordinates with the line element having the form

$$\begin{aligned} ds^2 &= g_{+-}dS^+dS^- + g_{w\overline{w}}dwd\overline{w} \\ &+ g_{+w}dS^+dw + g_{+\overline{w}}dS^+d\overline{w} \\ &+ g_{-w}dS^-dw + g_{-\overline{w}}dS^-d\overline{w} \ . \end{aligned} \tag{1.3.19}$$

Conformal transformations of M^4_+ leave the general form of this decomposition invariant. Also the transformations which reduces to analytic transformations $w \rightarrow f(w)$ in transversal degrees of freedom and hyper-analytic transformations $S^+ \rightarrow f(S^+), S^- \rightarrow f(S^-)$ in longitudinal degrees of freedom preserve this structure.

4. The basic idea is that of generalized Kähler structure meaning that the notion of Kähler function generalizes so that the non-vanishing components of metric are expressible as

$$\begin{aligned} g_{w\overline{w}} &= \partial_w\partial_{\overline{w}}K \ , \quad g_{+-} = \partial_{S^+}\partial_{S^-}K \ , \\ g_{w\pm} &= \partial_w\partial_{S^\pm}K \ , \quad g_{\overline{w}\pm} = \partial_{\overline{w}}\partial_{S^\pm}K \ . \end{aligned} \tag{1.3.20}$$

for the components of the metric. The expression in terms of Kähler function is coordinate invariant for the same reason as in case of ordinary Kähler metric. In the standard lightcone coordinates the Kähler function is given by

$$K = w_0\overline{w}_0 + uv \ , \quad w_0 = x + iy \ , \quad u = t - z \ , \quad v = t + z \ . \tag{1.3.21}$$

The Christoffel symbols satisfy the conditions

$$\left\{ {k \atop w\ \overline{w}} \right\} = 0 \ , \quad \left\{ {k \atop +-} \right\} = 0 \ . \tag{1.3.22}$$

If energy momentum tensor has only the components $T^{w\overline{w}}$ and T^{+-}, field equations are satisfied in M^4_+ degrees of freedom.

5. The Hamilton Jacobi structures related by these transformations can be regarded as being equivalent. Since light-like 3- surface is, as the dynamical evolution defined by the light front, fixed by the 2-surface serving as the light source, these structures should be in one-one correspondence with 2-dimensional surfaces with two surfaces regarded as equivalent if they correspond to different time=constant snapshots of the same light front, or are related by a conformal transformation of M^4_+. Obviously there should be quite large number of them. Note that the generating two-dimensional surfaces relate also naturally to quaternion conformal invariance and corresponding Kac Moody invariance for which deformations defined by the M^4 coordinates as functions of the light-cone coordinates of the light front evolution define Kac Moody algebra, which thus seems to appear naturally also at the level of solutions of field equations.

The task is to find all possible local light cone coordinates defining one-parameter families 2-surfaces defined by the condition $S_i = constant$, $i = +\ or\ = -$, dual to each other and expanding with light velocity. The basic open questions are whether the generalized Kähler function indeed makes sense and whether the physical intuition about 2-surfaces as light sources parameterizing the set of all possible Hamilton Jacobi structures makes sense.

Hamilton Jacobi structure means the existence of foliations of the M^4 projection of X^4 by 2-D surfaces analogous to string word sheets labeled by w and the dual of this foliation defined by partonic 2-surfaces labeled by the values of S_i. Also the foliation by light-like 3-surfaces Y^3_l labeled by $S_\pm$ with $S_\mp$ serving as light-like coordinate for Y^3_l is implied. This is what number theoretic compactification and $M^8 - H$ duality predict when space-time surface corresponds to hyper-quaternionic surface of M^8 [D3, E2].

Contact structure and generalized Kähler structure of CP_2 projection

In the case of 3-dimensional CP_2 projection it is assumed that one can introduce complex coordinates $(\xi,\overline{\xi})$ and the third coordinate s. These coordinates would correspond to a contact structure in 3-dimensional CP_2 projection defining transversal symplectic and Kähler structures. In these coordinates the transversal parts of the induced CP_2 Kähler form and metric would contain only components of type $g_{w\overline{w}}$ and $J_{w\overline{w}}$. The transversal Kähler field $J_{w\overline{w}}$ would induce the Kähler magnetic field and the components J_{sw} and $J_{s\overline{w}}$ the Kähler electric field.

It must be emphasized that the non-integrability of the contact structure implies that J cannot be parallel to the tangent planes of $s = constant$ surfaces, s cannot be parallel to neither A nor the dual of J, and ξ cannot vary in the tangent plane defined by J. A further important conclusion is that for the solutions with 3-dimensional CP_2 projection topologized Kähler charge density is necessarily non-vanishing by $A \wedge J \neq 0$ whereas for the solutions with $D_{CP_2} = 2$ topologized Kähler current vanishes.

Also the CP_2 projection is assumed to possess a generalized Kähler structure in the sense that all components of the metric except s_{ss} are derivable from a Kähler function by formulas similar to M^4_+ case.

$$s_{w\overline{w}} = \partial_w\partial_{\overline{w}}K \ \ , \quad s_{ws} = \partial_w\partial_s K \ \ , \quad s_{\overline{w}s} = \partial_{\overline{w}}\partial_s K \ \ . \tag{1.3.23}$$

Generalized Kähler property guarantees that the vanishing of the Christoffel symbols of CP_2 (rather than those of 3-dimensional projection), which are of type $\{^{\ k}_{\xi\ \overline{\xi}}\}$.

$$\{^{\ k}_{\xi\ \overline{\xi}}\} \ \ = \ \ 0 \ \ . \tag{1.3.24}$$

Here the coordinates of CP_2 have been chosen in such a manner that three of them correspond to the coordinates of the projection and fourth coordinate is constant at the projection. The upper index k refers also to the CP_2 coordinate, which is constant for the CP_2 projection. If energy momentum tensor has only components of type T^{+-} and $T^{w\overline{w}}$, field equations are satisfied even when if non-diagonal Christoffel symbols of CP_2 are present. The challenge is to discover solution ansatz, which guarantees this property of the energy momentum tensor.

A stronger variant of Kähler property would be that also s_{ss} vanishes so that the coordinate lines defined by s would define light like curves in CP_2. The topologization of the Kähler current however implies that CP_2 projection is a projection of a 3-surface with strong Kähler property. Using $(s,\xi,\overline{\xi},S^-)$ as coordinates for the space-time surface defined by the ansatz $(w = w(\xi,s), S^+ = S^+(s))$ one finds that g_{ss} must be vanishing so that stronger variant of the Kähler property holds true for $S^- = constant$ 3-surfaces.

The topologization condition for the Kähler current can be solved completely generally in terms of the induced metric using $(\xi,\overline{\xi},s)$ and some coordinate of M^4_+, call it x^4, as space-time coordinates. Topologization boils down to the conditions

$$\begin{aligned} \partial_\beta(J^{\alpha\beta}\sqrt{g}) \ \ &= \ \ 0 \text{ for } \ \alpha \in \{\xi,\overline{\xi},s\} \ \ , \\ g^{4i} \neq 0 \ \ . \end{aligned} \tag{1.3.25}$$

Thus 3-dimensional empty space Maxwell equations and the non-orthogonality of X^4 coordinate lines and the 3-surfaces defined by the lift of the CP_2 projection.

A solution ansatz yielding light-like current in $D_{CP_2} = 3$ case

The basic idea is that of generalized Kähler structure and solutions of field equations as maps or deformations of canonically imbedded M^4_+ respecting this structure and guaranteing that the only non-vanishing components of the energy momentum tensor are $T^{\xi\xi}$ and T^{s-} in the coordinates $(\xi,\overline{\xi},s,S^-)$.

1. The coordinates (w,S^+) are assumed to holomorphic functions of the CP_2 coordinates (s,ξ)

$$S^+ = S^+(s) \ , \quad w = w(\xi, s) \ . \tag{1.3.26}$$

Obviously S^+ could be replaced with S^-. The ansatz is completely symmetric with respect to the exchange of the roles of (s, w) and (S^+, ξ) since it maps longitudinal degrees of freedom to longitudinal ones and transverse degrees of freedom to transverse ones.

2. Field equations are satisfied if the only non-vanishing components of the energy momentum tensor are of type $T^{\xi\overline{\xi}}$ and T^{s-}. The reason is that the CP_2 Christoffel symbols for projection and projections of M^4_+ Christoffel symbols are vanishing for these lower index pairs.

3. By a straightforward calculation one can verify that the only manner to achieve the required structure of energy momentum tensor is to assume that the induced metric in the coordinates $(\xi, \overline{\xi}, s, S^-)$ has as non-vanishing components only $g_{\xi\overline{\xi}}$ and g_{s-}

$$g_{ss} = 0 \ , \quad g_{\xi s} = 0 \ , \quad g_{\overline{\xi}s} = 0 \ . \tag{1.3.27}$$

Obviously the space-time surface must factorize into an orthogonal product of longitudinal and transversal spaces.

4. The condition guaranteing the product structure of the metric is

$$\begin{aligned} s_{ss} &= m_{+w}\partial_s w(\xi, s)\partial_s S^+(s) + m_{+\overline{w}}\partial_s \overline{w}(\xi, s)\partial_s S^+(s) \ , \\ s_{s\xi} &= m_{+w}\partial_\xi w(\xi)\partial_s S^+(s) \ , \\ s_{s\overline{\xi}} &= m_{+w}\partial_{\overline{\xi}} w(\overline{\xi})\partial_s S^+(s) \ . \end{aligned} \tag{1.3.28}$$

Thus the function of dynamics is to diagonalize the metric and provide it with strong Kähler property. Obviously the CP_2 projection corresponds to a light-like surface for all values of S^- so that space-time surface is foliated by light-like surfaces and the notion of generalized conformal invariance makes sense for the entire space-time surface rather than only for its boundary or elementary particle horizons.

5. The requirement that the Kähler current is proportional to the instanton current means that only the j^- component of the current is non-vanishing. This gives the following conditions

$$\begin{aligned} & j^\xi \sqrt{g} = \partial_\beta (J^{\xi\beta}\sqrt{g}) = 0 \ , \quad j^{\overline{\xi}} \sqrt{g} = \partial_\beta (J^{\overline{\xi}\beta}\sqrt{g}) = 0 \ , \\ & j^+ \sqrt{g} = \partial_\beta (J^{+\beta}\sqrt{g}) = 0 \ . \end{aligned} \tag{1.3.29}$$

Since $J^{+\beta}$ vanishes, the condition

$$\sqrt{g} j^+ = \partial_\beta (J^{+\beta}\sqrt{g}) \ = \ 0 \tag{1.3.30}$$

is identically satisfied. Therefore the number of field equations reduces to three.

The physical interpretation of the solution ansatz deserves some comments.

1. The light-like character of the Kähler current brings in mind CP_2 extremals for which CP_2 projection is light like. This suggests that the topological condensation of CP_2 type extremal occurs on $D_{CP_2} = 3$ helical space-time sheet representing zitterbewegung. In the case of many-body system light-likeness of the current does not require that particles are massless if particles of opposite charges can be present. Field tensor has the form $(J^{\xi\bar{\xi}}, J^{\xi -}, J^{\bar{\xi} -})$. Both helical magnetic field and electric field present as is clear when one replaces the coordinates (S^+, S^-) with time-like and space-like coordinate. Magnetic field dominates but the presence of electric field means that genuine Beltrami field is not in question.

2. Since the induced metric is product metric, 3-surface is metrically product of 2-dimensional surface X^2 and line or circle and obeys product topology. If absolute minima correspond to asymptotic self-organization patterns, the appearance of the product topology and even metric is not so surprising. Thus the solutions can be classified by the genus of X^2. An interesting question is how closely the explanation of family replication phenomenon in terms of the topology of the boundary component of elementary particle like 3-surface relates to this. The heaviness and instability of particles which correspond to genera $g > 2$ (sphere with more than two handles) might have simple explanation as absence of (stable) $D_{CP_2} = 3$ solutions of field equations with genus $g > 2$.

3. The solution ansatz need not be the most general. Kähler current is light-like and already this is enough to reduce the field equations to the form involving only energy momentum tensor. One might hope of finding also solution ansätze for which Kähler current is time-like or space-like. Space-likeness of the Kähler current might be achieved if the complex coordinates $(\xi, \bar{\xi})$ and hyper-complex coordinates (S^+, S^-) change the role. For this solution ansatz electric field would dominate. Note that the possibility that Kähler current is always light-like cannot be excluded.

4. Suppose that CP_2 projection quite generally defines a foliation of the space-time surface by light-like 3-surfaces, as is suggested by the conformal invariance. If the induced metric has Minkowskian signature, the fourth coordinate x^4 and thus also Kähler current must be time-like or light-like so that magnetic field dominates. Already the requirement that the metric is non-degenerate implies $g_{s4} \neq 0$ so that the metric for the $\xi = constant$ 2-surfaces has a Minkowskian signature. Thus space-like Kähler current does not allow the lift of the CP_2 projection to be light-like.

Are solutions with time-like or space-like Kähler current possible in $D_{CP_2} = 3$ case?

As noticed in the section about number theoretical compactification, the flow of gauge currents along slices Y^3_l of $X^4(X^3_l)$ "parallel" to X^3_l requires only that gauge currents are parallel to Y^3_l and can thus space-like. The following ansatz gives good hopes for obtaining solutions with space-like and perhaps also time-like Kähler currents.

1. Assign to light-like coordinates coordinates (T, Z) by the formula $T = S^+ + S^-$ and $Z = S^+ - S^-$. Space-time coordinates are taken to be $(\xi, \bar{\xi}, s)$ and coordinate Z. The solution ansatz with time-like Kähler current results when the roles of T and Z are changed. It will however found that same solution ansatz can give rise to both space-like and time-like Kähler current.

2. The solution ansatz giving rise to a space-like Kähler current is defined by the equations

$$T = T(Z, s) \ , \quad w = w(\xi, s) \ . \tag{1.3.31}$$

   If T depends strongly on Z, the g_{ZZ} component of the induced metric becomes positive and Kähler current time-like.

3. The components of the induced metric are

$$
\begin{array}{ll}
g_{ZZ} = m_{ZZ} + m_{TT}\partial_Z T\partial_s T \ , & g_{Zs} = m_{TT}\partial_Z T\partial_s T \ , \\
g_{ss} = s_{ss} + m_{TT}\partial_s T\partial_s T \ , & g_{w\overline{w}} = s_{w\overline{w}} + m_{w\overline{w}}\partial_\xi w\partial_{\overline{\xi}}\overline{w} \ , \\
g_{s\xi} = s_{s\xi} \ , & g_{s\overline{\xi}} = s_{s\overline{\xi}} \ .
\end{array}
\tag{1.3.32}
$$

Topologized Kähler current has only Z-component and 3-dimensional empty space Maxwell's equations guarantee the topologization.

In CP_2 degrees of freedom the contractions of the energy momentum tensor with Christoffel symbols vanish if T^{ss}, $T^{\xi s}$ and $T^{\xi\xi}$ vanish as required by internal consistency. This is guaranteed if the condition

$$
J^{\xi s} = 0 \tag{1.3.33}
$$

holds true. Note however that $J^{\xi Z}$ is non-vanishing. Therefore only the components $T^{\xi\overline{\xi}}$ and $T^{Z\xi}$, $T^{Z\overline{\xi}}$ of energy momentum tensor are non-vanishing, and field equations reduce to the conditions

$$
\begin{aligned}
\partial_{\overline{\xi}}(J^{\xi\overline{\xi}}\sqrt{g}) + \partial_Z(J^{\xi Z}\sqrt{g}) &= 0 \ , \\
\partial_{\xi}(J^{\overline{\xi}\xi}\sqrt{g}) + \partial_Z(J^{\overline{\xi}Z}\sqrt{g}) &= 0 \ .
\end{aligned}
\tag{1.3.34}
$$

In the special case that the induced metric does not depend on z-coordinate equations reduce to holomorphicity conditions. This is achieve if T depends linearly on Z: $T = aZ$.

The contractions with M^4_+ Christoffel symbols come from the non-vanishing of $T^{Z\xi}$ and vanish if the Hamilton Jacobi structure satisfies the conditions

$$
\begin{array}{ll}
\left\{ {}^{k}_{T\ w} \right\} = 0 \ , & \left\{ {}^{k}_{T\ \overline{w}} \right\} = 0 \ , \\
\left\{ {}^{k}_{Z\ w} \right\} = 0 \ , & \left\{ {}^{k}_{Z\ \overline{w}} \right\} = 0
\end{array}
\tag{1.3.35}
$$

hold true. The conditions are equivalent with the conditions

$$
\left\{ {}^{k}_{\pm\ w} \right\} = 0 \ , \quad \left\{ {}^{k}_{\pm\ \overline{w}} \right\} = 0 \ . \tag{1.3.36}
$$

These conditions possess solutions (standard light cone coordinates are the simplest example). Also the second derivatives of $T(s, Z)$ contribute to the second fundamental form but they do not give rise to non-vanishing contractions with the energy momentum tensor. The cautious conclusion is that also solutions with time-like or space-like Kähler current are possible.

$D_{CP_2} = 4$ case

The preceding discussion was for $D_{CP_2} = 3$ and one should generalize the discussion to $D_{CP_2} = 4$ case.

1. Hamilton Jacobi structure for M^4_+ is expected to be crucial also now.

2. One might hope that for $D_{CP_2} = 4$ the Kähler structure of CP_2 defines a foliation of CP_2 by 3-dimensional contact structures. This requires that there is a coordinate varying along the field lines of the normal vector field X defined as the dual of the three-form $A \wedge dA = A \wedge J$. By the previous considerations the condition for this reads as $dX = d(log\phi) \wedge X$ and implies $X \wedge dX = 0$. Using the self duality of the Kähler form one can express X as $X^k = J^{kl}A_l$. By a brief calculation one finds that $X \wedge dX \propto X$ holds true so that (somewhat disappointingly) a foliation of CP_2 by contact structures does not exist.

For $D_{CP_2} = 4$ case Kähler current vanishes and this case corresponds to what I have called earlier Maxwellian phase since empty space Maxwell's equations are indeed satisfied.

1. Solution ansatz with a 3-dimensional M^4_+ projection

The basic idea is that the complex structure of CP_2 is preserved so that one can use complex coordinates (ξ^1, ξ^2) for CP_2 in which CP_2 Christoffel symbols and energy momentum tensor have automatically the desired properties. This is achieved the second light like coordinate, say v, is non-dynamical so that the induced metric does not receive any contribution from the longitudinal degrees of freedom. In this case one has

$$S^+ = S^+(\xi^1, \xi^2) \ , \quad w = w(\xi^1, \xi^2) \ , \quad S^- = constant \ . \tag{1.3.37}$$

The induced metric does possesses only components of type $g_{i\bar{j}}$ if the conditions

$$g_{+w} = 0 \ , \quad g_{+\overline{w}} = 0 \ . \tag{1.3.38}$$

This guarantees that energy momentum tensor has only components of type $T^{i\bar{j}}$ in coordinates (ξ^1, ξ^2) and their contractions with the Christoffel symbols of CP_2 vanish identically. In M^4_+ degrees of freedom one must pose the conditions

$$\left\{ {k \atop w+} \right\} = 0 \ , \quad \left\{ {k \atop \overline{w}+} \right\} = 0 \ , \quad \left\{ {k \atop ++} \right\} = 0 \ . \tag{1.3.39}$$

on Christoffel symbols. These conditions are satisfied if the the M^4_+ metric does not depend on S^+:

$$\partial_+ m_{kl} \ = \ 0 \ . \tag{1.3.40}$$

This means that m_{-w} and $m_{-\overline{w}}$ can be non-vanishing but like m_{+-} they cannot depend on S^+.

The second derivatives of S^+ appearing in the second fundamental form are also a source of trouble unless they vanish. Hence S^+ must be a linear function of the coordinates ξ^k:

$$S^+ \ = \ a_k\xi^k + \overline{a}_k\overline{\xi}^k \ . \tag{1.3.41}$$

Field equations are the counterparts of empty space Maxwell equations $j^\alpha = 0$ but with M^4_+ coordinates (u, w) appearing as dynamical variables and entering only through the induced metric. By holomorphy the field equations can be written as

$$\partial_j (J^{j\bar{i}}\sqrt{g}) = 0 \ , \quad \partial_{\bar{j}} (J^{\bar{j}i}\sqrt{g}) = 0 \ , \tag{1.3.42}$$

and can be interpreted as conditions stating the holomorphy of the contravariant Kähler form.

What is remarkable is that the M^4_+ projection of the solution is 3-dimensional light like surface and that the induced metric has Euclidian signature. Light front would become a concrete geometric object with one compactified dimension rather than being a mere conceptualization. One could see this as topological quantization for the notion of light front or of electromagnetic shock wave, or perhaps even as the realization of the particle aspect of gauge fields at classical level.

If the latter interpretation is correct, quantum classical correspondence would be realized very concretely. Wave and particle aspects would both be present. One could understand the interactions of charged particles with electromagnetic fields both in terms of absorption and emission of topological field quanta and in terms of the interaction with a classical field as particle topologically condenses at the photonic light front.

For CP_2 type extremals for which M^4_+ projection is a light like curve correspond to a special case of this solution ansatz: transversal M^4_+ coordinates are constant and S^+ is now arbitrary function of CP_2 coordinates. This is possible since M^4_+ projection is 1-dimensional.

2. Are solutions with a 4-dimensional M^4_+ projection possible?

The most natural solution ansatz is the one for which CP_2 complex structure is preserved so that energy momentum tensor has desired properties. For four-dimensional M^4_+ projection this ansatz does not seem to make promising since the contribution of the longitudinal degrees of freedom implies that the induced metric is not anymore of desired form since the components $g_{ij} = m_{+-}(\partial_{\xi^i}S^+\partial_{\xi^j}S^- + m_{+-}\partial_{\xi^i}S^-\partial_{\xi^j}S^+)$ are non-vanishing.

1. The natural dynamical variables are still Minkowski coordinates $(w, \overline{w}, S^+, S^-)$ for some Hamilton Jacobi structure. Since the complex structure of CP_2 must be given up, CP_2 coordinates can be written as (ξ, s, r) to stress the fact that only "one half" of the Kähler structure of CP_2 is respected by the solution ansatz.

2. The solution ansatz has the same general form as in $D_{CP_2} = 3$ case and must be symmetric with respect to the exchange of M^4_+ and CP_2 coordinates. Transverse coordinates are mapped to transverse ones and longitudinal coordinates to longitudinal ones:

$$(S^+, S^-) = (S^+(s,r), S^-(s,r)) \quad , \quad w = w(\xi) \ . \tag{1.3.43}$$

   This ansatz would describe ordinary Maxwell field in M^4_+ since the roles of M^4_+ coordinates and CP_2 coordinates are interchangeable.

It is however far from obvious whether there are any solutions with a 4-dimensional M^4_+ projection. That empty space Maxwell's equations would allow only the topologically quantized light fronts as its solutions would realize quantum classical correspondence very concretely.

$D_{CP_2} = 2$ case

Hamilton Jacobi structure for M^4_+ is assumed also for $D_{CP_2} = 2$, whereas the contact structure for CP_2 is in $D_{CP_2} = 2$ case replaced by the induced Kähler structure. Topologization yields vanishing Kähler current. Light-likeness provides a second manner to achieve vanishing Lorentz force but one cannot exclude the possibility of time- and space-like Kähler current.

1. Solutions with vanishing Kähler current

1. String like objects, which are products $X^2 \times Y^2 \subset M^4_+ \times CP_2$ of minimal surfaces Y^2 of M^4_+ with geodesic spheres S^2 of CP_2 and carry vanishing gauge current. String like objects allow considerable generalization from simple Cartesian products of $X^2 \times Y^2 \subset M^4 \times S^2$. Let $(w, \overline{w}, S^+, S^-)$ define the Hamilton Jacobi structure for M^4_+. $w = constant$ surfaces define minimal surfaces X^2 of M^4_+. Let ξ denote complex coordinate for a sub-manifold of CP_2 such that the imbedding to CP_2 is holomorphic: $(\xi^1, \xi^2) = (f^1(\xi), f^2(\xi))$. The resulting surface $Y^2 \subset CP_2$ is a minimal surface and field equations reduce to the requirement that the Kähler current vanishes: $\partial_{\overline{\xi}}(J^{\xi\overline{\xi}}\sqrt{g_2}) = 0$. One-dimensional strings are deformed to 3-dimensional cylinders representing magnetic flux tubes. The oscillations of string correspond to waves moving along string with light velocity, and for more general solutions they become TGD counterparts of Alfwen waves associated with magnetic flux tubes regarded as oscillations of magnetic flux lines behaving effectively like strings. It must be emphasized that Alfwen waves are a phenomenological notion not really justified by the properties of Maxwell's equations.

2. Also electret type solutions with the role of the magnetic field taken by the electric field are possible. $(\xi, \overline{\xi}, u, v)$ would provide the natural coordinates and the solution ansatz would be of the form

$$(s, r) = (s(u,v), r(u,v)) \quad , \quad \xi = constant \ , \tag{1.3.44}$$

   and corresponds to a vanishing Kähler current.

3. Both magnetic and electric fields are necessarily present only for the solutions carrying non-vanishing electric charge density (proportional to $\overline{B} \cdot \overline{A}$). Thus one can ask whether more general solutions carrying both magnetic and electric field are possible. As a matter fact, one must first answer the question what one really means with the magnetic field. By choosing the coordinates of 2-dimensional CP_2 projection as space-time coordinates one can define what one means with magnetic and electric field in a coordinate invariant manner. Since the CP_2 Kähler form for the CP_2 projection with $D_{CP_2} = 2$ can be regarded as a pure Kähler magnetic field, the induced Kähler field is either magnetic field or electric field.

The form of the ansatz would be

$$(s,r) = (s,r)\,(u,v,w,\overline{w}) \ \ , \quad \xi = constant \ \ . \tag{1.3.45}$$

As a matter fact, CP_2 coordinates depend on two properly chosen M^4 coordinates only.

1. Solutions with light-like Kähler current

There are large classes of solutions of field equations with a light-like Kähler current and 2-dimensional CP_2 projection.

1. Massless extremals for which CP_2 coordinates are arbitrary functions of one transversal coordinate $e = f(w,\overline{w})$ defining local polarization direction and light like coordinate u of M^4_+ and carrying in the general case a light like current. In this case the holomorphy does not play any role.

2. The string like solutions thickened to magnetic flux tubes carrying TGD counterparts of Alfwen waves generalize to solutions allowing also light-like Kähler current. Also now Kähler metric is allowed to develop a component between longitudinal and transversal degrees of freedom so that Kähler current develops a light-like component. The ansatz is of the form

$$\xi^i = f^i(\xi) \ \ , \ \ w = w(\xi) \ \ , \ \ S^- = s^- \ \ , \ \ S^+ = s^+ + f(\xi,\overline{\xi}) \ \ .$$

Only the components $g_{+\xi}$ and $g_{+\overline{\xi}}$ of the induced metric receive contributions from the modification of the solution ansatz. The contravariant metric receives contributions to $g^{-\xi}$ and $g^{-\overline{\xi}}$ whereas $g^{+\xi}$ and $g^{+\overline{\xi}}$ remain zero. Since the partial derivatives $\partial_\xi\partial_+h^k$ and $\partial_{\overline{\xi}}\partial_+h^k$ and corresponding projections of Christoffel symbols vanish, field equations are satisfied. Kähler current develops a non-vanishing component j^-. Apart from the presence of the electric field, these solutions are highly analogous to Beltrami fields.

Could $D_{CP_2} = 2 \rightarrow 3$ transition occur in rotating magnetic systems?

I have studied the imbeddings of simple cylindrical and helical magnetic fields in various applications of TGD to condensed matter systems, in particular in attempts to understand the strange findings about rotating magnetic systems [G2].

Let S^2 be the homologically non-trivial geodesic sphere of CP_2 with standard spherical coordinates $(U \equiv cos(\theta), \Phi)$ and let (t,ρ,ϕ,z) denote cylindrical coordinates for a cylindrical space-time sheet. The simplest possible space-time surfaces $X^4 \subset M^4_+ \times S^2$ carrying helical Kähler magnetic field depending on the radial cylindrical coordinate ρ, are given by:

$$\begin{array}{ll} U = U(\rho) \ \ , & \Phi = n\phi + kz \ \ , \\ J_{\rho\phi} = n\partial_\rho U \ \ , & J_{\rho z} = k\partial_\rho U \ \ . \end{array} \tag{1.3.46}$$

This helical field is not Beltrami field as one can easily find. A more general ansatz corresponding defined by

$$\Phi = \omega t + kz + n\phi$$

would in cylindrical coordinates give rise to both helical magnetic field and radial electric field depending on ρ only. This field can be obtained by simply replacing the vector potential with its rotated version and provides the natural first approximation for the fields associated with rotating magnetic systems.

A non-vanishing vacuum charge density is however generated when a constant magnetic field is put into rotation and is implied by the condition $\overline{E} = \overline{v} \times \overline{B}$ stating vanishing of the Lorentz force. This condition does not follow from the induction law of Faraday although Faraday observed this effect first. This is also clear from the fact that the sign of the charge density depends on the direction of rotation.

The non-vanishing charge density is not consistent with the vanishing of the Kähler 4-current and requires a 3-dimensional CP_2 projection and topologization of the Kähler current. Beltrami condition cannot hold true exactly for the rotating system. The conclusion is that rotation induces a phase transition $D_{CP_2} = 2 \rightarrow 3$. This could help to understand various strange effects related to the rotating magnetic systems [G2]. For instance, the increase of the dimension of CP_2 projection could generate join along boundaries contacts and wormhole contacts leading to the transfer of charge between different space-time sheets. The possibly resulting flow of gravitational flux to larger space-time sheets might help to explain the claimed antigravity effects.

1.3.4 $D_{CP_2} = 3$ phase allows infinite number of topological charges characterizing the linking of magnetic field lines

When space-time sheet possesses a $D = 3$-dimensional CP_2 projection, one can assign to it a non-vanishing and conserved topological charge characterizing the linking of the magnetic field lines defined by Chern-Simons action density $A \wedge dA/4\pi$ for induced Kähler form. This charge can be seen as classical topological invariant of the linked structure formed by magnetic field lines.

The topological charge can also vanish for $D_{CP_2} = 3$ space-time sheets. In Darboux coordinates for which Kähler gauge potential reads as $A = P_k dQ^k$, the surfaces of this kind result if one has $Q^2 = f(Q^1)$ implying $A = f dQ^1$, $f = P_1 + P_2 \partial_{Q_1} Q^2$, which implies the condition $A \wedge dA = 0$. For these space-time sheets one can introduce Q^1 as a global coordinate along field lines of A and define the phase factor $exp(i \int A_\mu dx^\mu)$ as a wave function defined for the entire space-time sheet. This function could be interpreted as a phase of an order order parameter of super-conductor like state and there is a high temptation to assume that quantum coherence in this sense is lost for more general $D_{CP_2} = 3$ solutions.

Chern-Simons action is known as helicity in electrodynamics [23]. Helicity indeed describes the linking of magnetic flux lines as is easy to see by interpreting magnetic field as incompressible fluid flow having A as vector potential: $B = \nabla \times A$. One can write A using the inverse of $\nabla \times$ as $A = (1/\nabla\times)B$. The inverse is non-local operator expressible as

$$\frac{1}{\nabla\times} B(r) = \int dV' \frac{(r - r')}{|r - r'|^3} \times B(r') \ ,$$

as a little calculation shows. This allows to write $\int A \cdot B$ as

$$\int dV A \cdot B = \int dV dV' B(r) \cdot \left(\frac{(r - r')}{|r - r'|^3} \times B(r') \right) \ ,$$

which is completely analogous to the Gauss formula for linking number when linked curves are replaced by a distribution of linked curves and an average is taken.

For $D_{CP_2} = 3$ field equations imply that Kähler current is proportional to the helicity current by a factor which depends on CP_2 coordinates, which implies that the current is automatically divergence free and defines a conserved charge for $D = 3$-dimensional CP_2 projection for which the instanton density vanishes identically. Kähler charge is not equal to the helicity defined by the inner product of magnetic field and vector potential but to a more general topological charge.

The number of conserved topological charges is infinite since the product of any function of CP_2 coordinates with the helicity current has vanishing divergence and defines a topological charge. A very natural function basis is provided by the scalar spherical harmonics of $SU(3)$ defining Hamiltonians of CP_2 canonical transformations and possessing well defined color quantum numbers. These functions define and infinite number of conserved charges which are also classical knot invariants in the sense that they are not affected at all when the 3-surface interpreted as a map from CP_2 projection to M^4_+ is deformed in M^4_+ degrees of freedom. Also canonical transformations induced by Hamiltonians in irreducible representations of color group affect these invariants via Poisson bracket action when the $U(1)$ gauge transformation induced by the canonical transformation corresponds to a single valued scalar function. These link invariants are additive in union whereas the quantum invariants defined by topological quantum field theories are multiplicative.

Also non-Abelian topological charges are well-defined. One can generalize the topological current associated with the Kähler form to a corresponding current associated with the induced electro-weak gauge fields whereas for classical color gauge fields the Chern-Simons form vanishes identically. Also in this case one can multiply the current by CP_2 color harmonics to obtain an infinite number of invariants in $D_{CP_2} = 3$ case. The only difference is that $A \wedge dA$ is replaced by $Tr(A \wedge (dA + 2A \wedge A/3))$.

There is a strong temptation to assume that these conserved charges characterize colored quantum states of the conformally invariant quantum theory as a functional of the light-like 3-surface defining boundary of space-time sheet or elementary particle horizon surrounding wormhole contacts. They would be TGD analogs of the states of the topological quantum field theory defined by Chern-Simons action as highest weight states associated with corresponding Wess-Zumino-Witten theory. These charges could be interpreted as topological counterparts of the isometry charges of configuration space of 3-surfaces defined by the algebra of canonical transformations of CP_2.

The interpretation of these charges as contributions of light-like boundaries to configuration space Hamiltonians would be natural. The dynamics of the induced second quantized spinor fields relates to that of Kähler action by a super-symmetry, so that it should define super-symmetric counterparts of these knot invariants. The anti-commutators of these super charges cannot however contribute to configuration space Kähler metric so that topological zero modes are in question. These Hamiltonians and their super-charge counterparts would be responsible for the topological sector of quantum TGD.

1.3.5 Preferred extremal property and the topologization/light-likeness of Kähler current?

The basic question is under what conditions the Kähler current is either topologized or light-like so that the Lorentz force vanishes. Does this hold for all preferred extremals of Kähler action? Or only asymptotically as suggested by the fact that generalized Beltrami fields can be interpreted as asymptotic self-organization patterns, when dissipation has become insignificant. Or does topologization take place in regions of space-time surface having Minkowskian signature of the induced metric? And what asymptotia actually means? Do absolute minima of Kähler action correspond to preferred extremals?

One can challenge the interpretation in terms of asymptotic self organization patterns assigned to the Minkowskian regions of space-time surface.

1. Zero energy ontology challenges the notion of approach to asymptotia in Minkowskian sense since the dynamics of light-like 3-surfaces is restricted inside finite volume $CD \subset M^4$ since the partonic 2-surfaces representing their ends are at the light-like boundaries of causal diamond in a given p-adic time scale.

2. One can argue that generic non-asymptotic field configurations have $D_{CP_2} = 4$, and would thus carry a vanishing Kähler four-current if Beltrami conditions were satisfied universally rather than only asymptotically. $j^\alpha = 0$ would obviously hold true also for the asymptotic configurations, in particular those with $D_{CP_2} < 4$ so that empty space Maxwell's field equations would be universally satisfied for asymptotic field configurations with $D_{CP_2} < 4$. The weak point of this argument is that it is 3-D light-like 3-surfaces rather than space-time surfaces which are the basic dynamical objects so that the generic and only possible case corresponds to $D_{CP_2} = 3$ for X^3_l. It is quite possible that preferred extremal property implies that $D_{CP_2} = 3$ holds true in the Minkowskian regions since these regions indeed represent empty space. Geometrically this would mean that the CP_2 projection does not change as the light-like coordinate labeling Y^3_l varies. This conforms nicely with the notion of quantum gravitational holography.

3. The failure of the generalized Beltrami conditions would mean that Kähler field is completely analogous to a dissipative Maxwell field for which also Lorentz force vanishes since $\overline{j} \cdot \overline{E}$ is non-vanishing (note that isometry currents are conserved although energy momentum tensor is not). Quantum classical correspondence states that classical space-time dynamics is by its classical non-determinism able to mimic the non-deterministic sequence of quantum jumps at

space-time level, in particular dissipation in various length scales defined by the hierarchy of space-time sheets. Classical fields would represent "symbolically" the average dynamics, in particular dissipation, in shorter length scales. For instance, vacuum 4-current would be a symbolic representation for the average of the currents consisting of elementary particles. This would seem to support the view that $D_{CP_2} = 4$ Minkowskian regions are present. The weak point of this argument is that there is fractal hierarchy of length scales represented by the hierarchy of causal diamonds (CDs) and that the resulting hierarchy of generalized Feynman graphs might be enough to represent dissipation classically.

4. One objection to the idea is that second law realized as an asymptotic vanishing of Lorentz-Kähler force implies that all space-like 3-surfaces approaching same asymptotic state have the same value of Kähler function assuming that the Kähler function assignable to space-like 3-surface is same for all space-like sections of $X^4(X^3_l)$ (assuming that one can realize general coordinate invariance also in this sense). This need not be the case. In any case, this need not be a problem since it would mean an additional symmetry extending general coordinate invariance. The exponent of Kähler function would be highly analogous to a partition function defined as an exponent of Hamiltonian with Kähler coupling strength playing the role of temperature.

It seems that asymptotic self-organization pattern need not be correct interpretation for non-dissipating regions, and the identification of light-like 3-surfaces as generalized Feynman diagrams encourages an alternative interpretation.

1. $M^8 - H$ duality states that also the H counterparts of co-hyper-hyperquaternionic surfaces of M^8 are preferred extremals of Kähler action. CP_2 type vacuum extremals represent the basic example of these and a plausible conjecture is that the regions of space-time with Euclidian signature of the induced metric represent this kind of regions. If this conjecture is correct, dissipation could be assigned with regions having Euclidian signature of the induced metric. This makes sense since dissipation has quantum description in terms of Feynman graphs and regions of Euclidian signature indeed correspond to generalized Feynman graphs. This argument would suggest that generalized Beltrami conditions or light-likeness hold true inside Minkowskian regions rather than only asymptotically.

2. One could of course play language games and argue that asymptotia is with respect to the Euclidian time coordinate inside generalized Feynman graps and is achieved exactly when the signature of the induced metric becomes Minkowskian. This is somewhat artificial attempt to save the notion of asymptotic self-organization pattern since the regions outside Feynman diagrams represent empty space providing a holographic representations for the matter at X^3_l so that the vanishing of $j^\alpha F_{\alpha\beta}$ is very natural.

3. What is then the correct identification of asymptotic self-organization pattern. Could correspond to the negative energy part of the zero energy state at the upper light-like boundary δM^4_- of CD? Or in the case of phase conjugate state to the positive energy part of the state at δM^4_+? An identification consistent with the fractal structure of zero energy ontology and TGD inspired theory of consciousness is that the entire zero energy state reached by a sequence of quantum jumps represents asymptotic self-organization pattern represented by the asymptotic generalized Feynman diagram or their superposition. Biological systems represent basic examples about self-organization, and one cannot avoid the questions relating to the relationship between experience and geometric time. A detailed discussion of these points can be found in [MPb].

Absolute minimization of Kähler action was the first guess for the criterion selecting preferred extremals. Absolute minimization in a strict sense of the word does not make sense in the p-adic context since p-adic numbers are not well-ordered, and one cannot even define the action integral as a p-adic number. The generalized Beltrami conditions and the boundary conditions defining the preferred extremals are however local and purely algebraic and make sense also p-adically. If absolute minimization reduces to these algebraic conditions, it would make sense.

1.3.6 Generalized Beltrami fields and biological systems

The following arguments support the view that generalized Beltrami fields play a key role in living systems, and that $D_{CP_2} = 2$ corresponds to ordered phase, $D_{CP_2} = 3$ to spin glass phase and $D_{CP_2} = 4$

to chaos, with $D_{CP_2} = 3$ defining life as a phenomenon at the boundary between order and chaos. If the criteria suggested by the number theoretic compactification are accepted, it is not clear whether D_{CP_2} extremals can define preferred extremals of Kähler action. For instance, cosmic strings are not preferred extremals and the Y_l^3 associated with MEs allow only covariantly constant right handed neutrino eigenmode of $D_K(X^2)$. The topological condensation of CP_2 type vacuum extremals around $D_{CP_2} = 2$ type extremals is however expected to give preferred extremals and if the density of the condensate is low enough one can still speak about $D_{CP_2} = 2$ phase. A natural guess is also that the deformation of $D_{CP_2} = 2$ extremals transforms light-like gauge currents to space-like topological currents allowed by $D_{CP_2} = 3$ phase.

Why generalized Beltrami fields are important for living systems?

Chirality, complexity, and high level of organization make $D_{CP_2} = 3$ generalized Beltrami fields excellent candidates for the magnetic bodies of living systems.

1. Chirality selection is one of the basic signatures of living systems. Beltrami field is characterized by a chirality defined by the relative sign of the current and magnetic field, which means parity breaking. Chirality reduces to the sign of the function ψ appearing in the topologization condition and makes sense also for the generalized Beltrami fields.

2. Although Beltrami fields can be extremely complex, they are also extremely organized. The reason is that the function α is constant along flux lines so that flux lines must in the case of compact Riemann 3-manifold belong to 2-dimensional $\alpha = constant$ closed surfaces, in fact two-dimensional invariant tori [21].

For generalized Beltrami fields the function ψ is constant along the flow lines of the Kähler current. Space-time sheets with 3-dimensional CP_2 projection serve as an illustrative example. One can use the coordinates for the CP_2 projection as space-time coordinates so that one space-time coordinate disappears totally from consideration. Hence the situation reduces to a flow in a 3-dimensional sub-manifold of CP_2. One can distinguish between three types of flow lines corresponding to space-like, light-like and time-like topological current. The 2-dimensional $\psi = constant$ invariant manifolds are sub-manifolds of CP_2. Ordinary Beltrami fields are a special case of space-like flow with flow lines belonging to the 2-dimensional invariant tori of CP_2. Time-like and light-like situations are more complex since the flow lines need not be closed so that the 2-dimensional $\psi = constant$ surfaces can have boundaries.

For periodic self-organization patterns flow lines are closed and $\psi = constant$ surfaces of CP_2 must be invariant tori. The dynamics of the periodic flow is obtained from that of a steady flow by replacing one spatial coordinate with effectively periodic time coordinate. Therefore topological notions like helix structure, linking, and knotting have a dynamical meaning at the level of CP_2 projection. The periodic generalized Beltrami fields are highly organized also in the temporal domain despite the potentiality for extreme topological complexity.

For these reasons topologically quantized generalized Beltrami fields provide an excellent candidate for a generic model for the dynamics of biological self-organization patterns. A natural guess is that many-sheeted magnetic and Z^0 magnetic fields and their generalizations serve as templates for the helical molecules populating living matter, and explain both chiral selection, the complex linking and knotting of DNA and protein molecules, and even the extremely complex and self-organized dynamics of biological systems at the molecular level.

The intricate topological structures of DNA, RNA, and protein molecules are known to have a deep significance besides their chemical structure, and they could even define something analogous to the genetic code. Usually the topology and geometry of bio-molecules is believed to reduce to chemistry. TGD suggests that space-like generalized Beltrami fields serve as templates for the formation of bio-molecules and bio-structures in general. The dynamics of bio-systems would in turn utilize the time-like Beltrami fields as templates. There could even exist a mapping from the topology of magnetic flux tube structures serving as templates for bio-molecules to the templates of self-organized dynamics. The helical structures, knotting, and linking of bio-molecules would thus define a symbolic representation, and even coding for the dynamics of the bio-system analogous to written language.

$D_{CP_2} = 3$ systems as boundary between $D_{CP_2} = 2$ order and $D_{CP_2} = 4$ chaos

The dimension of CP_2 projection is basic classifier for the asymptotic self-organization patterns.

1. $D_{CP_2} = 4$ phase, dead matter, and chaos

$D_{CP_2} = 4$ corresponds to the ordinary Maxwellian phase in which Kähler current and charge density vanish and there is no topologization of Kähler current. By its maximal dimension this phase would naturally correspond to disordered phase, ordinary "dead matter". If one assumes that Kähler charge corresponds to either em charge or Z^0 charge then the signature of this state of matter would be em neutrality or Z^0 neutrality.

2. $D_{CP_2} = 2$ phase as ordered phase

By the low dimension of CP_2 projection $D_{CP_2} = 2$ phase is the least stable phase possible only at cold space-time sheets. Kähler current is either vanishing or light-like, and Beltrami fields are not possible. This phase is highly ordered and much like a topological quantized version of ferro-magnet. In particular, it is possible to have a global coordinate varying along the field lines of the vector potential also now. The magnetic and Z^0 magnetic body of any system is a candidate for this kind of system. Z^0 field is indeed always present for vacuum extremals having $D_{CP_2} = 2$ and the vanishing of em field requires that that $sin^2(\theta_W)$ (θ_W is Weinberg angle) vanishes.

3. $D_{CP_2} = 3$ corresponds to living matter

$D_{CP_2} = 3$ corresponds to highly organized phase characterized in the case of space-like Kähler current by complex helical structures necessarily accompanied by topologized Kähler charge density $\propto \overline{A} \cdot \overline{B} \neq 0$ and Kähler current $\overline{E} \times \overline{A} + \phi\overline{B}$. For time like Kähler currents the helical structures are replaced by periodic oscillation patterns for the state of the system. By the non-maximal dimension of CP_2 projection this phase must be unstable against too strong external perturbations and cannot survive at too high temperatures. Living matter is thus excellent candidate for this phase and it might be that the interaction of the magnetic body with living matter makes possible the transition from $D_{CP_2} = 2$ phase to the self-organizing $D_{CP_2} = 3$ phase.

Living matter which is indeed populated by helical structures providing examples of space-like Kähler current. Strongly charged lipid layers of cell membrane might provide example of time-like Kähler current. Cell membrane, micro-tubuli, DNA, and proteins are known to be electrically charged and Z^0 charge plays key role in TGD based model of catalysis discussed in [L5]. For instance, denaturing of DNA destroying its helical structure could be interpreted as a transition leading from $D_{CP_2} = 3$ phase to $D_{CP_2} = 4$ phase. The prediction is that the denatured phase should be electromagnetically (or Z^0) neutral.

Beltrami fields result when Kähler charge density vanishes. For these configurations magnetic field and current density take the role of the vector potential and magnetic field as far as the contact structure is considered. For Beltrami fields there exist a global coordinate along the field lines of the vector potential but not along those of the magnetic field. As a consequence, the covariant consistency condition $(\partial_s - qeA_s)\Psi = 0$ frequently appearing in the physics of super conducting systems would make sense along the flow lines of the vector potential for the order parameter of Bose-Einstein condensate. If Beltrami phase is super-conducting, then the state of the system must change in the transition to a more general phase. It is impossible to assign slicing of 4-surface by 3-D surfaces labeled by a coordinate t varying along the flow lines. This means that one cannot speak about a continuous evolution of Schrödinger amplitude with t playing the role of time coordinate. One could perhaps say that the entire space-time sheet represents single quantum event which cannot be decomposed to evolution. This would conform with the assignment of macroscopic and macro-temporal quantum coherence with living matter.

The existence of these three phases brings in mind systems allowing chaotic de-magnetized phase above critical temperature T_c, spin glass phase at the critical point, and ferromagnetic phase below T_c. Similar analogy is provided by liquid phase, liquid crystal phase possible in the vicinity of the critical point for liquid to solid transition, and solid phase. Perhaps one could regard $D_{CP_2} = 3$ phase and life as a boundary region between $D_{CP_2} = 2$ order and $D_{CP_2} = 4$ chaos. This would naturally explain why life as it is known is possible in relatively narrow temperature interval.

Can one assign a continuous Schrödinger time evolution to light-like 3-surfaces?

Alain Connes wrote [28] about factors of various types using as an example Schrödinger equation for various kinds of foliations of space-time to time=constant slices. If this kind of foliation does not exist, one cannot speak about time evolution of Schrödinger equation at all. Depending on the character of the foliation one can have factor of type I, II, or III. For instance, torus with slicing $dx = ady$ in flat coordinates, gives a factor of type I for rational values of a and factor of type II for irrational values of a.

1. 3-D foliations and type III factors

Connes mentioned 3-D foliations V which give rise to type III factors. Foliation property requires a slicing of V by a one-form v to which slices are orthogonal (this requires metric).

1. The foliation property requires that v multiplied by suitable scalar is gradient. This gives the integrability conditions $dv = w \wedge v$, $w = -d\psi/\psi = -dlog(\psi)$. Something proportional to $log(\psi)$ can be taken as a third coordinate varying along flow lines of v: the flow defines a continuous sequence of maps of 2-dimensional slice to itself.

2. If the so called Godbillon-Vey invariant defined as the integral of $dw\wedge w$ over V is non-vanishing, factor of type III is obtained using Schrödinger amplitudes for which the flow lines of foliation define the time evolution. The operators of the algebra in question are transversal operators acting on Schrödinger amplitudes at each slice. Essentially Schrödinger equation in 3-D space-time would be in question with factor of type III resulting from the exotic choice of the time coordinate defining the slicing.

2. What happens in case of light-like 3-surfaces?

In TGD light-like 3-surfaces are natural candidates for V and it is interesting to look what happens in this case. Light-likeness is of course a disturbing complication since orthogonality condition and thus contravariant metric is involved with the definition of the slicing. Light-likeness is not however involved with the basic conditions.

1. The one-form v defined by the induced Kähler gauge potential A defining also a braiding is a unique identification for v. If foliation exists, the braiding flow defines a continuous sequence of maps of partonic 2-surface to itself.

2. Physically this means the possibility of a super-conducting phase with order parameter satisfying covariant constancy equation $D\psi = (d/dt - ieA)\psi = 0$. This would describe a supra current flowing along flow lines of A.

3. If the integrability fails to be true, one *cannot* assign Schrödinger time evolution with the flow lines of v. One might perhaps say that 3-surface behaves like single quantum event not allowing slicing into a continuous Schrödinger time evolution.

4. In TGD Schrödinger amplitudes are replaced by second quantized induced spinor fields. Hence one does not face the problem whether it makes sense to speak about Schrödinger time evolution of complex order parameter along the flow lines of a foliation or not. Also the fact that the "time evolution" for the modified Dirac operator corresponds to single position dependent generalized eigenvalue identified as Higgs expectation same for all transversal modes (essentially z^n labeled by conformal weight) is crucial since it saves from the problems caused by the possible non-existence of Schrödinger evolution.

4. Extremals of Kähler action

Some comments relating to the interpretation of the classification of the extremals of Kähler action by the dimension of their CP_2 projection are in order. It has been already found that the extremals can be classified according to the dimension D of the CP_2 projection of space-time sheet in the case that $A_a = 0$ holds true.

1. For $D_{CP_2} = 2$ integrability conditions for the vector potential can be satisfied for $A_a = 0$ so that one has generalized Beltrami flow and one can speak about Schrödinger time evolution associated with the flow lines of vector potential defined by covariant constancy condition $D\psi = 0$ makes sense. Kähler current is vanishing or light-like. This phase is analogous to a super-conductor or a ferromagnetic phase. For non-vanishing A_a the Beltrami flow property is lost but the analogy with ferromagnetism makes sense still.

2. For $D_{CP_2} = 3$ foliations are lost. The phase is dominated by helical structures. This phase is analogous to spin glass phase around phase transition point from ferromagnetic to non-magnetized phase and expected to be important in living matter systems.

3. $D_{CP_2} = 4$ is analogous to a chaotic phase with vanishing Kähler current and to a phase without magnetization. The interpretation in terms of non-quantum coherent "dead" matter is suggestive.

An interesting question is whether the ordinary 8-D imbedding space which defines one sector of the generalized imbedding space could correspond to $A_a = 0$ phase. If so, then all states for this sector would be vacua with respect to M^4 quantum numbers. M^4-trivial zero energy states in this sector could be transformed to non-trivial zero energy states by a leakage to other sectors.

1.3.7 About small perturbations of field equations

The study of small perturbations of the known solutions of field equations is a standard manner to get information about the properties of the solutions, their stability in particular. Fourier expansion is the standard manner to do the perturbation theory. In the recent case an appropriate modification of this ansatz might make sense if the solution in question is representable as a map $M^4_+ \rightarrow CP_2$, and the perturbations are rapidly varying when compared to the components of the induced metric and Kähler form so that one can make adiabatic approximation and approximate them as being effectively constant. Presumably also restrictions on directions of wave 4-vectors $k_\mu = (\omega, \overline{k}))$ are necessary so that the direction of wave vector adapts to the slowly varying background as in ray optics. Also Hamilton Jacobi structure is expected to modify the most straightforward approach. The four CP_2 coordinates are the dynamical variables so that the situation is relatively simple.

A completely different approach is inspired by the physical picture. In this approach one glues CP_2 type vacuum extremal to a known extremal and tries to deduce the behavior of the deformed extremal in the vicinity of wormhole throat by posing the general conditions on the slicing by light-like 3-surfaces Y^3_l. This approach is not followed now.

Generalized plane waves

Individual plane waves are geometrically very special since they represent a deformation of the space-time surface depending on single coordinate only. Despite this one might hope that plane waves or their appropriate modifications allowing to algebraize the treatment of small perturbations could give useful information also now.

1. Lorentz invariance plus the translational invariance due to the assumption that the induced metric and Kähler form are approximately constant encourage to think that the coordinates reduce Minkowski coordinates locally with the orientation of the local Minkowski frame depending slowly on space-time position. Hamilton Jacobi $(S^+, S^-, w, \overline{w})$ are a good candidate for this kind of coordinates. The properties of the Hamilton Jacobi structure and of the solution ansatz suggest that excitations are generalized plane waves in longitudinal degrees of freedom only so that four-momentum would be replaced by the longitudinal momentum. In transverse degrees of freedom one might expect that holomorphic plane-waves $exp(ik_T w)$, where k_T is transverse momentum, make algebraization possible.

   For time-like longitudinal momenta one can choose the local M^4 coordinates in such a manner that longitudinal momentum reduces to $(\omega_0, 0)$, where ω_0 plays the role of rest mass and is analogous to the plasma frequency serving as an infrared cutoff for plasma waves. In these coordinates the simplest candidates for excitations with time-like momentum would be of form $\Delta s^k = \epsilon a^k exp(i\omega_0 u)$, where s^k are some real coordinates for CP_2, a^k are Fourier coefficients, and time-like coordinate is defined as $u = S^+ + S^-$. The excitations moving with light velocity correspond to $\omega_0 = 0$, and one must treat this case separately using plane wave $exp(i\omega S^{\pm})$, where ω has continuum of values.

2. It is possible that only some preferred CP_2 coordinates are excited in longitudinal degrees of freedom. For $D_{CP_2} = 3$ ansatz the simplest option is that the complex CP_2 coordinate ξ depends analytically on w and the longitudinal CP_2 coordinate s obeys the plane wave ansatz. $\xi(w) = a \times exp(ik_T w)$, where k_T is transverse momentum allows the algebraization of the solution ansatz also in the transversal degrees of freedom so that a dispersion relation results. For imaginary values of k_T and ω the equations are real.

2. General form for the second variation of the field equations

For time-like four-momentum the second variation of field equations contains three kinds of terms. There are terms quadratic in ω_0 and coming from the second derivatives of the deformation, terms proportional to $i\omega_0$ coming from the variation with respect to the derivatives of CP_2 coordinates, and terms which do not depend on ω_0 and come from the variations of metric and Kähler form with respect to the CP_2 coordinates.

In standard perturbation theory the terms proportional to $i\omega_0$ would have interpretation as analogs of dissipative terms. This forces to assume that ω_0 is complex: note that in purely imaginary ω_0 the equations are real. The basic assumption is that Kähler action is able to mimic dissipation despite the fact that energy and momentum are conserved quantities. The vanishing of the Lorentz force has an interpretation as the vanishing of the dissipative effects. This would suggest that the terms proportional to $i\omega_0$ vanish for the perturbations of the solution preserving the non-dissipative character of the asymptotic solutions. This might quite well result from the vanishing of the contractions with the deformation of the energy momentum tensor with the second fundamental form and of energy momentum tensor with the deformation of the second fundamental form coming from first derivatives.

Physical intuition would suggest that dissipation-less propagation is possible only along special directions. Thus the vanishing of the linear terms should occur only for special directions of the longitudinal momentum vector, say for light-like four-momenta in the direction of coordinate lines of S^+ or S^-. Quite generally, the sub-space of allowed four-momenta is expected to depend on position since the components of metric and Kähler form are slowly varying. This dependence is completely analogous with that appearing in the Hamilton Jacobi (ray-optics) approach to the approximate treatment of wave equations and makes sense if the phase of the plane wave varies rapidly as compared to the variation of CP_2 coordinates for the unperturbed solution.

Complex values of ω_0 are also possible, and would allow to deduce important information about the rate at which small deviations from asymptotia vanish as well as about instabilities of the asymptotic solutions. In particular, for imaginary values of ω_0 one obtains completely well-defined solution ansatz representing exponentially decaying or increasing perturbation.

High energy limit

One can gain valuable information by studying the perturbations at the limit of very large four-momentum. At this limit the terms which are quadratic in the components of momentum dominate and come from the second derivatives of the CP_2 coordinates appearing in the second fundamental form. The resulting equations reduce for all CP_2 coordinates to the same condition

$$T^{\alpha\beta} k_\alpha k_\beta = 0 \ .$$

This condition is generalization of masslessness condition with metric replaced by the energy momentum tensor, which means that light velocity is replaced by an effective light velocity. In fact, energy momentum tensor effectively replaces metric also in the modified Dirac equation whose form is dictated by super symmetry. Light-like four momentum is a rather general solution to the condition and corresponds to $\omega_0 = 0$ case.

Reduction of the dispersion relation to the graph of swallowtail catastrophe

Also the general structure of the equations for small perturbations allows to deduce highly non-trivial conclusions about the character of perturbations.

1. The equations for four CP_2 coordinates are simultaneously satisfied if the determinant associated with the equations vanishes. This condition defines a 3-dimensional surface in the 4-dimensional space defined by ω_0 and coordinates of 3-space playing the role of slowly varying control parameters. 4×4 determinant results and corresponds to a polynomial which is of order $d=8$ in ω_0. If the determinant is real, the polynomial can depend on ω_0^2 only so that a fourth order polynomial in $w=\omega_0^2$ results.

2. Only complex roots are possible in the case that the terms linear in $i\omega_0$ are non-vanishing. One might hope that the linear term vanishes for certain choices of the direction of slowly varying four-momentum vector $k^\mu(x)$ at least. For purely imaginary values of ω_0 the equations determinant are real always. Hence catastrophe theoretic description applies in this case at least, and the so called swallow tail catastrophe [16] with three control parameters applies to the situation.

3. The general form of the vanishing determinant is

$$D(w,a,b,c) = w^4 - ew^3 - cw^2 - bw - a \ \ .$$

The transition from the oscillatory to purely dissipative case changes only the sign of w. By the shift $w=\hat{w}+e/4$ the determinant reduces to the canonical form

$$D(\hat{w},a,b,c) = \hat{w}^4 - c\hat{w}^2 - b\hat{w} - a$$

of the swallowtail catastrophe. This catastrophe has three control variables, which basically correspond to the spatial 3-coordinates on which the induced metric and Kähler form depend. The variation of these coefficients at the space-time sheet of course covers only a finite region of the parameter space of the swallowtail catastrophe. The number of real roots for $w=\omega_0^2$ is four, two, or none since complex roots appear in complex conjugate pairs for a real polynomial. The general shape of the region of 3-space is that for a portion of swallow tail catastrophe.

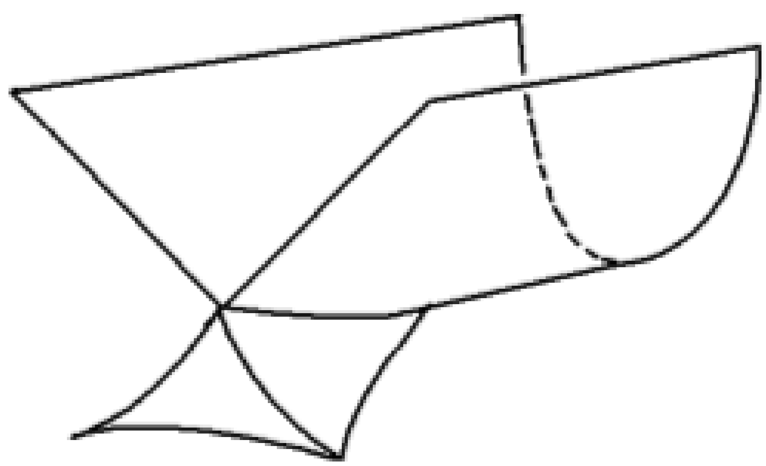

Figure 1.1: The projection of the bifurcation set of the swallowtail catastrophe to the 3-dimensional space of control variables. The potential function has four extrema in the interior of the swallowtail bounded by the triangles, no extrema in the valley above the swallowtail, and 2 extrema elsewhere.

4. The dispersion relation for the "rest mass" ω_0 (decay rate for the imaginary value of ω_0) has at most four real branches, which conforms with the fact that there are four dynamical variables. In real case ω_0 is analogous to plasma frequency acting as an infrared cutoff for the frequencies of plasma excitations. To get some grasp on the situation notice that for $a=0$ the swallowtail reduces to $\hat{w}=0$ and

$$\hat{w}^3 - c\hat{w} - b = 0 \ ,$$

which represents the cusp catastrophe easy to illustrate in 3-dimensional space. Cusp in turn reduces for $b = 0$ to $\hat{w} = 0$ and fold catastrophe $\hat{w} = \pm\sqrt{c}$. Thus the catastrophe surface becomes 4-sheeted for $c \geq 0$ for sufficiently small values of the parameters a and b. The possibility of negative values of $\hat{w}$ in principle allows $\omega^2 = \hat{w} + e/4 < 0$ solutions identifiable as exponentially decaying or amplified perturbations. At the high frequency limit the 4 branches degenerate to a single branch $T^{\alpha\beta}k_\alpha k_\beta = 0$, which as a special case gives light-like four-momenta corresponding to $\omega_0 = 0$ and the origin of the swallowtail catastrophe.

Figure 1.2: Cusp catastrophe. Vertical direction corresponds to the behavior variable and orthogonal directions to control variables.

5. It is quite possible that the imaginary terms proportional to $i\omega_0$ cannot be neglected in the time-like case. The interpretation would be as dissipative effects. If these effects are not too large, an approximate description in terms of butterfly catastrophe makes still sense. Note however that the second variation contains besides gravitational terms potentially large dissipative terms coming from the variation of the induced Kähler form and from the variation of CP_2 Christoffel symbols.

6. Additional complications are encountered at the points, where the induced Kähler field vanishes since the second variation vanishes identically at these points. By the arguments represented earlier, these points quite generally represent instabilities.

1.4 Vacuum extremals

Vacuum extremals come as two basic types: CP_2 type vacuum extremals for which the induced Kähler field and Kähler action are non-vanishing and the extremals for which the induced Kähler field vanishes. The deformations of both extremals are expected to be of fundamental importance in TGD universe. Vacuum extremals are not gravitational vacua and they are indeed fundamental in TGD inspired cosmology.

1.4.1 CP_2 type extremals

CP_2 type vacuum extremals

These extremals correspond to various isometric imbeddings of CP_2 to $M^4_+ \times CP_2$. One can also drill holes to CP_2. Using the coordinates of CP_2 as coordinates for X^4 the imbedding is given by the formula

$$\begin{aligned} m^k &= m^k(u) \ , \\ m_{kl}\dot{m}^k\dot{m}^l &= 0 \ , \end{aligned} \tag{1.4.1}$$

where $u(s^k)$ is an arbitrary function of CP_2 coordinates. The latter condition tells that the curve representing the projection of X^4 to M^4 is light like curve. One can choose the functions $m^i, i = 1, 2, 3$ freely and solve m^0 from the condition expressing light likeness so that the number of this kind of extremals is very large.

The induced metric and Kähler field are just those of CP_2 and energy momentum tensor $T^{\alpha\beta}$ vanishes identically by the self duality of the Kähler form of CP_2. Also the canonical current $j^\alpha = D_\beta J^{\alpha\beta}$ associated with the Kähler form vanishes identically. Therefore the field equations in the interior of X^4 are satisfied. The field equations are also satisfied on the boundary components of CP_2 type extremal because the non-vanishing boundary term is, besides the normal component of Kähler electric field, also proportional to the projection operator to the normal space and vanishes identically since the induced metric and Kähler form are identical with the metric and Kähler form of CP_2.

As a special case one obtains solutions for which M^4 projection is light like geodesic. The projection of $m^0 = constant$ surfaces to CP_2 is $u = constant$ 3-submanifold of CP_2. Geometrically these solutions correspond to a propagation of a massless particle. In a more general case the interpretation as an orbit of a massless particle is not the only possibility. For example, one can imagine a situation, where the center of mass of the particle is at rest and motion occurs along a circle at say (m^1, m^2) plane. The interpretation as a massive particle is natural. Amusingly, there is nice analogy with the classical theory of Dirac electron: massive Dirac fermion moves also with the velocity of light (zitterbewegung). The quantization of this random motion with light velocity leads to Virasoro conditions and this led to a breakthrough in the understanding of the p-adic QFT limit of TGD. Furthermore, it has turned out that Super Virasoro invariance is a general symmetry of the configuration space geometry and quantum TGD and appears both at the level of imbedding space and space-time surfaces.

The action for all extremals is same and given by the Kähler action for the imbedding of CP_2. The value of the action is given by

$$S = -\frac{\pi}{8\alpha_K} . \tag{1.4.2}$$

To derive this expression we have used the result that the value of Lagrangian is constant: $L = 4/R^4$, the volume of CP_2 is $V(CP_2) = \pi^2 R^4/2$ and the definition of the Kähler coupling strength $k_1 = 1/16\pi\alpha_K$ (by definition, πR is the length of CP_2 geodesics). Four-momentum vanishes for these extremals so that they can be regarded as vacuum extremals. The value of the action is negative so that these vacuum extremals are indeed favored by the minimization of the Kähler action. The absolute minimization of Kähler action suggests that ordinary vacuums with vanishing Kähler action density are unstable against the generation of CP_2 type extremals. There are even reasons to expect that CP_2 type extremals are for TGD what black holes are for GRT. Indeed, the nice generalization of the area law for the entropy of black hole [E5] supports this view.

In accordance with the basic ideas of TGD topologically condensed vacuum extremals should somehow correspond to massive particles. The properties of the CP_2 type vacuum extremals are in accordance with this interpretation. Although these objects move with a velocity of light, the motion can be transformed to a mere zitterbewegung so that the center of mass motion is trivial. Even the generation of the rest mass could might be understood classically as a consequence of the minimization of action. Long range Kähler fields generate negative action for the topologically condensed vacuum extremal (momentum zero massless particle) and Kähler field energy in turn is identifiable as the rest mass of the topologically condensed particle.

An interesting feature of these objects is that they can be regarded as gravitational instantons [25]. A further interesting feature of CP_2 type extremals is that they carry nontrivial classical color charges. The possible relationship of this feature to color confinement raises interesting questions. Could one model classically the formation of the color singlets to take place through the emission of "colorons": states with zero momentum but non-vanishing color? Could these peculiar states reflect the infrared properties of the color interactions?

Are CP_2 type non-vacuum extremals possible?

The isometric imbeddings of CP_2 are all vacuum extremals so that these extremals as such cannot correspond to physical particles. One obtains however nonvacuum extremals as deformations of these solutions. There are several types of deformations leading to nonvacuum solutions. In order to describe some of them, recall the expressions of metric and Kähler form of CP_2 in the coordinates (r, Θ, Ψ, Φ) [2] are given by

$$
\begin{aligned}
\frac{ds^2}{R^2} &= \frac{dr^2}{(1+r^2)^2} + \frac{r}{2(1+r^2))^2}(d\Psi + cos(\Theta)d\Phi)^2 \\
&+ \frac{r^2}{(4(1+r^2)}(d\Theta^2 + sin^2\Theta d\Phi^2) \ , \\
J &= \frac{r}{(1+r^2)}dr \wedge (d\Psi + cos(\Theta)d\Phi) \\
&- \frac{r^2}{(2(1+r^2)}sin(\Theta)d\Theta \wedge d\Phi \ .
\end{aligned}
\qquad (1.4.3)
$$

The scaling of the line element is defined so that πR is the length of the CP_2 geodesic line. Note that Φ and Ψ appear as "cyclic" coordinates in metric and Kähler form: this feature plays important role in the solution ansatze to be described.

Let $M^4 = M^2 \times E^2$ denote the decomposition of M^4 to a product of 2-dimensional Minkowski space and 2-dimensional Euclidian plane. This decomposition corresponds physically to the decomposition of momentum degrees of freedom for massless particle: E^2 corresponds to polarization degrees of freedom.

There are several types of nonvacuum extremals.

1. "Virtual particle" extremals: the mass spectrum is continuous (also Euclidian momenta are allowed) but these extremals reduce to vacuum extremals in the massless limit.

2. Massless extremals.

Consider first an example of virtual particle extremal. The simplest extremal of this type is obtained in the following form

$$
m^k = a^k\Psi + b^k\Phi \ . \qquad (1.4.4)
$$

Here a^k and b^k are some constant quantities. Field equations are equivalent to the conditions expressing four-momentum conservation and are identically satisfied the reason being that induced metric and Kähler form do not depend on the coordinates Ψ and Φ.

Extremal describes 3-surface, which moves with constant velocity in M^4. Four-momentum of the solution can be both space and time like. In the massless limit solution however reduces to a vacuum extremal. Therefore the interpretation as an off mass shell massless particle seems appropriate.

Massless extremals are obtained from the following solution ansatz.

$$
\begin{aligned}
m^0 &= m^3 = a\Psi + b\Phi \ , \\
(m^1, m^2) &= (m^1(r,\Theta), m^2(r,\Theta)) \ .
\end{aligned}
\qquad (1.4.5)
$$

Only E^2 degrees of freedom contribute to the induced metric and the line element is obtained from

$$
ds^2 = ds^2_{CP_2} - (dm^1)^2 - (dm^2)^2 \ . \qquad (1.4.6)
$$

Field equations reduce to conservation condition for the componenents of four-momentum in E^2 plane. By their cyclicity the coordinates Ψ and Φ disappear from field equations and one obtains essentially current conservation condition for two-dimensional field theory defined in space spanned by the coordinates r and Θ.

$$
\begin{aligned}
(J^i_a)_{,i} &= 0 \ , \\
J^i_a &= T^{ij} f^a_{,j}\sqrt{g} \ .
\end{aligned}
\qquad (1.4.7)
$$

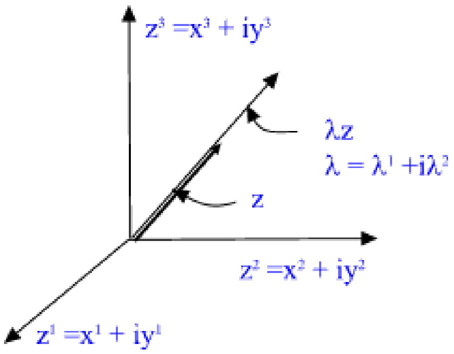

Figure 1.3: Topological sum of CP_2:s as Feynman graph with lines thickened to four-manifolds

Here the index i and a refer to r and Θ and to E^2 coordinates m^1 and m^2 respectively. T^{ij} denotes the canonical energy momentum tensor associated with Kähler action. One can express the components of T^{ij} in terms of induced metric and CP_2 metric in the following form

$$T^{ij} = (-g^{ik}g^{jl} + g^{ij}g^{kl}/2)s_{kl} \ . \quad (1.4.8)$$

This expression holds true for all components of the energy momentum tensor.

Since field equations are essentially two-dimensional conservation conditions they imply that components of momentum currents can be regarded as vector fields of some canonical transformations

$$J_a^i = \varepsilon^{ij}H^a_{,j} \ , \quad (1.4.9)$$

where ε^{ij} denotes two-dimensional constant symplectic form. An open problem is whether one could solve field equations exactly and whether there exists some nonlinear superposition principle for the solutions of these equations. Solutions are massless since transversal momentum densities vanish identically.

Consider as a special case the solution obtained by assuming that one E^2 coordinate is constant and second coordinate is function $f(r)$ of the variable r only. Field equations reduce to the following form

$$f_{,r} = \pm\frac{k}{(1+r^2)^{1/3}}\sqrt{r^2 - k^2(1+r^2)^{4/3}} \ . \quad (1.4.10)$$

The solution is well defined only for sufficiently small values of the parameter k appearing as integration constant and becomes ill defined at two singular values of the variable r. Boundary conditions are identically satisfied at the singular values of r since the radial component of induced metric diverges at these values of r. The result leads to suspect that the generation of boundary components dynamically is a general phenomenon so that all nonvacuum solutions have boundary components in accordance with basic ideas of TGD.

$CP_2\#CP_2\#...\#CP_2$:s as generalized Feynman graphs

There are reasons to believe that point like particles might be identified as CP_2 type extremals in TGD approach. Also the geometric counterparts of the massless on mass shell particles and virtual particles have been identified. It is natural to extend this idea to the level of particle interactions: the lines of Feynman diagrams of quantum field theory are thickened to four-manifolds, which are in a good approximation CP_2 type vacuum extremals. This would mean that generalized Feynman graphs are essentially connected sums of CP_2:s (see Fig. 1.4.1): $X^4 = CP_2\#CP_2....\#CP_2$).

Unfortunately, this picture seems to be oversimplified. First, it is questionable whether the cross sections for the scattering of CP_2 type extremals have anything to do with the cross sections associated with the standard gauge interactions. A naive geometric argument suggests that the cross section should reflect the geometric size of the scattered objects and therefore be of the order of CP_2 radius for topologically non-condensed CP_2 type extremals. The observed cross sections would result at the first level of condensation, where particles are effectively replaced by surfaces with size of order Compton length. Secondly, the $h_{vac} = -D$ rule, considered in the previous chapter, suggests that only real particles correspond to the CP_2 type extremals whereas virtual particles in general correspond to the vacuum extremals with a vanishing Kähler action. The reason is that the negative exponent of the Kähler action reduces the contribution of the CP_2 type extremals to the functional integral very effectively. Therefore the exchanges of CP_2 type extremals are suppressed by the negative exponent of the Kähler action very effectively so that geometric scattering cross section is obtained.

1.4.2 Vacuum extremals with vanishing Kähler field

Vacuum extremals correspond to 4-surfaces with vanishing Kähler field and therefore to gauge field zero configurations of gauge field theory. These surfaces have CP_2 projection, which is Legendre manifold. The condition expressing Legendre manifold property is obtained in the following manner. Kähler potential of CP_2 can be expressed in terms of the canonical coordinates (P_i, Q_i) for CP_2 as

$$A = \sum_k P_k dQ^k \ . \tag{1.4.11}$$

The conditions

$$P_k = \partial_{Q^k} f(Q^i) \ , \tag{1.4.12}$$

where $f(Q^i)$ is arbitrary function of its arguments, guarantee that Kähler potential is pure gauge. It is clear that canonical transformations, which act as local $U(1)$ gauge transformations, transform different vacuum configurations to each other so that vacuum degeneracy is enormous. Also M^4_+ diffeomorphisms act as the dynamical symmetries of the vacuum extremals. Some sub-group of these symmetries extends to the isometry group of the configuration space in the proposed construction of the configuration space metric. The vacuum degeneracy is still enhanced by the fact that the topology of the four-surface is practically free.

Vacuum extremals are certainly not absolute minima of the action. For the induced metric having Minkowski signature the generation of Kähler electric fields lowers the action. For Euclidian signature both electric and magnetic fields tend to reduce the action. Therefore the generation of Euclidian regions of space-time is expected to occur. CP_2 type extremals, identifiable as real (as contrast to virtual) elementary particles, can be indeed regarded as these Euclidian regions.

Particle like vacuum extremals can be classified roughly by the number of the compactified dimensions D having size given by CP_2 length. Thus one has $D_{CP_2} = 3$ for CP_2 type extremals, $D_{CP_2} = 2$ for string like objects, $D_{CP_2} = 1$ for membranes and $D_{CP_2} = 0$ for pieces of M^4. As already mentioned, the rule $h_{vac} = -D$ relating the vacuum weight of the Super Virasoro representation to the number of compactified dimensions of the vacuum extremal is very suggestive. $D < 3$ vacuum extremals would correspond in this picture to virtual particles, whose contribution to the generalized Feynman diagram is not suppressed by the exponential of Kähler action unlike that associated with the virtual CP_2 type lines.

M^4 type vacuum extremals (representable as maps $M^4_+ \to CP_2$ by definition) are also expected to be natural idealizations of the space-time at long length scales obtained by smoothing out small scale topological inhomogenities (particles) and therefore they should correspond to space-time of GRT in a reasonable approximation.

The reason would be "Yin-Yang principle".

1. Consider first the option for which Kähler function corresponds to an absolute minimum of Kähler action. Vacuum functional as an exponent of Kähler function is expected to concentrate on those 3-surfaces for which the Kähler action is non-negative. On the other hand, the

requirement that Kähler action is absolute minimum for the space-time associated with a given 3-surface, tends to make the action negative. Therefore the vacuum functional is expected to differ considerably from zero only for 3-surfaces with a vanishing Kähler action per volume. It could also occur that the degeneracy of 3-surfaces with same large negative action compensates the exponent of Kähler function.

2. If preferred extrema correspond to Kähler calibrations or their duals [E2], Yin-Yang principle is modified to a more local principle. For Kähler calibrations (their duals) the absolute value of action in given region is minimized (maximized). A given region with positive (negative sign) of action density favors Kähler electric (magnetic) fields. In long length scales the average density of Kähler action per four-volume tends to vanish so that Kähler function of the entire universe is expected to be very nearly zero. This regularizes the theory automatically and implies that average Kähler action per volume vanishes. Positive and finite values of Kähler function are of course favored.

In both cases the vanishing of Kähler action per volume in long length scales makes vacuum extremals excellent idealizations for the smoothed out space-time surface. Robertson-Walker cosmologies provide a good example in this respect. As a matter fact the smoothed out space-time is not a mere fictive concept since larger space-time sheets realize it as a essential part of the Universe.

Several absolute minima could be possible and the non-determinism of the vacuum extremals is not expected to be reduced completely. The remaining degeneracy could be even infinite. A good example is provided by the vacuum extremals representable as maps $M^4_+ \rightarrow D^1$, where D^1 is one-dimensional curve of CP_2. This degeneracy could be interpreted as a space-time correlate for the non-determinism of quantum jumps with maximal deterministic regions representing quantum states in a sequence of quantum jumps.

1.5 Non-vacuum extremals

1.5.1 Cosmic strings

Cosmic strings are extremals of type $X^2 \times S^2$, where X^2 is minimal surface in M^4_+ (analogous to the orbit of a bosonic string) and S^2 is the homologically non-trivial geodesic sphere of CP_2. The action of these extremals is positive and thus absolute minima are certainly not in question. One can however consider the possibility that these extremals are building blocks of the absolute minimum space-time surfaces since the absolute minimization of the Kähler action is global rather than a local principle. Cosmic strings can contain also Kähler charged matter in the form of small holes containing elementary particle quantum numbers on their boundaries and the negative Kähler electric action for a topologically condensed cosmic string could cancel the Kähler magnetic action.

The string tension of the cosmic strings is given by

$$T = \frac{1}{8\alpha_K R^2} \simeq .2210^{-6}\frac{1}{G} \ , \tag{1.5.1}$$

where $\alpha_K \simeq \alpha_{em}$ has been used to get the numerical estimate. The string tension is of the same order of magnitude as the string tension of the cosmic strings of GUTs and this leads to the model of the galaxy formation providing a solution to the dark matter puzzle as well as to a model for large voids as caused by the presence of a strongly Kähler charged cosmic string. Cosmic strings play also fundamental role in the TGD inspired very early cosmology.

1.5.2 Massless extremals

Massless extremals (or topological light rays) are characterized by massless wave vector p and polarization vector ε orthogonal to this wave vector. Using the coordinates of M^4 as coordinates for X^4 the solution is given as

$$\begin{aligned}
& s^k = f^k(u,v) \ , \\
& u = p\cdot m \ , \qquad v = \varepsilon\cdot m \ , \\
& p\cdot\varepsilon = 0 \ , \qquad p^2 = 0 \ .
\end{aligned}$$

CP_2 coordinates are arbitrary functions of $p \cdot m$ and $\varepsilon \cdot m$. Clearly these solutions correspond to plane wave solutions of gauge field theories. It is important to notice however that linear super position doesn't hold as it holds in Maxwell phase. Gauge current is proportional to wave vector and its divergence vanishes as a consequence. Also cylindrically symmetric solutions for which the transverse coordinate is replaced with the radial coordinate $\rho = \sqrt{m_1^2 + m_2^2}$ are possible. In fact, v can be *any* function of the coordinates m^1, m^2 transversal to the light like vector p.

Boundary conditions on the boundaries of the massless extremal are satisfied provided the normal component of the energy momentum tensor vanishes. Since energy momentum tensor is of the form $T^{\alpha\beta} \propto p^\alpha p^\beta$ the conditions $T^{n\beta} = 0$ are satisfied if the M^4 projection of the boundary is given by the equations of form

$$\begin{aligned} &H(p \cdot m, \varepsilon \cdot m, \varepsilon_1 \cdot m) = 0 \ , \\ &\qquad \varepsilon \cdot p = 0 \ , \qquad \varepsilon_1 \cdot p = 0 \ , \quad \varepsilon \cdot \varepsilon_1 = 0 \ . \end{aligned} \tag{1.5.2}$$

where H is arbitrary function of its arguments. Recall that for M^4 type extremals the boundary conditions are also satisfied if Kähler field vanishes identically on the boundary.

The following argument suggests that there are not very many manners to satisfy boundary conditions in case of M^4 type extremals. The boundary conditions, when applied to M^4 coordinates imply the vanishing of the normal component of energy momentum tensor. Using coordinates, where energy momentum tensor is diagonal, the requirement boils down to the condition that at least one of the eigen values of $T^{\alpha\beta}$ vanishes so that the determinant $det(T^{\alpha\beta})$ must vanish on the boundary: this condition defines 3-dimensional surface in X^4. In addition, the normal of this surface must have same direction as the eigen vector associated with the vanishing eigen value: this means that three additional conditions must be satisfied and this is in general true in single point only. The boundary conditions in CP_2 coordinates are satisfied provided that the conditions

$$J^{n\beta} J^k_{\ l} \partial_\beta s^l = 0$$

are satisfied. The identical vanishing of the normal components of Kähler electric and magnetic fields on the boundary of massless extremal property provides a manner to satisfy all boundary conditions but it is not clear whether there are any other manners to satisfy them.

The characteristic feature of the massless extremals is that in general the Kähler gauge current is non-vanishing. In ordinary Maxwell electrodynamcis this is not possible. This means that these extremals are accompanied by vacuum current, which contains in general case both weak and electromagnetic terms as well as color part.

A possible interpretation of the solution is as the exterior space-time to a topologically condensed particle with vanishing mass described by massless CP_2 type extremal, say photon or neutrino. In general the surfaces in question have boundaries since the coordinates s^k are are bounded: this is in accordance with the general ideas about topological condensation. The fact that massless plane wave is associated with CP_2 type extremal combines neatly the wave and particle aspects at geometrical level.

The fractal hierarchy of space-time sheets implies that massless extremals should interesting also in long length scales. The presence of a light like electromagnetic vacuum current implies the generation of coherent photons and also coherent gravitons are generated since the Einstein tensor is also non-vanishing and light like (proportional to $k^\alpha k^\beta$). Massless extremals play an important role in the TGD based model of bio-system as a macroscopic quantum system. The possibility of vacuum currents is what makes possible the generation of the highly desired coherent photon states.

1.5.3 Generalization of the solution ansatz defining massless extremals (MEs)

The solution ansatz for MEs has developed gradually to an increasingly general form and the following formulation is the most general one achieved hitherto. Rather remarkably, it rather closely resembles the solution ansatz for the CP_2 type extremals and has direct interpretation in terms of geometric optics. Equally remarkable is that the latest generalization based on the introduction of the local light cone coordinates was inspired by quantum holography principle.

The solution ansatz for MEs has developed gradually to an increasingly general form and the following formulation is the most general one achieved hitherto. Rather remarkably, it rather closely resembles the solution ansatz for the CP_2 type extremals and has direct interpretation in terms of geometric optics. Equally remarkable is that the latest generalization based on the introduction of the local light cone coordinates was inspired by quantum holography principle.

Local light cone coordinates

The solution involves a decomposition of M^4_+ tangent space localizing the decomposition of Minkowski space to an orthogonal direct sum $M^2 \oplus E^2$ defined by light-like wave vector and polarization vector orthogonal to it. This decomposition defines what might be called local light cone coordinates.

1. Denote by m^i the linear Minkowski coordinates of M^4. Let (S^+, S^-, E^1, E^2) denote local coordinates of M^4_+ defining a *local* decomposition of the tangent space M^4 of M^4_+ into a direct *orthogonal* sum $M^4 = M^2 \oplus E^2$ of spaces M^2 and E^2. This decomposition has interpretation in terms of the longitudinal and transversal degrees of freedom defined by local light-like four-velocities $v_\pm = \nabla S_\pm$ and polarization vectors $\epsilon_i = \nabla E^i$ assignable to light ray.

2. With these assumptions the coordinates $(S_\pm, E^i)$ define local light cone coordinates with the metric element having the form

$$ds^2 = 2g_{+-}dS^+dS^- + g_{11}(dE^1)^2 + g_{22}(dE^2)^2 \quad . \tag{1.5.3}$$

   If complex coordinates are used in transversal degrees of freedom one has $g_{11} = g_{22}$.

3. This family of light cone coordinates is not the most general family since longitudinal and transversal spaces are orthogonal. One can also consider light-cone coordinates for which one non-diagonal component, say m_{1+}, is non-vanishing if the solution ansatz is such that longitudinal and transversal spaces are orthogonal for the induced metric.

A conformally invariant family of local light cone coordinates

The simplest solutions to the equations defining local light cone coordinates are of form $S_\pm = k \cdot m$ giving as a special case $S_\pm = m^0 \pm m^3$. For more general solutions of from

$$S_\pm = m^0 \pm f(m^1, m^2, m^3) \ , \ (\nabla_3 f)^2 = 1 \ ,$$

where f is an otherwise arbitrary function, this relationship reads as

$$S^+ + S^- = 2m^0 \ .$$

This condition defines a natural rest frame. One can integrate f from its initial data at some two-dimensional $f = constant$ surface and solution describes curvilinear light rays emanating from this surface and orthogonal to it. The flow velocity field $\overline{v} = \nabla f$ is irrotational so that closed flow lines are not possible in a connected region of space and the condition $\overline{v}^2 = 1$ excludes also closed flow line configuration with singularity at origin such as $v = 1/\rho$ rotational flow around axis.

One can identify E^2 as a local tangent space spanned by polarization vectors and orthogonal to the flow lines of the velocity field $\overline{v} = \nabla f(m^1, m^2, m^3)$. Since the metric tensor of any 3-dimensional space allows always diagonalization in suitable coordinates, one can always find coordinates (E^1, E^2) such that (f, E^1, E^2) form orthogonal coordinates for $m^0 = constant$ hyperplane. Obviously one can select the coordinates E^1 and E^2 in infinitely many manners.

Closer inspection of the conditions defining local light cone coordinates

Whether the conformal transforms of the local light cone coordinates $\{S_\pm = m^0 \pm f(m^1, m^2, m^3), E^i\}$ define the only possible compositions $M^2 \oplus E^2$ with the required properties, remains an open question. The best that one might hope is that any function S^+ defining a family of light-like curves defines a local decomposition $M^4 = M^2 \oplus E^2$ with required properties.

1. Suppose that S^+ and S^- define light-like vector fields which are not orthogonal (proportional to each other). Suppose that the polarization vector fields $\epsilon_i = \nabla E^i$ tangential to local E^2 satisfy the conditions $\epsilon_i \cdot \nabla S^+ = 0$. One can formally integrate the functions E^i from these condition since the initial values of E^i are given at $m^0 = constant$ slice.

2. The solution to the condition $\nabla S_+ \cdot \epsilon_i = 0$ is determined only modulo the replacement

$$\epsilon_i \rightarrow \hat{\epsilon}_i = \epsilon_i + k\nabla S_+ \ ,$$

where k is any function. With the choice

$$k = -\frac{\nabla E^i \cdot \nabla S^-}{\nabla S^+ \cdot \nabla S^-}$$

one can satisfy also the condition $\hat{\epsilon}_i \cdot \nabla S^- = 0$.

3. The requirement that also $\hat{\epsilon}_i$ is gradient is satisfied if the integrability condition

$$k = k(S^+)$$

is satisfied: in this case $\hat{\epsilon}_i$ is obtained by a gauge transformation from ϵ_i. The integrability condition can be regarded as an additional, and obviously very strong, condition for S^- once S^+ and E^i are known.

4. The problem boils down to that of finding local momentum and polarization directions defined by the functions S^+, S^- and E^1 and E^2 satisfying the orthogonality and integrability conditions

$$\begin{array}{ll} (\nabla S^+)^2 = (\nabla S^-)^2 = 0 \ , & \nabla S^+ \cdot \nabla S^- \neq 0 \ , \\ \nabla S^+ \cdot \nabla E^i = 0 \ , & \frac{\nabla E^i \cdot \nabla S^-}{\nabla S^+ \cdot \nabla S^-} = k_i(S^+) \ . \end{array}$$

The number of integrability conditions is 3+3 (all derivatives of k_i except the one with respect to S^+ vanish): thus it seems that there are not much hopes of finding a solution unless some discrete symmetry relating S^+ and S^- eliminates the integrability conditions altogether.

A generalization of the spatial reflection $f \rightarrow -f$ working for the separable Hamilton Jacobi function $S_\pm = m^0 \pm f$ ansatz could relate S^+ and S^- to each other and trivialize the integrability conditions. The symmetry transformation of M^4_+ must perform the permutation $S^+ \leftrightarrow S^-$, preserve the light-likeness property, map E^2 to E^2, and multiply the inner products between M^2 and E^2 vectors by a mere conformal factor. This encourages the conjecture that all solutions are obtained by conformal transformations from the solutions $S_\pm = m^0 \pm f$.

General solution ansatz for MEs for given choice of local light cone coordinates

Consider now the general solution ansatz assuming that a local wave-vector-polarization decomposition of M^4_+ tangent space has been found.

1. Let $E(S^+, E^1, E^2)$ be an arbitrary function of its arguments: the gradient ∇E defines at each point of E^2 an S^+-dependent (and thus time dependent) polarization direction orthogonal to the direction of local wave vector defined by ∇S^+. Polarization vector depends on E^2 position only.

2. Quite a general family of MEs corresponds to the solution family of the field equations having the general form

$$s^k = f^k(S^+, E) \ ,$$

where s^k denotes CP_2 coordinates and f^k is an arbitrary function of S^+ and E. The solution represents a wave propagating with light velocity and having definite S^+ dependent polarization in the direction of ∇E. By replacing S^+ with S^- one obtains a dual solution. Field equations are satisfied because energy momentum tensor and Kähler current are light-like so that all tensor contractions involved with the field equations vanish: the orthogonality of M^2 and E^2 is essential for the light-likeness of energy momentum tensor and Kähler current.

3. The simplest solutions of the form $S_\pm = m^0 \pm m^3$, $(E^1, E^2) = (m^1, m^2)$ and correspond to a cylindrical MEs representing waves propagating in the direction of the cylinder axis with light velocity and having polarization which depends on point (E^1, E^2) and S^+ (and thus time). For these solutions four-momentum is light-like: for more general solutions this cannot be the case. Polarization is in general case time dependent so that both linearly and circularly polarized waves are possible. If m^3 varies in a finite range of length L, then 'free' solution represents geometrically a cylinder of length L moving with a light velocity. Of course, ends could be also anchored to the emitting or absorbing space-time surfaces.

4. For the general solution the cylinder is replaced by a three-dimensional family of light like curves and in this case the rectilinear motion of the ends of the cylinder is replaced with a curvilinear motion with light velocity unless the ends are anchored to emitting/absorbing space-time surfaces. The non-rotational character of the velocity flow suggests that the freely moving particle like 3-surface defined by ME cannot remain in a infinite spatial volume. The most general ansatz for MEs should be useful in the intermediate and nearby regions of a radiating object whereas in the far away region radiation solution is excepted to decompose to cylindrical ray like MEs for which the function $f(m^1, m^2, m^2)$ is a linear function of m^i.

5. One can try to generalize the solution ansatz further by allowing the metric of M^4_+ to have components of type g_{i+} or g_{i-} in the light cone coordinates used. The vanishing of T^{11}, T^{+1}, and T^{--} is achieved if $g_{i\pm} = 0$ holds true for the induced metric. For $s^k = s^k(S^+, E^1)$ ansatz neither $g_{2\pm}$ nor g_{1-} is affected by the imbedding so that these components of the metric must vanish for the Hamilton Jacobi structure:

$$ds^2 = 2g_{+-}dS^+dS^- + 2g_{1+}dE^1dS^+ + g_{11}(dE^1)^2 + g_{22}(dE^2)^2 \quad . \tag{1.5.4}$$

$g_{1+} = 0$ can be achieved by an additional condition

$$m_{1+} = s_{kl}\partial_1 s^k \partial_+ s^k \quad . \tag{1.5.5}$$

The diagonalization of the metric seems to be a general aspect of absolute minima. The absence of metric correlations between space-time degrees of freedom for asymptotic self-organization patterns is somewhat analogous to the minimization of non-bound entanglement in the final state of the quantum jump.

Are the boundaries of space-time sheets quite generally light like surfaces with Hamilton Jacobi structure?

Quantum holography principle naturally generalizes to an approximate principle expected to hold true also in non-cosmological length and time scales.

1. The most general ansatz for topological light rays or massless extremals (MEs) inspired by the quantum holographic thinking relies on the introduction of the notion of local light cone coordinates S_+, S_-, E_1, E_2. The gradients ∇S_+ and ∇S_- define two light like directions just like Hamilton Jacobi functions define the direction of propagation of wave in geometric optics. The two polarization vector fields ∇E_1 and ∇E_2 are orthogonal to the direction of propagation defined by either S_+ or S_-. Since also E_1 and E_2 can be chosen to be orthogonal, the metric of M^4_+ can be written locally as $ds^2 = g_{+-}dS_+dS_- + g_{11}dE_1^2 + g_{22}dE_2^2$. In the earlier ansatz S_+ and S_- where restricted to the variables $k \cdot m$ and $\tilde{k} \cdot m$, where k and $\tilde{k}$ correspond to light like momentum and its mirror image and m denotes linear M^4 coordinates: these MEs describe cylindrical structures with constant direction of wave propagation expected to be most important in regions faraway from the source of radiation.

2. Boundary conditions are satisfied if the 3-dimensional boundaries of MEs have one light like direction (S_+ or S_- is constant). This means that the boundary of ME has metric dimension $d = 2$ and is characterized by an infinite-dimensional super-symplectic and super-conformal symmetries just like the boundary of the imbedding space $M^4_+ \times CP_2$: The boundaries are like moments for mini big bangs (in TGD based fractal cosmology big bang is replaced with a silent whisper amplified to not necessarily so big bang).

3. These observations inspire the conjecture that boundary conditions for M^4 like space-time sheets fixed by the absolute minimization of Kähler action quite generally require that space-time boundaries correspond to light like 3-surfaces with metric dimension equal to $d = 2$. This does not yet imply that light like surfaces of imbedding space would take the role of the light cone boundary: these light like surface could be seen only as a special case of causal determinants analogous to event horizons.

1.5.4 Maxwell phase

"Maxwell phase" corresponds to small deformations of the M^4 type vacuum extremals. Since energy momentum tensor is quadratic in Kähler field the term proportional to the contraction of the energy momentum tensor with second fundamental form drops from field equations and one obtains in lowest order the following field equations

$$j^\alpha J^k_{\ l} s^l_{,\alpha} = 0 \ . \tag{1.5.6}$$

These equations are satisfied if Maxwell's equations

$$j^\alpha = 0 \tag{1.5.7}$$

hold true. Massless extremals and Maxwell phase clearly exclude each other and it seems that they must corresponds to different space-time sheets.

The explicit construction of these extremals reduces to the task of finding an imbedding for an arbitrary free Maxwell field to H. One can also allow source terms corresponding to the presence of the point like charges: these should correspond to the regions of the space-time, where the flat space-time approximation of the space-time fails. The regions where the approximation defining the Maxwell phase fails might correspond to a topologically condensed CP_2 type extremals, for example. As a consequence, Kähler field is superposition of radiation type Kähler field and of Coulombic term. A second possibility is the generation of "hole" with similar Coulombic Kähler field.

An important property of the Maxwell phase (also of massless extremals) is its approximate canonical invariance. Canonical transformations do not spoil the extremal property of the four-surface in the approximation used, since it corresponds to a mere $U(1)$ gauge transformation. This implies the counter part of the vacuum degeneracy, that is, the existence of an enormous number of four-surfaces with very nearly the same action. Also there is an approximate $Diff(M^4_+)$ invariance.

The canonical degeneracy has some very interesting consequences concerning the understanding of the electro-weak symmetry breaking and color confinement. Kähler field is canonical invariant and satisfies Maxwells equations. This is in accordance with the identification of Kähler field as $U(1)$ part of the electro-weak gauge field. Electromagnetic gauge field is a superposition of Kähler field and Z^0 field: $\gamma = 3J - sin^2(\theta_W)Z^0/2$ so that also electromagnetic gauge field is long ranged assuming that Z^0 and W^+ fields are short ranged. These fields are not canonical invariants and their behavior seems to be essentially random, which implies short range correlations and the consequent massivation.

There is an objection against this argument. For the known $D < 4$ solutions of field equations weak fields are not random at all. These situations could represent asymptotic configurations assignable to space-time sheets. This conforms with the interpretation that weak gauge fields are essentially massless within the asymptotic space-time sheets representing weak bosons. Gauge fields are however transferred between space-time sheets through # contacts modelable as pieces of CP_2 type extremals having $D_{CP_2} = 4$. In contrast to Kähler and color gauge fluxes, weak gauge fluxes are not conserved in the Euclidian time evolution between the 3-D causal horizons separating the Euclidian # contact from space-time sheets with Minkowskian signature. This non-conservation implying the loss of coherence in the transfer of fields between space-time sheets is a plausible mechanism for the loss of correlations and massivation of the weak gauge fields.

Classical gluon fields are proportional to Kähler field and to the Hamiltonians associated with the color isometry generators.

$$g^A_{\alpha\beta} = kH^A J_{\alpha\beta} \ . \tag{1.5.8}$$

This implies that the direction of gluon fields in color algebra is random. One can always perform a canonical transformation, which reduces to a global color rotation in some arbitrary small region of space-time and reduces to identity outside this region. The proportionality of a gluon field to Kähler form implies that there is a classical long range correlation in X^4 degrees of freedom: in this sense classical gluon fields differ from massive electro-weak fields in Maxwell phase.

1.5.5 Stationary, spherically symmetric extremals

The stationary, spherically symmetric extremals of the Kähler action imbeddable in $M^4 \times S^2$, where S^2 is geodesic sphere, are the simplest extremals, which one can study as models for the space-time surrounding a topologically condensed particle, say CP_2 type vacuum extremal. In the region near the particle the spherical symmetry is an unrealistic assumption since it excludes the presence of magnetic fields needed to cancel the total Kähler action. The stationarity is also unrealistic assumption since zitterbewegung seems to provide a necessary mechanism for generating Kähler magnetic field and for satisfying boundary conditions. Also the imbeddability to $M^4 \times S^2$ implies unrealistic relationship between Z^0 and photon charges.

According to the general wisdom, the generation of a Kähler electric field must take place in order to minimize the action and it indeed turns out that the extremal is characterized by essentially $1/r^2$ Kähler electric field. The necessary presence of a hole or of a topologically condensed object is also demonstrated: it is impossible to find extremals well defined in the region surrounding the origin. It is impossible to satisfy boundary conditions at a hole: this is in accordance with the idea that Euclidian region corresponding to a CP_2 type extremal performing zitterbewegung is generated. In case of CP_2 extremal radius is of the order of the Compton length of the particle and in case of a "hole" of the order of Planck length. The value of the vacuum frequency ω is of order of particle mass whereas for macroscopic vacuum extremals it must be of the order of $1/R$. This does not lead to a contradiction if the concept of a many-sheeted space-time is accepted.

The Poincare energy of the exterior region is considerably smaller than the gravitational mass; this conforms with the interpretation that gravitational mass is sum of absolute values of positive and negative inertial masses associated with matter and negative energy antimatter. It is quite possible that classical considerations cannot provide much understanding concerning the inertial masses of topologically condensed particles. Electro-weak gauge forces are considerably weaker than the gravitational force at large distances, when the value of the frequency parameter ω is of order $1/R$. Both these desirable properties fail to be true if CP_2 radius is of order Planck length as believed earlier.

In light of the general ideas about topological condensation it is clear that in planetary length scales these kind of extremals cannot provide a realistic description of space-time. Indeed, spherically symmetric extremals predict a wrong rate for the precession of the perihelion of Mercury. Scwhartschild and Reissner-Nordström metric do this and indeed allow imbedding as vacuum extremals for which the inertial masses of positive energy matter and negative energy antimatter sum up to zero.

This does not yet resolve the interpretational challenge due to the unavoidable long range color and weak gauge fields. A dark matter hierarchy giving rise to a hierarchy of color and electro-weak physics characterized by increasing values of weak and confinement scales explains these fields. # contacts involve a pair of causal horizons at which the Euclidian metric signature of # contact transforms to Minkowskian one. These causal horizons have interpretation as partons so that # contact can be regarded as a bound state of partons bound together by a gravitational instanton (CP_2 type extremal). # contacts provide basic example of dark matter creating long ranged weak fields.

An important result is the correlation between the sign of the vacuum frequency ω and that of the Kähler charge, which is of opposite sign for fermions and anti-fermions. This suggests an explanation for matter-antimatter asymmetry. Matter and antimatter condense stably on disjoint regions of the space-time surface at different space-time sheets. Stable antimatter could correspond to negative time orientation and negative energy. This leads to a model for the primordial generation of matter as spontaneous generation of zero energy # contacts between space-time sheets of opposite time orientations. If CP conjugation is not exact symmetry, # contacts and their CP conjugates are created with slightly different rates and this gives rise to CP asymmetry at each of the two space-time sheets involved. After the splitting of # contacts and subsequent annihilation of particles and antiparticles at each space-time sheet, the two space-time sheets contain only positive energy matter and negative energy antimatter. This model is developed in more detail in [F6] by applying general number theoretic ideas and p-adic length scale hypothesis.

General solution ansatz

The general form of the solution ansatz is obtained by assuming that the space-time surface in question is a sub-manifold of $M^4 \times S^2$, where S^2 is the homologically non-trivial geodesic sphere of CP_2. S^2 is most conveniently realized as $r = \infty$ surface of CP_2, for which all values of the coordinate Ψ correspond to same point of CP_2 so that one can use Θ and Φ as the coordinates of S^2.

The solution ansatz is given by the expression

$$\begin{aligned} cos(\Theta) &= u(r) \ , \\ \Phi &= \omega t \ , \\ m^0 &= \lambda t \ , \\ r_M &= r \ , \quad \theta_M = \theta \ , \quad \phi_M = \phi \ . \end{aligned} \tag{1.5.9}$$

The induced metric is given by the expression

$$ds^2 = \left[\lambda^2 - \frac{R^2}{4}\omega^2(1-u^2)\right] dt^2 - (1+\frac{R^2}{4}\theta_{,r}^2)dr^2 - r^2 d\Omega^2 \ . \tag{1.5.10}$$

The value of the parameter λ is fixed by the condition $g_{tt}(\infty) = 1$:

$$\lambda^2 - \frac{R^2}{4}\omega^2(1-u(\infty)^2) = 1 \ . \tag{1.5.11}$$

From the condition $e^0 \wedge e^3 = 0$ the non-vanishing components of the induced Kähler field are given by the expression

$$J_{tr} = \frac{\omega}{4}u_{,r} \ . \tag{1.5.12}$$

Geodesic sphere property implies that Z^0 and photon fields are proportional to Kähler field:

$$\begin{aligned} \gamma &= (3-p/2)J \ , \\ Z^0 &= J \ . \end{aligned} \tag{1.5.13}$$

From this formula one obtains the expressions

$$\begin{aligned} Q_{em} &= \frac{(3-p/2)}{4\pi\alpha_{em}}Q_K \ , \quad Q_Z = \frac{1}{4\pi\alpha_Z}Q \ , \\ Q &\equiv \frac{J_{tr}4\pi r^2}{\sqrt{-g_{rr}g_{tt}}} \ . \end{aligned} \tag{1.5.14}$$

for the electromagnetic and Z^0 charges of the solution using e and g_Z as unit.

Field equations can be written as conditions for energy momentum conservation (two equations is in principle all what is needed in the case of geodesic sphere). Energy conservation holds identically true and conservation of momentum, say, in z-direction gives the equation

$$(T^{rr}z_{,r})_{,r} + (T^{\theta\theta}z_{,\theta})_{,\theta} = 0 \ . \tag{1.5.15}$$

Using the explicit expressions for the components of the energy momentum tensor

$$\begin{aligned} T^{rr} &= g^{rr}L/2 \ , \\ T^{\theta\theta} &= -g^{\theta\theta}L/2 \ , \\ L &= g^{tt}g^{rr}(J_{tr})^2\sqrt{g}/2 \ , \end{aligned} \tag{1.5.16}$$

and the following notations

$$\begin{aligned} A &= g^{tt}g^{rr}r^2\sqrt{-g_{tt}g_{rr}} \ , \\ X &\equiv (J_{tr})^2 \ , \end{aligned} \tag{1.5.17}$$

the field equations reduce to the following form

$$(g^{rr}AX)_{,r} - \frac{2AX}{r} = 0 \ . \tag{1.5.18}$$

In the approximation $g^{rr} = 1$ this equation can be readily integrated to give $AX = C/r^2$. Integrating Eq. (1.5.18), one obtains integral equation for X

$$J_{tr} = \frac{q}{r_c}(|g_{rr}|^3 g_{tt})^{1/4} exp(\int_{r_c}^{r} dr\frac{g_{rr}}{r})\frac{1}{r} \ , \tag{1.5.19}$$

where q is integration constant, which is related to the charge parameter of the long range Kähler electric field associated with the solution. r_c denotes the critical radius at which the solution ceases to be well defined.

The inspection of this formula shows that J_{tr} behaves essentially as $1/r^2$ Coulomb field. This behavior doesn't depend on the detailed properties of the solution ansatz (for example the imbeddability to $M^4 \times S^2$): stationarity and spherical symmetry is what matters only. The compactness of CP_2 means that stationary, spherically symmetric solution is not possible in the region containing origin. This is in concordance with the idea that either a hole surrounds the origin or there is a topologically condensed CP_2 extremal performing zitterbewegung near the origin and making the solution non-stationary and breaking spherical symmetry.

Second integration gives the following integral equation for CP_2 coordinate $u = cos(\Theta)$

$$u(r) = u_0 + \frac{4q}{\omega}\int_{r_c}^{r}(-g_{rr}^3 g_{tt})^{1/4}\frac{1}{r}exp(\int_{r_c}^{r} dr\frac{g_{rr}}{r}) \ . \tag{1.5.20}$$

Here u_0 denotes the value of the coordinate u at $r = r_0$.

The form of the field equation suggests a natural iterative procedure for the numerical construction of the solution for large values of r.

$$u_n(r) = T_{n-1} \ , \tag{1.5.21}$$

where T_{n-1} is evaluated using the induced metric associated with u_{n-1}. The physical content of the approximation procedure is clear: estimate the gravitational effects using lower order solution since these are expected to be small.

A more convenient manner to solve u is based on Taylor expansion around the point $V \equiv 1/r = 0$. The coefficients appearing in the power series expansion $u = \sum_n u_n A^n V^n$: $A = q/\omega$ can be solved by calculating successive derivatives of the integral equation for u.

The lowest order solution is simply

$$u_0 = u_\infty \ , \tag{1.5.22}$$

and the corresponding metric is flat metric. In the first order one obtains for $u(r)$ the expression

$$u = u_\infty - \frac{4q}{\omega r} \ , \tag{1.5.23}$$

which expresses the fact that Kähler field behaves essentially as $1/r^2$ Coulomb field. The behavior of u as a function of r is identical with that obtained for the imbedding of the Reissner-Nordström solution.

To study the properties of the solution we fix the signs of the parameters in the following manner:

$$u_\infty < 0 \ , \quad q < 0 \ , \quad \omega > 0 \tag{1.5.24}$$

(reasons become clear later).

Concerning the behavior of the solution one can consider two different cases.

1) The condition $g_{tt} > 0$ hold true for all values of Θ. In this case u decreases and the rate of decrease gets faster for small values of r. This means that in the lowest order the solution becomes certainly ill defined at a critical radius $r = r_c$ given by the the condition $u = 1$: the reason is that u cannot get values large than one. The expression of the critical radius is given by

$$\begin{aligned} r_c &\geq \frac{4q}{(|u_\infty| + 1)\omega} \\ &= \frac{4\alpha Q_{em}}{(3 - p/2)} \frac{1}{(|u_\infty| + 1)\omega} \ . \end{aligned} \tag{1.5.25}$$

The presence of the critical radius for the actual solution is also a necessity as the inspection of the expression for J_{tr} shows: $\partial_r \theta$ grows near the origin without bound and $u = 1$ is reached at some finite value of r. Boundary conditions require that the quantity $X = T^{rr}\sqrt{g}$ vanishes at critical radius (no momentum flows through the boundary). Substituting the expression of J_{tr} from the field equation to T^{rr} the expression for X reduces to a form, from which it is clear that X cannot vanish. The cautious conclusion is that boundary conditions cannot be satisfied and the underlying reason is probably the stationarity and spherical symmetry of the solution. Physical intuition suggests that that CP_2 type extremal performing zitterbewegung is needed to satisfy the boundary conditions.

2) g_{tt} vanishes for some value of Θ. In this case the radial derivative of u together with g_{tt} can become zero for some value of $r = r_c$. Boundary conditions can be satisfied only provided $r_c = 0$. Thus it seems that for the values of ω satisfying the condition $\omega^2 = \frac{4\lambda^2}{R^2 sin^2(\Theta_0)}$ it might be possible to find a globally defined solution. The study of differential equation for u however shows that the ansatz doesn't work. The conclusion is that although the boundary is generated it is not possible to satisfy boundary conditions.

A direct calculation of the coefficients u_n from power series expansion gives the following third order polynomial approximation for u ($V = 1/r$)

$$\begin{aligned} u &= \sum_n u_n A^n V^n \ , \\ u_0 &= u_\infty (< 0) \ , \quad u_1 = 1 \ , \\ u_2 &= K|u_\infty| \ , \quad u_3 = K(1 + 4K|u_\infty|) \ , \\ A &\equiv \frac{4q}{\omega} \ , \quad K \equiv \omega^2 \frac{R^2}{4} \ . \end{aligned} \tag{1.5.26}$$

The coefficients u_2 and u_3 are indeed positive which means that the value of the critical radius gets larger at least in these orders.

Solution contains three parameters: Kähler electric flux $Q = 4\pi q$, parameter ωR and parameter u_∞. The latter parameters can be regarded as parameters describing the properties of a flat vacuum extremal (lowest order solution) to which particle like solution is glued and are analogous to the parameters describing symmetry broken vacuum in gauge theories.

Solution is not a realistic model for topological condensation

The solution does not provide realistic model for topological condensation although it gives indirect support for some essential assumptions of TGD based description of Higgs mechanism.

1. When the value of ω is of the order of CP_2 mass the solution could be interpreted as the "exterior metric" of a "hole".
   i) The radius of the hole is of the order of CP_2 length and its mass is of the order of CP_2 mass.
   ii) Kähler electric field is generated and charge renormalization takes place classically at CP_2 length scales as is clear from the expression of $Q(r)$: $Q(r) \propto (\frac{-g_{rr}}{g_{tt}})^{1/4}$ and charge increases at short distances.
   iii) The existence of the critical radius is unavoidable but boundary conditions cannot be satisfied. The failure to satisfy boundary conditions might be related to stationarity or to the absence of magnetic field. The motion of the boundary component with velocity of light might be the only manner to satisfy boundary conditions. Second possibility is the breaking of spherical symmetry by the generation of a static magnetic field.
   iv) The absence of the Kähler magnetic field implies that the Kähler action has an infinite magnitude and the probability of the configuration is zero. A more realistic solution ansatz would break spherical symmetry containing dipole type magnetic field in the nearby region of the hole. The motion of the boundary with a velocity of light could serves as an alternative mechanism for the generation of magnetic field. The third possibility, supported by physical intuition, is that one must give up "hole" type extremal totally.

2. For sufficiently large values of r and for small values of ω (of the order of elementary particle mass scale), the solution might provide an approximate description for the region surrounding elementary particle. Although it is not possible to satisfy boundary conditions the order of magnitude estimate for the size of critical radius ($r_c \simeq \alpha/\omega$) should hold true for more realistic solutions, too. The order of magnitude for the critical radius is smaller than Compton length or larger if the vacuum parameter ω is larger than the mass of the particle. In macroscopic length scales the value of ω is of order $1/R$. This does not lead to a contradiction if the many-sheeted space-time concept is accepted so that $\omega < m$ corresponds to elementary particle space-time sheet. An unrealistic feature of the solution is that the relationship between Z^0 and em charges is not correct: Z^0 charge should be very small in these length scales.

Exterior solution cannot be identified as a counter part of Schwartshild solution

The first thing, which comes into mind is to ask whether one might identify exterior solution as the TGD counterpart of the Schwartshild solution. The identification of gravitational mass as absolute value of inertial mass which is negative for antimatter implies that vacuum extremals are vacua only with respect to the inertial four-momentum and have a non-vanishing gravitational four-momentum. Hence, in the approximation that the net density of inertial mass vanishes, vacuum extremals provide the proper manner to model matter, and the identification of spherically symmetric extremal as the counterpart of Scwhartschild metric is certainly not possible. It is however useful to show explicitly that the identification is indeed unrealistic. The solution is consistent with Equivalence Principle but the electro-weak gauge forces are considerably weaker than gravitational forces. A wrong perihelion shift is also predicted so that the identification as an exterior metric of macroscopic objects is out of question.

1. Is Equivalence Principle respected?

TGD predicts the possibility of negative classical energy for space-time sheets with negative time orientation, and the only manner to second quantize induced spinor fields without diverging vacuum energy is by assuming that fermions have positive energies and anti-fermions negative energies (vice versa for phase conjugate fermions). This modifies the original form of Equivalence Principle: gravitational mass can be interpreted as absolute value of inertial mass so that the density of gravitational mass becomes the difference of densities of inertial mass for matter and antimatter (or vice versa). This interpretation leads to an elegant solution of the basic interpretational difficulties created by the conservation of inertial four-momentum and non-conservation of gravitational four-momentum.

The gravitational mass of the solution is determined from the asymptotic behavior of g_{tt} and is given by

$$M_{gr} = \frac{R^2}{G}\omega q u_\infty \ , \tag{1.5.27}$$

and is proportional to the Kähler charge q of the solution.

One can estimate the gravitational mass density also by applying Newtonian approximation to the time component of the metric $g_{tt} = 1 - 2\Phi_{gr}$. One obtains Φ_{gr} corresponds in the lowest order approximation to a solution of Einstein's equations with the source consisting of a mass point at origin and the energy density of the Kähler electric field. The effective value of gravitational constant is however $G_{eg} = 8R^2\alpha_K$. Thus the only sensible interpretation is that the density of Kähler (inertial) energy is only a fraction $G/G_{eq} \equiv \epsilon \simeq .22 \times 10^{-6}$ of the density of gravitational mass. Hence the densities of positive energy matter and negative energy antimatter cancel each other in a good approximation.

The work with cosmic strings lead to a possible interpretation of the solution as a space-time sheet containing topologically condensed magnetic flux tube idealizable as a point. The negative Kähler electric action must cancel the positive Kähler magnetic action. The resulting structure in turn can condense to a vacuum extremal and Schwartshild metric is a good approximation for the metric.

One can estimate the contribution of the exterior region ($r > r_c$) to the inertial mass of the system and Equivalence principle requires this to be a fraction of order ϵ about the gravitational mass unless the region $r < r_c$ contains negative inertial mass density, which is of course quite possible. Approximating the metric with a flat metric and using first order approximation for $u(r)$ the energy reduces just to the standard Coulomb energy of charged sphere with radius r_c

$$\begin{aligned} M_I(ext) &= \frac{1}{32\pi\alpha_K}\int_{r>r_c} E^2\sqrt{g}d^3x \\ &\simeq \frac{\lambda q^2}{2\alpha_K r_c} \ , \\ \lambda &= \sqrt{1+\frac{R^2}{4}\omega^2(1-u_\infty^2)}\ (>1) \ . \end{aligned} \tag{1.5.28}$$

Approximating the metric with flat metric the contribution of the region $r > r_c$ to the energy of the solution is given by

$$M_I(ext) = \frac{1}{8\alpha_K}\lambda q\omega(1+|u_\infty|) \ . \tag{1.5.29}$$

The contribution is proportional to Kähler charge as expected. The ratio of external inertial and gravitational masses is given by the expression

$$\begin{aligned} \frac{M_I(ext)}{M_{gr}} &= \frac{G}{4R^2\alpha_K}x \ , \\ x &= \frac{(1+|u_\infty|)}{|u_\infty|} > 1 \ . \end{aligned} \tag{1.5.30}$$

In the approximation used the the ratio of external inertial and gravitational masses is of order 10^{-6} for $R \sim 10^4\sqrt{G}$ implied by the p-adic length scale hypothesis and for $x \sim 1$. The result conforms with the above discussed interpretation.

2. Z^0 and electromagnetic forces are much weaker than gravitational force

The extremal in question carries Kähler charge and therefore also Z^0 and electromagnetic charge. This implies long range gauge interactions, which ought to be weaker than gravitational interaction in the astrophysical scales. This is indeed the case as the following argument shows.

Expressing the Kähler charge using Planck mass as unit and using the relationships between gauge fields one obtains a direct measure for the strength of the Z^0 force as compared with the strength of gravitational force.

$$Q_Z \equiv \varepsilon_Z M_{gr}\sqrt{G} \ . \tag{1.5.31}$$

The value of the parameter ε_Z should be smaller than one. A transparent form for this condition is obtained, when one writes $\Phi = \omega t = \Omega m^0 : \Omega = \lambda\omega$:

$$\varepsilon_Z = \frac{\alpha_K}{\alpha_Z}\frac{1}{\pi(1+|u_\infty|)\Omega R}\sqrt{\frac{G}{R}} \ . \tag{1.5.32}$$

The order of magnitude is determined by the values of the parameters $\sqrt{\frac{G}{R^2}} \sim 10^{-4}$ and ΩR. Global Minkowskian signature of the induced metric implies the condition $\Omega R < 2$ for the allowed values of the parameter ΩR. In macroscopic length scales one has $\Omega R \sim 1$ so that Z^0 force is by a factor of order 10^{-4} weaker than gravitational force. In elementary particle length scales with $\omega \sim m$ situation is completely different as expected.

3. The shift of the perihelion is predicted incorrectly

The g_{rr} component of Reissner-Nordström and TGD metrics are given by the expressions

$$g_{rr} = -\frac{1}{(1-\frac{2GM}{r})} \ , \tag{1.5.33}$$

and

$$g_{rr} \simeq 1 - \frac{\frac{Rq}{\omega^2}}{\left[1-(u_\infty - \frac{4q}{\omega r})^2\right] r^4} \ , \tag{1.5.34}$$

respectively. For reasonable values of q, ω and u_∞ the this terms is extremely small as compared with $1/r$ term so that these expressions differ by $1/r$ term.

The absence of the $1/r$ term from g_{rr}-component of the metric predicts that the shift of the perihelion for elliptic plane orbits is about $2/3$ times that predicted by GRT so that the identification as a metric associated with objects of a planetary scale leads to an experimental contradiction. Reissner-Nordström solutions are obtained as vacuum extremals so that standard predictions of GRT are obtained for the planetary motion.

One might hope that the generalization of the form of the spherically symmetric ansatz by introducing the same modification as needed for the imbedding of Reissner-Nordstrm̈ metric might help. The modification would read as

$$\begin{aligned} cos(\Theta) &= u(r) \ , \\ \Phi &= \omega t + f(r) \ , \\ m^0 &= \lambda t + h(r) \ , \\ r_M &= r \ , \quad \theta_M = \theta \ , \quad \phi_M = \phi \ . \end{aligned} \tag{1.5.35}$$

The vanishing of the g_{tr} component of the metric gives the condition

$$\lambda \partial_r h - \frac{R^2}{4} sin^2(\Theta)\omega \partial_r f \quad = \quad 0 \ . \qquad (1.5.36)$$

The expression for the radial component of the metric transforms to

$$g_{rr} \quad \simeq \quad \partial_r h^2 - 1 - \frac{R^2}{4}(\partial_r \Theta)^2 - \frac{R^2}{4} sin^2(\Theta)\partial_r f^2 \ , \qquad (1.5.37)$$

Essentially the same perihelion shift as for Schwartschild metric is obtained if g_{rr} approaches asymptotically to its expression for Schwartschild metric. This is guaranteed if the following conditions hold true:

$$f(r)_{r\rightarrow\infty} \rightarrow \omega r \ , \ \Lambda^2 - 1 = \frac{R^2\omega^2}{4} sin^2(\Theta_\infty) \ll \frac{2GM}{\langle r \rangle} \ . \qquad (1.5.38)$$

In the second equation $\langle r \rangle$ corresponds to the average radius of the planetary orbit.

The field equations for this ansatz can be written as conditions for energy momentum and color charge conservation. Two equations are enough to determine the functions $\Theta(r)$ and $f(r)$. The equation for momentum conservation is same as before. Second field equation corresponds to the conserved isometry current associated with the color isometry $\Phi \rightarrow \Phi + \epsilon$ and gives equation for f.

$$[T^{rr} f_{,r} s_{\Phi\Phi} \sqrt{g}]_{,r} \quad = \quad 0 \ . \qquad (1.5.39)$$

The conservation laws associated with other infinitesimal $SU(2)$ rotations of S^2_I should be satisfied identically. This equation can be readily integrated to give

$$T^{rr} f_{,r} s_{\Phi\Phi} \sqrt{g_{tt}g_{rr}} \quad = \quad \frac{C}{r^2} \ . \qquad (1.5.40)$$

Unfortunately, the result is inconsistent with the $1/r^4$ behavior of T^{rr} and $f \rightarrow \omega r$ implies by correct red shift.

It seems that the only possible way out of the difficulty is to replace spherical symmetry with a symmetry with respect to the rotations around z-axis. The simplest modification of the solution ansatz is as follows:

$$m^0 = \lambda t + h(\rho) \ , \quad \Phi = \omega t + k\rho \quad .$$

Thanks to the linear dependence of Φ on ρ, the conservation laws for momentum and color isospin reduce to the same condition. The ansatz induces a small breaking of spherical symmetry by adding to $g_{\rho\rho}$ the term

$$(\partial_\rho h)^2 - \frac{R^2}{4} sin^2(\Theta)k^2 \ .$$

One might hope that in the plane $\theta = \pi/2$, where $r = \rho$ holds true, the ansatz could behave like Schwartschild metric if the conditions discussed above are posed (including the condition $k = \omega$). The breaking of the spherical symmetry in the planetary system would be coded already to the gravitational field of Sun.

Also the study of the imbeddings of Reissner-Nordström metric as vacuum extremals and the investigation of spherically symmetric (inertial) vacuum extremals for which gravitational four-momentum is conserved [D3] leads to the conclusion that the loss of spherical symmetry due to rotation is inevitable characteristic of realistic solutions.

1.5.6 Maxwell hydrodynamics as a toy model for TGD

The field equations of TGD are extremely non-linear and all known solutions have been discovered by symmetry arguments. Chern-Simons term plays essential role also in the construction of solutions of field equations and at partonic level defines braiding for light-like partonic 3-surfaces expected to play key role in the construction of S-matrix. The inspiration for this section came from Terence Tao's blog posting *2006 ICM: Etienne Ghys, Knots and dynamics* [27] giving an elegant summary about amazing mathematical results related to knots, links, braids and hydrodynamical flows in dimension $D = 3$. Posting tells about really amazing mathematical results related to knots.

Chern-Simons term as helicity invariant

Tao mentions helicity as an invariant of fluid flow. Chern-Simons action defined by the induced Kähler gauge potential for light-like 3-surfaces has interpretation as helicity when Kähler gauge potential is identified as fluid velocity. This flow can be continued to the interior of space-time sheet. Also the dual of the induced Kähler form defines a flow at the light-like partonic surfaces but not in the interior of space-time sheet. The lines of this flow can be interpreted as magnetic field lines. This flow is incompressible and represents a conserved charge (Kähler magnetic flux).

The question is which of these flows should define number theoretical braids. Perhaps both of them can appear in the definition of S-matrix and correspond to different kinds of partonic matter (electric/magnetic charges, quarks/leptons?,...). Second kind of matter could not flow in the interior of space-time sheet. Or could interpretation in terms of electric magnetic duality make sense?

Helicity is not gauge invariant and this is as it must be in TGD framework since CP_2 symplectic transformations induce $U(1)$ gauge transformation, which deforms space-time surface an modifies induced metric as well as classical electroweak fields defined by induced spinor connection. Gauge degeneracy is transformed to spin glass degeneracy.

Maxwell hydrodynamics

In TGD Maxwell's equations are replaced with field equations which express conservation laws and are thus hydrodynamical in character. With this background the idea that the analogy between gauge theory and hydrodynamics might be applied also in the reverse direction is natural. Hence one might ask what kind of relativistic hydrodynamics results if assumes that the action principle is Maxwell action for the four-velocity u^α with the constraint term saying that light velocity is maximal signal velocity.

1. For massive particles the length of four-velocity equals to 1: $u^\alpha u_\alpha = 1$. In massless case one has $u^\alpha u_\alpha = 0$. Geometrically this means that one has sigma model with target space which is 3-D Lobatschevski space or at light-cone boundary. This condition means the addition of constraint term

$$\lambda(u^\alpha u_\alpha - \epsilon) \tag{1.5.41}$$

to the Maxwell action. $\epsilon = 1/0$ holds for massive/massless flow. In the following the notation of electrodynamics is used to make easier the comparison with electrodynamics.

2. The constraint term destroys gauge invariance by allowing to express A^0 in terms of A^i but in general the constraint is not equivalent to a choice of gauge in electrodynamics since the solutions to the field equations with constraint term are not solutions of field equations without it. One obtains field equations for an effectively massive em field with Lagrange multiplier λ having interpretation as photon mass depending on space-time point:

$$\begin{aligned} j^\alpha &= \partial_\beta F^{\alpha\beta} = \lambda A^\alpha \ , \\ A^\alpha &\equiv u^\alpha \ , \ F^{\alpha\beta} = \partial^\beta A^\alpha - \partial^\alpha A^\beta \ . \end{aligned} \tag{1.5.42}$$

3. In electrodynamic context the natural interpretation would be in terms of spontaneous massivation of photon and seems to occur for both values of ϵ. The analog of em current given by λA^{α} is in general non-vanishing and conserved. This conservation law is quite strong additional constraint on the hydrodynamics. What is interesting is that breaking of gauge invariance does not lead to a loss of charge conservation.

4. One can solve λ by contracting the equations with A_{α} to obtain

$$\lambda = j^{\alpha}A_{\alpha}$$

for $\epsilon = 1$. For $\epsilon = 0$ one obtains

$$j^{\alpha}A_{\alpha} = 0$$

stating that the field does not dissipate energy: λ can be however non-vanishing unless field equations imply $j^{\alpha} = 0$. One can say that for $\epsilon = 0$ spontaneous massivation can occur. For $\epsilon = 1$ massivation is present from the beginning and dissipation rate determines photon mass: a natural interpretation for $\epsilon = 1$ would be in terms of thermal massivation of photon. Non-tachyonicity fixes the sign of the dissipation term so that the thermodynamical arrow of time is fixed by causality.

5. For $\epsilon = 0$ massless plane wave solutions are possible and one has

$$\partial_{\alpha}\partial_{\beta}A^{\beta} = \lambda A_{\alpha} \ .$$

$\lambda = 0$ is obtained in Lorentz gauge which is consistent with the condition $\epsilon = 0$. Also superpositions of plane waves with same polarization and direction of propagation are solutions of field equations: these solutions represent dispersionless precisely targeted pulses. For superpositions of plane waves λ with 4-momenta, which are not all parallel λ is non-vanishing so that non-linear self interactions due to the constraint can be said to induce massivation. In asymptotic states for which gauge symmetry is not broken one expects a decomposition of solutions to regions of space-time carrying this kind of pulses, which brings in mind final states of particle reactions containing free photons with fixed polarizations.

6. Gradient flows satisfying the conditions

$$A_{\alpha} = \partial_{\alpha}\Phi \ , \ A^{\alpha}A_{\alpha} = \epsilon \tag{1.5.43}$$

give rise to identically vanishing hydrodynamical gauge fields and $\lambda = 0$ holds true. These solutions are vacua since energy momentum tensor vanishes identically. There is huge number of this kind of solutions and spin glass degeneracy suggests itself. Small deformations of these vacuum flows are expected to give rise to non-vacuum flows.

7. The counterparts of charged solutions are of special interest. For $\epsilon = 0$ the solution $(u^0, u^r) = (Q/r)(1,1)$ is a solution of field equations outside origin and corresponds to electric field of a point charge Q. In fact, for $\epsilon = 0$ any ansatz $(u^0, u^r) = f(r)(1,1)$ satisfies field equations for a suitable choice of $\lambda(r)$ since the ratio of equations associate with j^0 and j^r gives an equation which is trivially satisfied. For $\epsilon = 1$ the ansatz $(u^0, u^r) = (cosh(u), sinh(u))$ expressing solution in terms of hyperbolic angle linearizes the field equation obtained by dividing the equations for j^0 and j^r to eliminate λ. The resulting equation is

$$\partial_r^2 u + \frac{2\partial_r u}{r} = 0$$

for ordinary Coulomb potential and one obtains $(u^0, u^r) = (cosh(u_0 + k/r), sinh(u_0 + k/r))$. The charge of the solution at the limit $r \rightarrow \infty$ approaches to the value $Q = sinh(u_0)k$ and diverges at the limit $r \rightarrow 0$. The charge increases exponentially as a function of $1/r$ near origin rather than logarithmically as in QED and the interpretation in terms of thermal screening suggests itself. Hyperbolic ansatz might simplify considerably the field equations also in the general case.

Similarities with TGD

There are strong similarities with TGD which suggests that the proposed model might provide a toy model for the dynamics defined by Kähler action.

1. Also in TGD field equations are essentially hydrodynamical equations stating the conservation of various isometry charges. Gauge invariance is broken for the induced Kähler field although Kähler charge is conserved. There is huge vacuum degeneracy corresponding to vanishing of induced Kähler field and the interpretation is in terms of spin glass degeneracy.

2. Also in TGD dissipation rate vanishes for the known solutions of field equations and a possible interpretation is as space-time correlates for asympotic non-dissipating self organization patterns.

3. In TGD framework massless extremals represent the analogs for superpositions of plane waves with fixed polarization and propagation direction and representing targeted and dispersionless propagation of signal. Gauge currents are light-like and non-vanishing for these solutions. The decomposition of space-time surface to space-time sheets representing particles is much more general counterpart for the asymptotic solutions of Maxwell hydrodynamics with vanishing λ.

4. In TGD framework one can consider the possibility that the four-velocity assignable to a macroscopic quantum phase is proportional to the induced Kähler gauge potential. In this kind of situation one could speak of a quantal variant of Maxwell hydrodynamics, at least for light-like partonic 3-surfaces. For instance, the condition

$$D^\alpha D_\alpha \Psi = 0 \ \ , \ \ D_\alpha \Psi = (\partial_\alpha - iq_K A_\alpha)\Psi$$

   for the order parameter of the quantum phase corresponds at classical level to the condition $p^\alpha = q_K Q^\alpha + l^\alpha$, where q_K is Kähler charge of fermion and l^α is a light-like vector field naturally assignable to the partonic boundary component. This gives $u^\alpha = (q_K Q^\alpha + l^\alpha)/m$, $m^2 = p^\alpha p_\alpha$, which is somewhat more general condition. The expressibility of u^α in terms of the vector fields provided by the induced geometry is very natural.

   The value ϵ depends on space-time region and it would seem that also $\epsilon = -1$ is possible meaning tachyonicity and breaking of causality. Kähler gauge potential could however have a time-like pure gauge component in M^4 possibly saving the situation. The construction of quantum TGD at parton level indeed forces to assume that Kähler gauge potential has Lorentz invariant M^4 component $A_a = \textit{constant}$ in the direction of the light-cone proper time coordinate axis a. Note that the decomposition of configuration space to sectors consisting of space-time sheets inside future or past light-cone of M^4 is an essential element of the construction of configuration space geometry and does not imply breaking of Poincare invariance. Without this component $u_\alpha u^\alpha$ could certainly be negative. The contribution of M^4 component could prevent this for preferred extremals.

If TGD is taken seriously, these similarities force to ask whether Maxwell hydrodynamics might be interpreted as a nonlinear variant of electrodynamics. Probably not: in TGD em field is proportional to the induced Kähler form only in special cases and is in general non-vanishing also for vacuum extremals.

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Chapter 2

General View About Physics in Many-Sheeted Space-Time: Part I

2.1 Introduction

The concept of topological condensation unifies two disparate approaches to TGD, namely TGD as a Poincare invariant theory of gravitation and TGD as a generalization of the string model. The idea is that classical 3- space with matter can be regarded as a 3-surface obtained by "gluing" particle like 3-surfaces to the background 3-surface with possibly macroscopic size: resulting topological inhomogenities correspond to matter. The "gluing" of two n-manifolds together by topological sum means the following operation: drill spherical holes to both n-manifolds and connect the resulting boundary components S^{n-1} with a tube $D^1 \times S^{n-1}$ (see Fig. 2.1.1). Of course, several # contacts, which are tiny 'wormholes' connecting two parallel space-time sheets, are expected to be present in the general case.

2.1.1 Various types of topological condensation

One can in fact distinguish between three kinds of topological condensation.

1. 3-dimensional topological condensation, which is expected to give rise to the formation of bound states (not necessary all possible bound states).

2. 4-dimensional topological condensation, which results from the properties of the Kähler action: the minimizing four surface associated with a given set of 3-surfaces is in general connected so that long range interactions are generated between the 3-surfaces. This mechanism is in principle all what is needed to generate the so called classical space-time. Although the physical state can consist of arbitrarily many disjoint 3-surfaces, the space-time associated with these surfaces is connected and resembles the "classical" space-time, when topological inhomogenities are smoothed out. It should be noticed that 4-dimensional topological condensation corresponds to unstable 3-dimensional topological condensation. For the visualization purposes, one can consider a simplified example: instead of 3-surfaces consider strings so that space-time is replaced with a two-surface having strings as its boundaries.

3. 2-dimensional topological condensation: boundaries of the 3- surfaces are joined together by a tube $D^1 \times D^2$. This process will be referred as a formation of join along boundaries bonds.

There are also reasons to suspect that the actual macroscopic 3-space is not connected but corresponds to a large macroscopic 3-surface, classical 3-space, plus a gas of small particle like 3-surfaces, "Baby Universes". It is to be expected that the effects related to the vapor phase particles are very small. An idealization is obviously needed in order to obtain something resembling the topologically trivial 3-space of the standard theories: topological inhomogenities of size smaller than a given length scale L are smoothed out and their presence is described using various currents, such as energy momentum tensor, gauge currents and particle number currents. To be precise, this works only provided

Figure 2.1: Topological sum of two manifolds

one takes the limit $L \to \infty$ since TGD space-time could well be many sheeted in arbitrarily long length scales.

2.1.2 Implications of the topological non-triviality of macroscopic space-time

If one accepts that 3-space is topologically nontrivial, one must sooner or later end up asking following questions. What does 3-space actually look like in various scales? What are the general physical consequences of the new space time concept? Are they seen at elementary particle level only or perhaps at atomic, molecular, etc. levels? What is the 3-topology of the solid/liquid/gas state? What about macroscopic bodies: what do they correspond topologically?

In the following the general ideas about the topological condensation are discussed. These ideas have developed gradually in parallel with the development of the configuration space geometry and Quantum TGD, through the study of the extremals of Kähler action and through the attempts to apply TGD inspired ideas to many not so well understood phenomena like Higgs mechanism or more generally, particle massivation, color confinement, super fluidity, super conductivity, hydrodynamic turbulence, etc.. The ideas to be represented may look rather wild, when encountered outside the context defined by twenty years of personal work with many trials and errors and moments of discovery. It is the internal consistency rather than quantitative details, as well as the radically new approach provided to the problems of even macroscopic physics, which makes the scenario so exciting.

2.1.3 Topics of the chapter

The topics to be discussed in the sequel will be following:

1. The question what 3-space looks like in various scales and end up to a purely topological description for the generation of structures. Topological arguments imply a finite size for non-vacuum 3-surfaces and the conservation of the gauge and gravitational fluxes requires that 3-surface feeds these fluxes to a larger 3-surface via # contacts situated near the boundaries of the 3-surface. Renormalization group invariance (RGI) hypothesis suggests that 3-surfaces with all sizes are important in the functional integral and this leads to the idea of the many-sheeted space-time with hierarchical, fractal like structure such that each level of the hierarchy corresponds to a characteristic length scale.

2. The general space-time picture suggested by RGI hypothesis can be justified mathematically. Due to the compactness of CP_2, a general space-time surface representable as a map $M^4 \to CP_2$ decomposes into regions, "topological field quanta", characterized by certain vacuum quantum numbers and 3-surface is in general unstable against the decay to disjoint components along the boundaries of the field quanta. Topological field quanta have finite size depending on the values of the vacuum quantum numbers: the size increases as the values of the vacuum quantum numbers increase. Topological field quantum is therefore a good candidate for a quantum coherent system provided some Bose Einstein condensate or quantum coherent state is available. The BE condensate or coherent state of the light # contacts near the boundaries of the topological field quantum is a good candidate in this respect.

   The requirement of the gauge charge conservation in turn implies the hierarchical structure of the topological condensate: gauge fluxes must go somewhere from the outer boundaries of the topological field quantum with finite size and this 'somewhere' must be a larger topological field quantum, which in turn feeds its gauge fluxes to a larger topological field quantum,.... Of course, the nonlinearity of the theory could allow vacuum charge densities which can cancel the net charge near boundaries.

Most importantly, topological field quanta allow discrete scalings as a dynamical symmetry. p-Adic length scale hypothesis states that the allowed scaling factors correspond to powers of $\sqrt{p}$, where the prime p satisfies $p \simeq 2^k$, k integer with prime values favored. p-Adic fractality (actually multi-p-fractality) can be justified more rigorously by a precise formulation for the fusion of real and various p-adic physics based on the generalization of the notion of number [E1].

The physical consequences of the new space-time picture are nontrivial at all length scales.

(a) A natural interpretation for the hierarchical structure is in terms of bound state formation. Quarks condense to form hadrons, nucleons condense to form atomic nuclei, nuclei and electrons condense to form atoms, how atoms condense to form molecules, and so on. One ends up with a general picture for the topology of 3-space associated with, say, solid state and with the idea that even the macroscopic bodies of the everyday world correspond to topologically condensed 3-surfaces.

(b) The join of 3-surfaces along their boundaries defines a new kind of interaction, which in fact has been used in phenomenological modelling of and usually believed to result from Schrödinger equation. At the macroscopic level this interaction is rather familiar to us since it means that two macroscopic bodies just touch each other!

(c) The possibility to understand general qualitative features of the charge renormalization topologically in the proposed scenario for space-time, is considered. This rough vision represents one of the oldest strata in the evolution of TGD: in [C5] the recent view about space-time correlates of gauge charges is developed.

(d) In TGD context there are purely topological necessary conditions for quantum coherence and a topological description for dissipative phenomena. The formation of the join along boundaries bonds plays a decisive role in the description and this process provides a universal manner to generate macroscopic quantum systems.

(e) There is also a topological description for the formation of the supra phases and the phase of the order parameter of the supra phase ground state contains information about the homotopy of the join along boundaries condensate.

The proper understanding of the concepts of gauge charges and fluxes and their gravitational counterparts in TGD space-time has taken a lot of efforts. At the fundamental level gauge charges assignable to light-like 3-D elementary particle horizons surrounding a topologically condensed CP_2 type extremals can be identified as the quantum numbers assignable to fermionic oscillator operators generating the state associated with horizon identifiable as a parton. Quantum classical correspondence requires that commuting classical gauge charges are quantized and this is expected to be true by the generalized Bohr orbit property of the space-time surface.

The most dramatic prediction obvious from the beginning but mis-interpreted for about 26 years is the presence of long ranged classical electro-weak and color gauge fields in the length scale of the space-time sheet. The only interpretation consistent with quantum classical correspondence is in terms of a hierarchy of scaled up copies of standard model physics corresponding to p-adic length scale hierarchy and dark matter hierarchy labelled by arbitrarily large values of dynamical quantized Planck constant. Chirality selection in the bio-systems provides direct experimental evidences for this fractal hierarchy of standard model physics.

3. There are some non-trivial questions. Do vacuum charge densities give rise to renormalization effects or imply non-conservation so that weak charges would be screened above intermediate boson length scale? Could one assign the non-conservation of gauge fluxes to the wormhole (#) contacts, which are identifiable as pieces of CP_2 extremals and for which electro-weak gauge currents are not conserved so that weak gauge fluxes would be non-vanishing but more or less random so that long range correlations would be lost? After almost two decades after posing

these questions it has become clear that vacuum currents are light-like for preferred extremals of Kähler action and do not give rise to renormalization effects in given p-adic length scale so that coupling constant evolution reduces to discrete p-adic coupling constant evolution also at classical level.

4. # (or wormhole-) contacts feeding gauge fluxes from a given sheet of the 3-space to a larger one are a necessary concomitant of the many-sheeted space-time concept. Their physical interpretation remained unclear for a long time.

   (a) # contacts can be regarded as particles carrying classical charges defined by the gauge fluxes but behaving as extremely tiny dipoles quantum mechanically in the case that gauge charge is conserved. # contacts must be light, which suggests that they can form Bose-Einstein condensates and coherent states. The real surprise (after 27 years of TGD) was that Higgs boson can be identified as a wormhole contact so that the generation of vacuum expectation value of Higgs field would correspond to a formation of coherent state of wormhole contacts with quantum numbers of Higgs particle.

   (b) It took some time to realize that all gauge bosons could be regarded as wormhole contacts and that fermions correspond naturally to wormhole throats of topologically condensed CP_2 type extremals. Graviton in turn would correspond to a pair of wormhole contacts connected by flux tubes so that stringlike object is in question. This picture follows unavoidably from the assumption that fermions are free at partonic level and leads to a detailed understanding of particle massivation at the level of first principles.

I have not discussed in this chapter the most recent developments in quantum TGD in detail except by references to the next chapter, where these developments are summarized.

2.2 What do space-like 3-surfaces look like?

This section provides a general picture of space-like 3-surfaces starting renormalization group invariance from spin glass analogy, the selection of preferred extremals of the Kähler action as generalized Bohr orbits, and from the special properties of the induced gauge fields implied by the compactness of CP_2.

This summary does not consider light-like 3-surfaces associated with wormhole throats and light-like boundaries of space-time sheets are much more suitable for the formulation of quantum TGD. In principle the two notions are dual to each other. Light-like 3-surfaces can be seen as a generalization of Feynman diagrams with lines represented by light-like 3-manifolds meeting along their 2-D ends representing vertices.

2.2.1 Renormalization group invariance, quantum criticality and topology of 3-space

Renormalization group invariance, quantum criticality, and spin glass analogy are basic notions of quantum TGD but it is far from clear what these notions really mean at the level of space-time physics.

What quantum criticality means?

RGI (Renormalization group invariance) hypothesis states essentially that TGD Universe is quantum critical meaning that quantum theory is mathematically equivalent with a statistical system at critical point. S-matrix elements are analogous to thermal averages of observables, α_K corresponds to critical temperature and the vacuum functional $exp(K)$ corresponds to $exp(-H/T)$. The physical interpretation of the Kähler function suggests that $\alpha_K(phys)$ might correspond to a critical temperature at which spontaneous Kähler magnetization and formation Kähler electric fields compete.

The analogy with spin glass phase in four-dimensional sense is an additional characteristics feature. This allows the critical value of the α_K to depend on the zero modes of the configuration space metric.

The naive idealized interpretation for the quantum criticality would be that 3-surfaces with all possible sizes contribute to the functional integral. In realistic situations there is some upper bound for the size and duration quantum fluctuations and the size of the largest space-time sheet involved would define the scales in question.

Spin glass analogy leads to the idea that configuration space decomposes into regions D_p characterized by the p-adic prime p such that one can associate a hierarchy of p-adic length scales $L_p(n) = \sqrt{p}^{n-1}l$, $l \sim 10^4\sqrt{G}$ to each value of p [E5]. The critical value of α_K can in principle depend on p but the recent view is that α_K and perhaps also gravitational constant are invariant under p-adic coupling constant evolution. p-Adic length scales scales define natural upper bounds for the scale of quantum fluctuations associated with the quantum critical space-time sheet. Dark matter hierarchy in turn assigns to each p-adic length scale a hierarchy of further length scales scaled up by the values of $\hbar/\hbar_0$. The typical duration of quantum fluctuation would correspond to the typical geometric duration of maximal deterministic region inside space-time sheet.

What are the competing phases?

Quite generally, critical systems are characterized by long range correlations (correlation length ξ diverges) for the competing phases present in the system. Physically this means the coexistence of arbitrarily large volumes of the two phases. Both Kähler magnetized 3-surfaces and 3-surfaces containing predominantly Kähler electric fields contribute significantly to the functional integral are present. At the infinite volume limit the Kähler action per volume must vanish since otherwise the vacuum functional vanishes: TGD cosmology [D5] is in accordance with this picture.

The problem of identifying the preferred extremals of Kähler action has been one of the most longstanding challenges of TGD. The solution of the problem came via the formulation of configuration space geometry from the notion of number theoretical compactification [E2] in terms of second quantized induced spinor field at light-like 3-surfaces [B4]. The original hypothesis was that preferred extremals correspond to absolute minima of Kähler action. The recent formulation in terms of boundary conditions at light-like surfaces is consistent with what is known about extremals of Kähler action [D1]. This formulation does not exclude absolute minimization or some variant of it. Note however that for the absolute minimization of Kähler action Kähler electric fields dominate and it is not clear whether there are solutions for which the Kähler action of the entire Universe is finite.

How quantum fluctuations and thermal fluctuations relate to each other?

An experimental fact is that quantum critical systems such as high temperature superconductors [J1, J2, J3] exist in a rather narrow parameter range, and one can say that quantum criticality becomes visible only when quantum fluctuations are not masked by thermal fluctuations. One should express this fact using TGD based notions.

p-Adic and dark matter hierarchies correspond also to hierarchies for quantum jumps with time scales given the average geometric duration for quantum jump. This hierarchy means quantum parallel dissipation about which hadrons as quantum systems containing quarks as dissipating subsystem at shorter p-adic length and time scale give a basic example.

At given space-time sheet short scale thermal fluctuations would have interpretation as quantum parallel fluctuations at smaller space-time sheets topologically condensed to the space-time sheet in question whereas the quantum critical fluctuations would correspond to the quantum fluctuations in the scale of the space-time sheet. The duration of maximal deterministic space-time region would correspond to the duration of single quantum state in the sequence of quantum jumps. The interpretation would be that only at quantum criticality the quantal fluctuations in long time scales can mask the thermal fluctuations in shorter scales.

How quantum measurement theory relates to quantum criticality?

A further question is how quantum measurement theory relates to this picture. Configuration space zero modes represent non-quantum fluctuating classical observables correlating with quantum numbers and in quantum measurement a localization in zero modes occurs. Does this mean that the localization in zero modes breaks quantum criticality above the time scale corresponding to the typical geometric time duration of quantum jump by selecting precise values of zero modes?

Formation of join along boundaries condensates and visible-to-dark phase transitions as mechanisms giving rise to quantum critical systems

The phase transition from visible to dark matter, and more generally, the transitions increasing the value of Planck constant define the first mechanism leading to the formation of larger quantum critical system and long range quantum fluctuations can be assigned to dark matter.

The formation of a join along boundaries condensate means also a formation of a quantum critical system. The 3-surfaces with a typical size of order L_p combine together by join along boundaries bonds to form larger surfaces. Above criticality there are no bonds, below criticality all 3-surfaces combine to form larger condensates and at criticality there are join along boundaries condensates with all possible sizes up to the cutoff length scale. Note that, at least for small values of p, the surfaces with typical sizes $\sqrt{p}^n L_p$, $n = ..0, 1, 2, ...$ correspond to the presence of all surface sizes related by a fractal scaling for a given p. A more precise formulation for what the fusion of p-adic and real physics [E2] means supports the view that topological field quanta allow a discrete scaling symmetry identifiable as scalings by powers of $\sqrt{p}$.

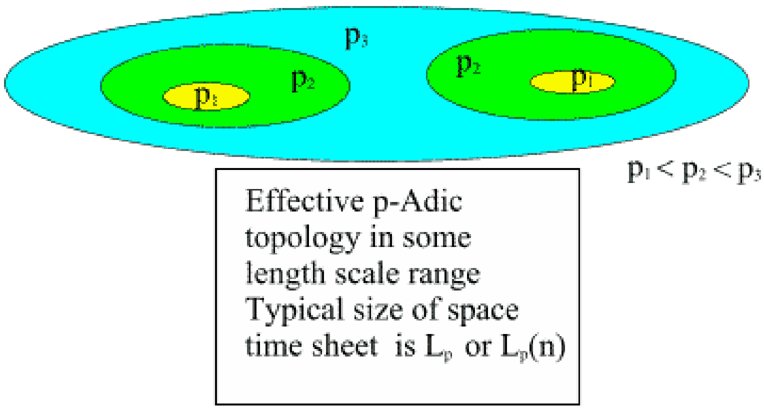

Figure 2.2: Hierarchical, fractal like structure of topological condensate predicted by RGI hypothesis: 2-dim. visualization

2.2.2 3-surfaces can have outer boundaries

In length scales larger than hadronic length scale 3-surface with size L means roughly a condensate of smaller scale 3-surfaces on a piece of Minkowski space of size L. It is quite essential that these surfaces have finite size and therefore have outer boundary. The finite size of the 3-surfaces follows from the minimization of the Kähler action and from the compactness of CP_2. The argument goes as follows.

The matter inside a 3-surface creates gauge fields. In particular, the minimization of the absolute value of Kähler action in a region with definite sign of action density implies that matter serves as a source of either Kähler magnetic or Kähler electric fields. For instance, the Kähler electric field created by a constant mass distribution increases without bound. The smooth imbeddings of the gauge fields are however not possible globally and space-time decomposes into topological field quanta and their boundaries correspond to edges of space time. The elimination of the edges leads to a 3-space consisting of disjoint components. Simple examples are provided by a cylindrically symmetric imbedding of a constant magnetic field and the Kähler electric field created by a constant mass distribution, which fail for certain critical radii.

One can understand at general level how the compactness of CP_2 enters into the game. The point is that the gauge potentials associated with the induced gauge fields are bounded functions of CP_2 coordinates. For instance, for a geodesic sphere S^2 of CP_2 gauge potentials are just proportional to $A = sin(\Theta)d\Phi$. For a generic gauge field the gauge potential is not bounded (as an example consider gauge potentials of the Coulomb field or Kähler electric field created by a constant charge distribution or by a constant magnetic field). Therefore for certain values of CP_2 coordinates the representation of the gauge potential as an induced gauge potential fails. The failure takes place at some 3-surface of X^4. One can continue the embedding by changing the values of vacuum quantum numbers but certain CP_2 coordinates possess discontinuous or even infinite derivatives on the boundary so that undesirable edges of space time result. The manner to get rid of edges is to allow boundary for X^3 so that a region, where the the representation of the gauge potential as induced gauge potential works defines a natural unit of space-time, which might be called topological field quantum. In the sequel this phenomenon will be considered in more detail.

An obvious question is what happens to the gauge fluxes of long range gauge fields near the boundaries of the topological field quantum. Same question applies also to the gravitational flux associated with the Newtonian potential at the non-relativistic limit. One possibility is the appearance of neutralizing vacuum gauge charges and negative gravitational masses near the boundaries of the field quantum, perhaps related to vacuum polarization: this alternative must be realized for the particles of vapor phase. Second possibility is topological condensation on a larger topological field quantum so that gauge and gravitational fluxes flow to the larger topological field quantum via # contacts. The larger field quantum in turn must feed its gauge fluxes in a similar manner to larger field quantum so that the hierarchical structure of topological condensate is implied by the compactness of CP_2 and gauge flux conservation. Criticality implies only that 3-surfaces of arbitrarily large size are possible and therefore the number of the condensate levels and corresponding length scales $L(n)$ is infinite. Without criticality there would be some upper bound for 3-surfaces and only vapor phase would be possible.

The # contacts feeding the gauge fluxes from level p_n to level p_{n+1} are located near the boundaries of topological field quanta: otherwise long range gauge fields would not be possible inside the topological field quanta. A more quantitative hypothesis is that # contacts are located in the boundary layer having thickness of order L_{p_n}. If topological field quantum at level n has the minimum size of order L_{p_n} then the # contacts neutralize the physical gauge charges on the average.

A natural identification for wormhole contacts is as slightly deformed pieces of CP_2 type vacuum extremals having Euclidian signature of induced metric. Wormhole throats are identified as 3-surfaces at which the signature of induced metric changes and are therefore light-like 3-surfaces. The realization that these surfaces are ideal for the formulation of quantum TGD meant breakthrough in the construction of quantum TGD. The interpretation of the wormhole contacts as elementary bosons was crucial for understanding boson massivation and Higgs mechanism [F2].

2.2.3 Topological field quantization

Topological field quantization is a very general phenomenon differentiating between the TGD based and Maxwellian field concepts and results from the compactness of CP_2 only, being independent of any dynamical assumptions.

Topological field quantization occurs for surfaces representable as maps from M^4 to CP_2 and means that space time surface decomposes into regions characterized by certain vacuum quantum numbers characterizing the dependence of the phase angles Ψ and Φ associated with the two complex coordinates ξ_1 and ξ_2 of CP_2. There are two frequency type vacuum quantum numbers ω_1 and ω_2 characterizing the time dependence, two wave vector like quantum numbers k_1, k_2 characterizing the z-dependence and two integer valued vacuum quantum numbers n_1, n_2 characterizing the angle dependence of these phase angles. Topological field quantization fixes unique M^4 and CP_2 coordinates inside the field quantum and is analogous to a choice of a quantization axis.

Topological field quanta

Before considering the general form of the surfaces representable as maps $M^4 \rightarrow CP_2$ some comments about CP_2 coordinates are needed:

1. The so called Eguchi-Hanson coordinates for CP_2 are given $(r, u, \Psi, \Phi) \in [0, \infty] \times [-1, 1] \times [0, 4\pi] \times [0, 2\pi]$ (see Appendix [Appendix]). Ψ and and Φ are angle like coordinates closely related to the phases of the two complex coordinates of CP_2 and are the interesting variables in the sequel.

2. There are following types of coordinate singularities.

(a) For $r = 0$ all values of Ψ and Φ correspond to same point of CP_2.

(b) For $r = \infty$ all values of Ψ correspond to same point of CP_2. For $u = 1$ and $u = -1$ also all values of Φ correspond to same point of CP_2.

Consider now the space-time surface representable as a graph of a map $M^4 \rightarrow CP_2$. The general form of the angle coordinates Ψ and Φ as functions of M^4 cylindrical coordinates (t, z, ρ, ϕ) is given by the expression

$$
\begin{aligned}
\Phi &= \omega_1 t + k_1 z + n_1 \phi + \text{Fourier expansion} \ , \\
\Psi &= \omega_2 t + k_2 z + n_2 \phi + \text{Fourier expansion} \ .
\end{aligned} \tag{2.2.1}
$$

There always exists a rest frame, where k_1 or k_2 vanishes. The Fourier expansion is single valued in ϕ and finite in z and t. The vacuum quantum numbers ω_1 and ω_2 are frequency type vacuum quantum numbers to be referred as "electric" quantum numbers. The quantum numbers (n_1, n_2) are integer valued and will be referred to as "magnetic" quantum numbers.

The values of the vacuum quantum numbers can change at the boundaries of the regions of space-time determined by the conditions
i) $r = 0$ and $(r = \infty, u = \pm 1)$: here all vacuum quantum numbers can change
ii) $r = \infty$: here only ω_2, n_2 and k_2 can change.
Also the choice of CP_2 coordinates and M^4 coordinates can in principle change: different CP_2 coordinates are related by color rotation and different M^4 coordinates by Lorentz transformation.

In general, the boundaries of the regions correspond to edges of space-time in the sense that CP_2 coordinates possess discontinuous or infinite derivatives at the boundaries of the field quanta. A natural manner to get rid of the edges is to consider 3- surfaces consisting of a single region only so that single region of this kind, topological field quantum, is a natural unit of 3-space. There is however an important exception to this. The join along boundaries interaction very probably means the gluing of two topological field quanta together along their boundaries and provides a manner to construct coherent quantum systems from smaller units.

The sizes of the topological field quanta are indeed finite so that the boundary of 3-space (quite essential for the ideas described before) is an unavoidable consequence of the compactness of CP_2 and the minimization of the Kähler action. The dependence of the size of the 3-surface on the vacuum quantum numbers is in accordance with the proposed interpretation: at the limit of large vacuum quantum numbers the size of the topological field quantum becomes macroscopic and at small vacuum quantum number limit the size of the surface becomes small.

Very complicated hierarchical structures predicted by the RGI are in principle possible since topological field quanta can suffer topological condensation on larger field quanta. Field quanta can become nested and both spatial and temporal structures (nesting in time like direction) are possible.

The vacuum quantum numbers associated with vacuum extremals

Vacuum extremals define a reasonable starting point for TGD based model for gravitational interactions. For vacuum extremals classical em and Z^0 fields are proportional to each other (see the Appendix of the book):

$$
\begin{aligned}
Z^0 &= 2e^0 \wedge e^3 = \frac{r}{F^2}(k+u)\frac{\partial r}{\partial u} du \wedge d\Phi = (k+u) du \wedge d\Phi \ , \\
r &= \sqrt{\frac{X}{1-X}} \ , \ X = D|k+u| \ , \\
\gamma &= -\frac{p}{2} Z^0 \ .
\end{aligned} \tag{2.2.2}
$$

For a vanishing value of Weinberg angle ($p = sin^2(\theta_w) = 0$) em field vanishes and only Z^0 field remains as a long range gauge field.

The study of the imbeddings of the Schwartshild metric as vacuum extremals (gravitational mass is non-vanishing but inertial mass vanishes) shows that astrophysical length scales correspond to large vacuum quantum number limit of TGD. Any mass vacuum extremal is necessarily accompanied by long ranged electro-weak and color fields and from the requirement that the corresponding force is weaker than the gravitational force one obtains that the value of the parameter ω_1 is of the order of $1/R \sim 10^{-4}\sqrt{G}$.

A simple example about the decomposition of space-time into topological field quanta is obtained by considering the cylindrically symmetric imbedding of a constant magnetic field in the z-direction as a vacuum extremal. Electromagnetic field can be written as $F^{em}_{\rho\phi} = B_0\rho$ and using the general results from the Appendix of the book one can write

$$
\begin{aligned}
u = u(\rho) \ , & \quad \Phi = n_1\phi \ , \\
r = \sqrt{\tfrac{X}{1-X}} \ , & \quad X = D|k+u| \ , \\
A^{em}_{\phi} = \frac{B_0\rho^2}{2} & = -\frac{p}{2}n_1(k+u)\partial_\rho u \ .
\end{aligned}
\tag{2.2.3}
$$

Assuming that $(r,u) = (0,0)$ holds true at z-axis, the equation for em gauge potential A^{em} fixes the relationship between ρ and u as

$$
u = -k \pm \sqrt{k^2 - \frac{2B_0\rho^3}{3n_1p}} \ . \tag{2.2.4}
$$

The finite value range $0 \leq u \leq 1$ implies that the imbedding fails for certain values of ρ. Also the requirement that u is real implies an upper bound for ρ: the larger the value of n_1 the larger the critical radius. Imbedding can fail also for $X < 0$ and $X > 1$ corresponding to critical values of u equal $u_0 = -k$ and $D|(k+u_1)| = 1$.

2.3 Basic phenomenology of topological condensation

The notions of topological condensate (or many-sheeted space-time) and p-adic length scale hierarchy are in a central role in TGD and for a long time it seemed that the physical interpretation of these notions is relatively straightforward. In the following I will summarize the basic ideas about topological condensation and gauge fluxes as they were before the identification of wormhole contacts as gauge bosons. The discussion of wormhole (#-) contacts of this section was written roughly two decades before the realization that they allow interpretation as gauge bosons and Higg particle. I decided to keep the section almost as such and consider this interpretation later.

2.3.1 Basic concepts

It is good to discuss the basic notions before discussing the definition of gauge charges and gauge fluxes.

CP_2 type vacuum extremals

CP_2 type extremals behave like elementary particles (in particular, light-likeness of M^4 projection gives rise to Virasoro conditions). CP_2 type vacuum extremals have however vanishing four-momentum although they carry classical color charges. This raises the question how they can gain elementary particle quantum numbers.

In topological condensation of CP_2 type vacuum extremal a light-like causal horizon (wormhole throat) is created. Number theoretical considerations strongly suggest that the horizon carries elementary particle numbers and can be identified as a parton. The quantum numbers or parton would serve as sources of the classical gauge fields created by the causal horizon.

In topological evaporation CP_2 type vacuum extremal carrying only classical color charges is created. This would suggest that the scattering of CP_2 type vacuum extremals defines a topological quantum field theory resulting as a limit of quantum gravitation (CP_2 is gravitational instanton) and that CP_2 type extremals define the counterparts of vacuum lines appearing in the formulation of generalized Feynman diagrams [C2].

The question how to assign to wormhole throats M^4 quantum numbers such as four-momentum found a convincing answer only after the proper understanding of how Equivalence Principle is realized in TGD. The formulation of the theory in terms of light-like surfaces was crucial in this respect. This point will be discussed later sections: suffice it to say that a connection with string model was a crucial element in the picture.

contacts as parton pairs

The earlier view about # contacts as passive mediators of classical gauge and gravitational fluxes is not quite correct. The basic modification is due to the fact that one can assign parton or parton pair to the # contact so that it becomes a particle like entity. This means that an entire p-adic hierarchy of new physics is predicted.

1. Formally # contact can be constructed by drilling small spherical holes S^2 in the 3-surfaces involved and connecting the spherical boundaries by a tube $S^2 \times D^1$. For instance, CP_2 type extremal can be glued to space-time sheet with Minkowskian signature or space-time sheets with Minkowskian signature can be connected by # contact having Euclidian signature of the induced metric. Also more general contacts are possible since S^2 can be replaced with a 2-surface of arbitrary genus and family replication phenomenon can be interpreted in terms of the genus.

   The # contact connecting two space-time sheets with Minkowskian signature of metric is accompanied by two "elementary particle horizons", which are light-like 3-surfaces at which the induced 4-metric becomes degenerate. Since these surfaces are causal horizons, it is not clear whether # contacts can mediate classical gauge interactions. If there is an electric gauge flux associated with elementary particle horizon it tends to be either infinite by the degeneracy of the induced metric. It is not quite clear whether boundary conditions allow to have finite gauge fluxes of electric type. What is required that the normal component F_{n0} of electric field vanishes but $F^{n0}\sqrt{g_4}$ approaches to a finite finite value. A similar difficulty is encountered when one tries to assign gravitational flux to the # contact: in this case even the existence of flux in non-singular case is far from obvious. Hence the naive extrapolation of Newtonian picture might not be quite correct.

2. Number theoretical considerations suggests that the two light-like horizons associated with # contacts connecting space-time sheets act as dynamical units analogous to shock waves or light fronts carrying quantum numbers so that the identification as partons is natural. Quantum holography would suggest itself in the sense that the quantum numbers associated with causal horizons would determine the long range fields inside space-time sheets involved.

3. # contacts can be modeled in terms of CP_2 type extremals topologically condensed simultaneously to the two space-time sheets involved. The topological condensation of CP_2 type extremal creates only single parton and this encourages the interpretation as elementary particle. The gauge currents for CP_2 type vacuum extremals have a vanishing covariant divergence so that there are no conserved charges besides Kähler charge. Hence electro-weak gauge charges are not conserved classically in the region between causal horizons whereas color gauge charges are. This could explain the vacuum screening of electro-weak charges at space-time level. This is required since for the known solutions of field equations other than CP_2 type extremals vacuum screening does not occur.

4. In the special case space-time sheets have opposite time orientations and the causal horizons carry opposite quantum numbers (with four-momentum included) the # contact would serve the passive role of flux mediator and one could assign to the contact generalized gauge fluxes as quantum numbers associated with the causal horizons. This is the case if the contact is created from vacuum in topological condensation so that the quantum numbers associated with the horizons define naturally generalized gauge fluxes. Kind of generalized quantum dipoles living in two space-times simultaneously would be in question. # contacts in the ground state for space-time sheets with opposite time orientation can be also seen as zero energy parton-antiparton pairs bound together by a piece of CP_2 type extremal.

5. When space-time sheets have same time orientation, the two-parton state associated with the # contact has non-vanishing energy and it is not clear whether it can be stable.

$\#_B$ contacts as bound parton pairs

Besides # contacts also join along boundaries bonds (JABs, $\#_B$ contacts) are possible. They can connect outer boundaries of space-time sheets or the boundaries of small holes associated with the interiors of two space-time sheets which can have Minkowskian signature of metric and can mediate classical gauge fluxes and are excellent candidates for mediators of gauge interactions between space-time sheet glued to a larger space-time sheet by topological sum contacts and join along boundaries contacts. The size scale of the causal horizons associated with parton pairs can be arbitrary whereas the size scale of # contacts is given by CP_2 radius.

The existence of the holes for real space-time surfaces is a natural consequence of the induced gauge field concept: for sufficiently strong gauge fields the imbeddability of gauge field as an induced gauge field fails and hole in space-time appears as a consequence. The holes connected by $\#_B$ contacts obey field equations, and a good guess is that they are light-like 3-surfaces and carry parton quantum numbers. This would mean that both # and $\#_B$ contacts allow a fundamental description in terms of pair of partons.

Magnetic flux tubes provide a representative example of $\#_B$ contact. Instead of $\#_B$ contact also more descriptive terms such as join along boundaries bond (JAB), color bond, and magnetic flux tube are used. $\#_B$ contacts serve also as a space-time correlate for bound state formation and one can even consider the possibility that entanglement might have braiding of bonds defined by # contacts as a space-time correlate [E9].

It seems difficult to exclude join along boundaries contacts between between holes associated with the two space-time sheets at different levels of p-adic hierarchy. If these contacts are possible, a transfer of conserved gauge fluxes would be possible between the two space-time sheets and one could speak about interaction in conventional sense.

Topological condensation and evaporation

Topological condensation corresponds to a formation of # or $\#_B$ contacts between space-time sheets. Topological evaporation means the splitting of # or $\#_B$ contacts. In the case of elementary particles the process changes almost nothing since the causal horizon carrying parton quantum numbers does not disappear. The evaporated CP_2 type vacuum extremal having interpretation as a gravitational instanton can carry only color quantum numbers.

As # contact splits partons are created at the two space-time sheets involved. This process can obviously generate from vacuum space-time sheets carrying particles with opposite signs of energies and other quantum numbers. Positive energy matter and negative energy anti-matter could be thus created by the formation of # contacts with zero net quantum numbers which then split to produce pair of positive and negative energy particles at different space-time sheets having opposite time orientations. This mechanism would allow a creation of positive energy matter and negative energy antimatter with an automatic separation of matter and antimatter at space-time sheets having different time orientation. This might resolve elegantly the puzzle posed by matter-antimatter asymmetry.

The creation of # contact leads to an appearance of radial gauge field in condensate and this seems to be impossible at the limit of infinitely large space-time sheet since it involves a radical instantaneous change in field line topology. The finite size of the space-time sheet can however resolve the difficulty.

If all quantum numbers of elementary particle are expressible as gauge fluxes, the quantum numbers of topologically evaporated particles should vanish. In the case of color quantum numbers and Poincare quantum numbers there is no obvious reason why this should be the case. Despite this the cancelation of the interior quantum numbers by those at boundaries or light-like causal determinants could occur and would conform with the effective 2-dimensionality stating that quantum states are characterized by partonic boundary states associated with causal determinants. This could be also seen as a holographic duality of interior and boundary degrees of freedom [A2].

The recent formulation of quantum TGD based on the identification of light-like surfaces associated with wormhole throats as carriers of fermionic quantum numbers and identification of gauge bosons and Higgs as wormhole contacts forces to conclude that a 3-surface containing now wormhole contacts represents vacuum or does not correspond to a preferred extremal of Kähler action.

2.3.2 Gauge charges and gauge fluxes

The concepts of mass and gauge charge in TGD has been a source of a chronic headache. There are several questions waiting for a definite answer. How to define gauge charge? What is the microscopic physics behind the gauge charges necessarily accompanying long range gravitational fields? Are these gauge charges quantized in elementary particle level? Can one associate to elementary particles classical electro-weak gauge charges equal to its quantized value or are all electro-weak charges screened at intermediate boson length scale? Is the generation of the vacuum gauge charges, allowed in principle by the induced gauge field concept, possible in macroscopic length scales? What happens to the gauge charges in topological evaporation? Should Equivalence Principle be modified in order to understand the fact that Robertson-Walker metrics are inertial but not gravitational vacua.

How to define the notion of gauge charge?

In TGD gauge fields are not primary dynamical variables but induced from the spinor connection of CP_2. There are two manners to define gauge charges.

1. In purely group theoretical approach one can associate non-vanishing gauge charge to a 3-surface of finite size and quantization of the gauge charge follows automatically. This definition should work at Planck length scales, when particles are described as 3-surfaces of CP_2 size and classical space-time mediating long range interactions make no sense. Gauge interactions are mediated by gauge boson exchange, which in TGD has topological description in terms of CP_2 type vacuum extremals [D1].

2. Second definition of gauge charge is as a gauge flux over a closed surface. In this case quantization is not obvious nor perhaps even possible at classical level except perhaps for Abelian charges. For a closed 3-surface gauge charge vanishes and one might well argue that this is the case for finite 3-surface with boundary since the boundary conditions might well generate gauge charge near the boundary canceling the gauge charge created by particles condensed on 3-surface. This would mean that at low energies (photon wavelength large than size of the 3-surfaces) the 3-surfaces in vapor phase look like neutral particles. Only at high energies the evaporated particles would behave as ordinary elementary particles. Furthermore, particle leaves in topological evaporation its gauge charge in the condensate.

   The alternative possibility that the long range $\frac{1}{r^2}$ gauge field associated with particle disappears in the evaporation, looks topologically impossible at the limit when larger space-time sheet has infinite size: only the simultaneous evaporation of opposite gauge charges might be possible in this manner at this limit. Topological evaporation provides a possible mechanism for the generation of vacuum gauge charges, which is one basic difference between TGD and standard gauge theories.

There is a strong temptation to draw a definite conclusion but it is better to be satisfied with a simplifying working hypothesis that gauge charges are in long length scales definable as gauge fluxes and vanish for macroscopic 3-surfaces of finite size in vapor phase. This would mean that the topological evaporation of say electron as an electromagnetically charged particle would not be possible except at CP_2 length scale: in the evaporation from secondary condensation level electron would leave its gauge charges in the condensate. Vapor phase particle still looks electromagnetically charged in length scales smaller than the size of the particle surface if the neutralizing charge density is near (or at) the boundary of the surface and gauge and gravitational interactions are mediated by the exchange of CP_2 type extremals.

This conclusion is supported also by the recent formulation of quantum TGD in which wormhole throats are carriers of elementary particles. For instance, a closed cosmic string without any topologically condensed matter does not represent preferred extremal of Kähler action but a closed cosmic string containing topological condensate of CP_2 type vacuum extremals carrying fermionic quantum numbers represents a non-vacuum state in vapor phase and a good candidate for a preferred extremal. In the same manner CP_2 type extremal topologically condensed on a closed 3-surface would represent a particle -say electron- in vapour phase. What is essential that both signatures of the induced metric are involved.

In what sense could # contacts feed gauge fluxes?

One can associate with the # throats magnetic gauge charges $\pm Q_i$ defined as gauge flux running to or from the throat. The magnetic charges are of opposite sign and equal magnitude on the two space-time sheets involved. For Kähler form the value of magnetic flux is quantized and non-vanishing only if the the $t = constant$ section of causal horizon corresponds to a non-trivial homology equivalence class in CP_2 so that # contact can be regarded as a homological magnetic monopole. In this case # contacts can be regarded as extremely small magnetic dipoles formed by tightly bound # throats possessing opposite magnetic gauge charges. # contacts couple to the difference of the classical gauge fields associated with the two space-time sheets and matter-# contact and # contact-# contact interaction energies are in general non-vanishing.

Electric gauge fluxes through # throat evaluated at the light-like elementary particle horizon X_l^3 tend to be either zero or infinite. The reason is that without appropriate boundary conditions the normal component of electric $F^{tn}\sqrt{g_4}$ either diverges or is infinite since g^{tt} diverges by the effective three-dimensionality of the induced metric at X_l^3. Number theoretical compactification leads to the identification of boundary conditions at light-like 3-surfaces X_l^3 representing wormhole throats and for the induced Kähler form and metric the conditions $J_{ni} = 0$ and $g_{ni} = 0$ hold true. If these conditions apply to all components of neutral part of electro-weak gauge field, it is possible in principle to have non-vanishing and finite electric gauge fluxes. Color gauge fluxes would be also finite because color gauge field is of form $H^A J_{\alpha\beta}$. RG invariance of the gauge couplings inside given causal diamond requires that the gauge fluxes are conserved for the slicing of $X^4(X_l^3)$ by light-like 3-surfaces parallel to X_l^3. This condition can be satisfied for the known extremals of Kähler action.

Note that the conservation of four-momentum for a slicing of $X^4(X_l^3)$ by light-like surfaces requires that the conserved four-momentum vanishes for them (no out-flow of momentum through wormhole contacts so that four-momentum for space-like 3-surfaces is conserved). As a consequence, four-momentum density must vanish at X_l^3. These conditions are quite stringent and are expected to fix the dynamics at light-like 3-surfaces to high degree and imply quantization conditions expected on basis of Bohr orbit analogy.

Quantum classical correspondence suggests that classical gauge fluxes correspond to the gauge charges assignable to elementary particles.

1. This would mean that the gauge flux for a component of induced electro-weak gauge field equals to corresponding gauge coupling multiplied by the value of quantized charge for the fermion (or many-fermion state) associated with the wormhole throat (note that the induced gauge fields by definition contain gauge coupling as a hidden normalization factor). The creation of a # contact between two space-time sheets creates two causal horizons identifiable as partons and carrying conserved charges assignable with the states created using the fermionic oscillator operators associated with the second quantized induced spinor field.

2. If # contact mediates only gauge flux, these charges must be of opposite sign so that electric gauge fluxes through the throats would be equal to the quantal gauge charges multiplied by gauge coupling so that gauge coupling normalization would have a classical description. By light-likeness the wormhole contacts behave like massless particles classically and this could be seen as a good argument for the identification of neutral wormhole contacts as gauge bosons or Higgs type particles.

3. If the the net gauge charges of # contact do not vanish, it can be said to possess net gauge charge and does not serve as a passive flux mediator anymore. The proper interpretation is as W bosons and gluons with non-vanishing color isospin and hyper charge.

4. Internal consistency would mildly suggest that # contacts are possible only between space-time sheets of opposite time orientation so that four-momenta associated with the # throats would be of opposite sign but need not cancel each other. The gauge fluxes between space-time sheets of same time orientation would flow along $\#_B$ bonds.

In the gravitational case an additional difficulty is caused by the fact that it is not at all clear whether the notion of gravitational flux is well defined. The solution of this difficulty is in terms of the stringy description of gravitational interaction provided by the geometry of the preferred extremals of Kähler action.

Are the gauge fluxes through # and $\#_B$ contacts quantized?

The preferred extremal property of $X^4(X^3_l)$ and stationary phase property of the phase factor (the counterpart of $exp(ij^\mu A_\mu \sqrt{g} d^4x)$ restricted to X^3_l) selecting preferred X^3_l for given quantum numbers characterizing the dependence of quantum state on quantum numbers of wormhole throat allow to expect that the gauge fluxes through neutral #- and $\#_B$ contacts are quantized. The most natural guess would be that the unit of electric electromagnetic flux for $\#_B$ contact is 1/3 since this makes it possible for the electromagnetic gauge flux of quarks to flow to larger space-time sheets. Anyons could however mean more general quantization rules [F12]. The quantization of electromagnetic gauge flux could serve as a unique experimental signature for # and $\#_B$ contacts and their currents. The contacts can carry also magnetic fluxes. In the case of $\#_B$ contacts the flux quantization would be dynamical and analogous to that appearing in super conductors.

Hierarchy of gauge and gravitational interactions

The observed elementary particles are identified as CP_2 type extremals topologically condensed at space-time sheets with Minkowski signature of induced metric with elementary particle horizon being responsible for the parton aspect. This suggests that at CP_2 length scale gauge and gravitational interactions correspond to the exchanges of CP_2 type extremals with light-like M^4 projection with branching of CP_2 type extremal serving as the basic vertex as discussed first in the earliest attempt to construct [C2] and more than decade later in terms of generalized Feynman diagrams.

Gauge and gravitational interactions between the partons assignable to the two throats associated with # contact would be mediated by the Euclidian region # contact, which as a piece of CP_2 type vacuum extremal can be regarded as a gravitational instanton. The identification of wormhole throats and contacts as elementary particles allows to identify light-like 3-surfaces as generalized Feynman diagrams.

The gauge fluxes flowing through the $\#_B$ contacts would mediate higher level gauge and interactions between different levels of the hierarchy of space-time sheets rather than directly between CP_2 type extremals described by generalized Feynman diagrams and classical gauge fields.

2.3.3 Can one regard # *resp.* $\#_B$ contacts as particles *resp.* string like objects?

#-contacts have obvious particle like aspects identifiable as either partons or parton pairs. $\#_B$ contacts in turn behave like string like objects. Using the terminology of M-theory, $\#_B$ contacts connecting the boundaries of space-time sheets could be also seen as string like objects connecting two branes. Again the ends holes at the ends of $\#_B$ contacts carry well defined gauge charges.

contacts as particles and $\#_B$ contacts as string like objects?

The fact that # contacts correspond to parton pairs raises the hope that it is possible to apply p-adic thermodynamics to calculate the masses of # contact and perhaps even the masses of the partons. If this the case, one has an order of magnitude estimate for the first order contribution to the mass of the parton as $m \sim 1/L(p_i)$, $i = 1, 2$. It can of course happen that the first order contribution vanishes: in this case an additional factor $1/\sqrt{p_i}$ appears in the estimate and makes the mass extremely small.

For # contacts connecting space-time sheets with opposite time orientations the vanishing of the net four-momentum requires $p_1 = p_2$. According to the number theoretic considerations below it is possible to assign several p-adic primes to a given space-time sheet and the largest among them, call it p_{max}, determines the p-adic mass scale. The milder condition is that p_{max} is same for the two space-time sheets.

There are some motivations for the working hypothesis that neutral # contacts and the ends of $\#_B$ contacts feeding the gauge fluxes to the lower condensate levels or vice versa tend to be located near the boundaries of space-time sheets. For gauge charges which are not screened by vacuum charges (em and color charges) the imbedding of the gauge fields created by the interior gauge charges becomes impossible near the boundaries and the only possible manner to satisfy boundary conditions is that gauge fluxes flow to the larger space-time sheet and space-time surface becomes a vacuum extremal of the Kähler action near the boundary. If # contacts are interpreted as gauge bosons this statement would mean that space-time sheet behaves like an ideal conductor not allowing radiation fields to penetrate into its interior.

For gravitational interaction $\#_B$ contacts would have interpretation as string like objects mediating gravitational interaction. One might well argue that there is some upper bound for the gravitational flux associated with single $\#_B$ contact most naturally given by Planck mass or CP_2 mass so that the number of gravitational contacts would be proportional to the mass of the system. The equality of gravitational and inertial masses would mean that the gravitational mass associated with $\#_B$ contacts or more generally- stringy word-sheets assignable to space-time surface in the manner to be described later- is equal to the inertial mass of the system.

Could # and $\#_B$ contacts form macroscopic quantum phases?

The description as # contact as a parton pair suggests that it is possible to assign to # contacts inertial mass, say of order $1/L(p)$, they should be describable using d'Alembert type equation for a scalar field. # contacts couple dynamically to the geometry of the space-time since the induced metric defines the d'Alembertian. There is a mass gap and hence # contacts could form a Bose-Einstein (BE) condensate to the ground state. If # contacts are located near the boundary of the space-time surface, the d'Alembert equation would be 3-dimensional. One can also ask whether # contacts define a particular form of dark matter having only gravitational interactions with the ordinary matter.

Also coherent states of # contacts are possible and as will be found, Higgs mechanism could be understood as a generation of coherent state of neutral Higgs particles identified as wormhole contacts having quantum numbers of left (right) handed fermion and right (left) handed antifermion.

Also the probability amplitudes for the positions of the ends of $\#_B$ contacts located at the boundary of the space-time sheet could be described using an order parameter satisfying d'Alembert equation with some mass parameter and whether the notion of Bose-Einstein condensate makes sense also now. The model for atomic nucleus assigns to the ends of the $\#_B$ contact realized as a color magnetic flux tube having at its ends quark and anti-quark with mass scale given by $k = 127$ (MeV scale) [F8].

This heuristic picture states nothing dramatically new if # contacts are identified as bosons and $\#_B$ contacts as string like objects. The only new element is that scaled up variants of elementary particles and stringy objects are predicted with mass scales coming as $1/L_p$.

2.3.4 TGD based description of external fields

The description of a system in external field provides a nontrivial challenge for TGD since the system corresponds now to a p-adic space-time sheet k_1 condensed on background 3-surface $k_2 > k_1$. The problem is to understand how external fields penetrate into the smaller space-time sheet and also how the gauge fluxes inside the smaller space-time sheet flow to the external space-time sheet. One should also understand how the penetrating magnetic or electric field manages to preserve its value (if it does so). A good example is provided by the description of system, such as atom or nucleus, in external magnetic or electric field. There are several mechanisms of field penetration:

Induction mechanism

In the case of induction fields are mediated from level k_1 to levels $k_2 \neq k_1$. The external field at given level k_1 acts on # and $\#_B$ throats (both accompanied by a pair of partons) connecting levels k_2 and k_1. The motion of # and $\#_B$ contacts, induced by the gauge and gravitational couplings of partons involved to classical gauge and gravitational fields, creates gauge currents serving as sources of classical gauge field at the space-time sheets involved. This mechanism involves "dark" partons not predicted by standard model.

A good example is provided by the rotation of charged # throats induced by a constant magnetic field, which in turn creates constant magnetic field inside a cylindrical condensate space-time sheet. A second example is the polarization of the charge density associated with the # throats in the external electric field, which in turn creates a constant electric field inside the smaller space-time sheet.

One can in principle formulate general field equations governing the penetration of a classical gauge field from a given condensate level to other levels. The simplified description is based on the introduction of series of fields associated with various condensate levels as analogs of H and B and D and E fields in the ordinary description of the external fields. The simplest assumption is that the fields are linearly related. A general conclusion is that due to the delicacies of the induced field concept, the fields on higher levels appear in the form of flux quanta and typically the field strengths at the higher condensate levels are stronger so that the penetration of field from lower levels to the higher ones means a decomposition into separate flux tubes.

The description of magnetization in terms of the effective field theory of Weiss introduces effective field H, which is un-physically strong: a possible explanation as a field consisting of flux quanta at higher condensate levels. A general order of magnitude estimate for field strength of magnetic flux quantum at condensate level k is as $1/L^2(k)$.

Penetration of magnetic fluxes via # contacts

At least magnetic gauge flux can flow from level p_1 to level p_2 via # contacts. These surfaces are of the form $X^2 \times D^1$, where X^2 is a closed 2-surface. The simplest topology for X^2 is that of sphere S^2. This leads to the first nontrivial result. If a nontrivial magnetic flux flows through the contact, it is quantized. The reason is that magnetic flux is necessarily over a closed surface.

The concept of induced gauge field implies that magnetic flux is nontrivial only if the surface X^2 is homologically nontrivial: CP_2 indeed allows homologically nontrivial sphere. Ordinary magnetic field can be decomposed into co-homologically trivial term plus a term proportional to Kähler form and the flux of ordinary magnetic field comes only from the part of the magnetic field proportional to the Kähler form and the magnetic flux is an integer multiple of some basic flux.

The proposed mechanism predicts that magnetic flux can change only in multiples of basic flux quantum. In super conductors this kind of behavior has been observed. Dipole magnetic fields can be transported via several # contacts: the minimum is one for ingoing and one for return flux so that magnetic dipoles are actual finite sized dipoles on the condensed surface. Also the transfer of magnetic dipole field of, say neutron inside nucleus, to lower condensate level leads to similar magnetic dipole structure on condensate level. For this mechanism the topological condensation of elementary particle, say charged lepton space-time sheet, would involve at least two # contacts and the magnetic moment is proportional to the distance between these contacts. The requirement that the magnetic dipole formed by the # contacts gives the magnetic moment of the particle gives an estimate for the distance d between # throats: by flux quantization the general order of magnitude is given by $d \sim \frac{\alpha_{em} 2\pi}{m}$.

Penetration of electric gauge fluxes via # contacts

For # contact for the opposite gauge charges of partons define the value of generalized gauge electric flux between the two space-time sheets. In this case it is also possible to interpret the partons as sources of the fields at the two space-time sheets. If the # contacts are near the boundary of the smaller space-time sheet the interpretation as a flow of gauge flux to a larger space-time sheet is perfectly sensible. The partons near the boundary can be also seen as generators of a gauge field compensating the gauge fluxes from interior.

The distance between partons can be much larger than p-adic cutoff length $L(k)$ and a proper spatial distribution guarantees homogeneity of the magnetic or electric field in the interior. The distances of the magnetic monopoles are however large in this kind of situation and it is an open problem whether this kind of mechanism is consistent with experimental facts.

An estimate for the electric gauge flux Q_{em} flowing through the # contact is obtained as $n \sim \frac{E}{QL(k)}$: $Q \sim EL^2(k)$, which is of same order of magnitude as electric gauge flux over surface of are $L^2(k)$. In magnetic case the estimate gives $Q_M \sim BL^2(k)$: the quantization of Q_M is consistent with homogeneity requirement only provided the condition $B > \frac{\Phi_0}{L^2(k)}$, where Φ_0 is elementary flux quantum, holds true. This means that flux quantization effects cannot be avoided in weak magnetic fields. The second consequence is that too weak magnetic field cannot penetrate at all to the condensed surface: this is certainly the case if the total magnetic flux is smaller than elementary flux quantum. A good example is provided by the penetration of magnetic field into cylindrical super conductor through the end of the cylinder. Unless the field is strong enough the penetrating magnetic field decomposes into vortex like flux tubes or does not penetrate at all.

The penetration of flux via dipoles formed by # contacts from level to a second level in the interior of condensed surface implies phenomena analogous to the generation of polarization (magnetization) in dielectric (magnetic) materials. The conventional description in terms of fields H, B, M and D, E, P

has nice topological interpretation (which does not mean that the mechanism is actually at work in condensed matter length scales). Magnetization M (polarization P) can be regarded as the density of fictitious magnetic (electric) dipoles in the conventional theory: the proposed topological picture suggests that these quantities essentially as densities for # contact pairs. The densities of M and P are of opposite sign on the condensed surface and condensate. $B = H - M$ corresponds to the magnetic field at condensing surface level reduced by the density $-M$ of # contact dipoles in the interior. H denotes the external field at condensate level outside the condensing surface, M $(-M)$ is the magnetic field created by the # contact dipoles at condensate (condensed) level. Similar interpretation can be given for D, E, P fields. The penetrating field is homogenous only above length scales larger than the distance between # throats of dipoles: p-adic cutoff scale $L(k)$ gives natural upper bound for this distance: if this is the case and the density of the contacts is at least of order $n \sim \frac{1}{L^3(k)}$ the penetrating field can be said to be constant also inside the condensed surface.

In condensed matter systems the generation of ordinary polarization and magnetization fields might be related to the permanent # contacts of atomic surfaces with, say, $k = 139$ level. The field created by the neutral atom contains only dipole and higher multipoles components and therefore at least two # contacts per atom is necessary in gas phase, where join along boundaries contacts between atoms are absent. In the absence of external field these dipoles tend to have random directions. In external field # throats behave like opposite charges and their motion in external field generates dipole field. The expression of the polarization field is proportional to the density of these static dipole pairs in static limit. # contacts make possible the penetration of external field to atom, where it generates atomic transitions and leads to the emission of dipole type radiation field, which gives rise to the frequency dependent part of dielectric constant.

Penetration of gauge fluxes via $\#_B$ contacts

Gauge flux can also flow through $\#_B$ contacts through the boundary of the condensed surface or through the small holes in its interior. The quantization of electric charge quantization would reduce to the quantization of electric gauge flux in $\#_B$ contacts. If there are partons at the ends of contact they affect the gauge gauge flux.

The penetration via $\#_B$ contacts necessitates the existence of join along boundaries bonds starting from the boundary of the condensed system and ending to the boundary component of a hole in the background surface. The field flux flows simply along the 3-dimensional stripe $X^2 \times D^1$: since X^2 has boundary no flux quantization is necessary. This mechanism guarantees automatically the homogeneity of the penetrating field inside the condensed system

An important application for the theory of external fields is provided by bio-systems in which the penetration of classical electromagnetic fields between different space-time sheets should play central role: what makes the situation so interesting is that the order parameter describing the # and $\#_B$ Bose-Einstein condensates carries also phase information besides the information about the strength of the normal component of the penetrating field.

2.3.5 Number theoretical considerations

Number theoretical considerations allow to develop more quantitative vision about the how p-adic length scale hypothesis relates to the ideas just described.

How to define the notion of elementary particle?

p-Adic length scale hierarchy forces to reconsider carefully also the notion of elementary particle. p-Adic mass calculations led to the idea that particle can be characterized uniquely by single p-adic prime characterizing its mass squared. It however turned out that the situation is probably not so simple.

The work with modeling dark matter suggests that particle could be characterized by a collection of p-adic primes to which one can assign weak, color, em, gravitational interactions, and possibly also other interactions. It would also seem that only the space-time sheets containing common primes in this collection can interact. This suggests the notions of relative and partial darkness. An entire hierarchy of weak and color physics such that weak bosons and gluons of given physics are characterized by a given p-adic prime p and also the fermions of this physics contain space-time sheet characterized by same p-adic prime, say M_{89} as in case of weak interactions. In this picture the decay widths of weak bosons do not pose limitations on the number of light particles if weak interactions for them are characterized by p-adic prime $p \neq M_{89}$. Same applies to color interactions.

The p-adic prime characterizing the mass of the particle would perhaps correspond to the largest p-adic prime associated with the particle. Graviton which corresponds to infinitely long ranged interactions, could correspond to the same p-adic prime or collection of them common to all particles. This might apply also to photons. Infinite range might mean that the join along boundaries bonds mediating these interactions can be arbitrarily long but their transversal sizes are characterized by the p-adic length scale in question.

The natural question is what this collection of p-adic primes characterizing particle means? The hint about the correct answer comes from the number theoretical vision, which suggests that at fundamental level the branching of boundary components or more generally wormhole throats to two or more components, completely analogous to the branching of line in Feynman diagram, defines vertices [C2, C4].

1. If space-time sheets correspond holographically to multi-p p-adic topology such that largest p determines the mass scale, the description of particle reactions in terms of branchings indeed makes sense. This picture allows also to understand the existence of different scaled up copies of QCD and weak physics. Multi-p p-adicity could number theoretically correspond to q-adic topology for $q = m/n$ a rational number consistent with p-adic topologies associated with prime factors of m and n ($1/p$-adic topology is homeomorphic with p-adic topology).

2. One could also imagine that different p-adic primes in the collection correspond to different space-time sheets condensed at a larger space-time sheet or boundary components of a given space-time sheet. If the boundary topologies for gauge bosons are completely mixed, as the model of hadrons forces to conclude, this picture is consistent with the topological explanation of the family replication phenomenon and the fact that only charged weak currents involve mixing of quark families. The problem is how to understand the existence of different copies of say QCD. The second difficult question is why the branching leads always to an emission of gauge boson characterized by a particular p-adic prime, say M_{89}, if this p-adic prime does not somehow characterize also the particle itself.

What effective p-adic topology really means?

The need to characterize elementary particle p-adically leads to the question what p-adic effective topology really means. p-Adic mass calculations leave actually a lot of room concerning the answer to this question.

1. The naivest option is that each space-time sheet corresponds to single p-adic prime. A more general possibility is that the boundary components of space-time sheet correspond to different p-adic primes. This view is not favored by the view that each particle corresponds to a collection of p-adic primes each characterizing one particular interaction that the particle in question participates.

2. A more abstract possibility is that a given space-time sheet or boundary component can correspond to several p-adic primes. Indeed, a power series in powers of given integer n gives rise to a well-defined power series with respect to all prime factors of n and effective multi-p-adicity could emerge at the level of field equations in this manner.

One could say that space-time sheet or boundary component corresponds to several p-adic primes through its effective p-adic topology in a hologram like manner. This option is the most flexible one as far as physical interpretation is considered. It is also supported by the number theoretical considerations predicting the value of gravitational coupling constant [E3].

An attractive hypothesis is that only space-time sheets characterized by integers n_i having common prime factors can be connected by join along boundaries bonds and can interact by particle exchanges and that each prime p in the decomposition corresponds to a particular interaction mediated by an elementary boson characterized by this prime.

The physics of quarks and hadrons provides an immediate test for this interpretation. The surprising and poorly understood conclusion from the p-adic mass calculations was that the p-adic primes characterizing light quarks u,d,s satisfy $k_q < 107$, where $k = 107$ characterizes hadronic space-time sheet [F4].

1. The interpretation of $k = 107$ space-time sheet as a hadronic space-time sheet implies that quarks topologically condense at this space-time sheet so that $k = 107$ cannot belong to the collection of primes characterizing quark.

2. Quark space-time sheets must satisfy $k_q < 107$ unless $\hbar$ is large for the hadronic space-time sheet so that one has $k_{eff} = 107+22 = 129$. This predicts two kinds of hadrons. Low energy hadrons consists of u, d, and s quarks with $k_q < 107$ so that hadronic space-time sheet must correspond to $k_{eff} = 129$ and large value of $\hbar$. One can speak of confined phase. This allows also $k = 127$ light variants of quarks appearing in the model of atomic nucleus [F8]. The hadrons consisting of c,t,b and the p-adically scaled up variants of u,d,s having $k_q > 107$, $\hbar$ has its ordinary value in accordance with the idea about asymptotic freedom and the view that the states in question correspond to short-lived resonances.

2.4 The new space time picture and some of its consequences

The previous considerations suggest that TGD space-time has a hierarchical, fractal like structure consisting of an infinite number of condensate levels n characterized by length scale $L(n) < L(n+1)$ identifiable as a typical size for 3-surface at level n. Spin glass analogy suggests that the label n corresponds to preferred primes characterizing p-adic length scales and to values of Planck constant labelling levels of dark matter hierarchy. p-Adic fractality means that for each p there is actually a length scale hierarchy coming in powers of $\sqrt{p}$. An infinite hierarchy of copies of standard model physics is an unavoidable prediction if quantum classical correspondence is taken seriously and can be identified as dark matter hierarchy.

2.4.1 Topological condensation and formation of bound states

It is tempting to identify the physical counterpart of the topological condensate in the length scale L as a bound state with size L. If this assumption is accepted then one ends up to the rather beautiful general scenario for the hierarchical structure of the 3-space. Quarks (3-surface of size of CP_2 length, so called CP_2 type extremals to be discussed later) condense around the hadronic 3-surfaces, hadrons condense around a piece of Minkowski space with size of order $10^{-14} - 10^{-15}$ meters to form nuclei, nuclei and electrons condense to form atoms of size of the order 10^{-10} meters or larger, atoms condense to form molecules, etc.

Generalizing the previous ideas, one ends up to a rather exciting possibility for a topological description of the macroscopic states of matter. Consider solids as an example. Solids correspond to a regular lattice of atomic or molecular 3-surfaces condensed to background 3-space. There are two kinds of forces binding the structure together.
i) There are interactions mediated via the the fields of the background 3-space and these correspond to the ordinary electric forces.
ii) There is interaction resulting from the "contacts" between the boundaries of the neighboring atoms (for a two-dimensional visualization see Fig. 2.4.1). Join along boundaries bond means mathematically a tube $D^2 \times D^1$ connecting the boundaries together or equivalently, topological condensation for the boundaries. This interaction is completely new and has as its counterpart the forces generated by the electron exchange between atoms believed to explain the binding between the atoms of certain solids. It is however clear that something quite new is introduced so that the conventional belief that Schrödinger equation in a flat 3-space alone explains these interactions would not be correct in TGD context. That the approach based on Schrödinger equation have not lead to contradictions can be understood also: what join along boundaries bond makes is to select among possible solutions of Schrödinger equation those realized in Nature by forcing the Schrödinger amplitude to the bridges connecting different structural units.

The topological description of the liquid state goes along similar lines. Now however the contacts between neighboring atoms are not so rigid the reason being that thermal noise continually splits these contacts. A completely new element is the emergence of the vacuum quantum numbers and should lead to effects differentiating between TGD and more conventional approaches.

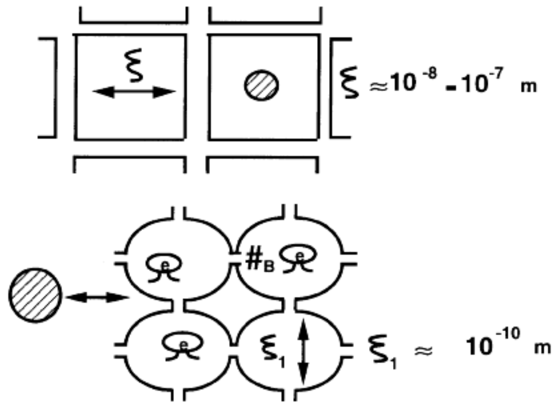

Figure 2.3: How one could understand the solid state topologically in terms of the join along boundaries interaction: 2-dim. visualization

2.4.2 3-topology and chemistry

The practical models for chemical systems rely on the assumption that a chemical element has a well defined geometric shape. If this assumption is made then Schrödinger equation in electronic degrees of freedom combined with symmetry considerations gives satisfactory results. The general belief is that the complete Scrödinger equation treating quantum mechanically also the positions of the atoms predicts also the geometric structure of the chemical compounds. Unfortunately, in practice it is not possible to check numerically the correctness of this belief.

The "join along boundaries" interaction is a second standard phenomenological concept in the chemistry. What happens that reactants join along a part of their boundaries together to form a transition state (or a final state) and the reaction takes place in the new geometry. The chemistry of the biological systems relies heavily on this concept. For example, the catalytic action of the enzymes is often understood on the basis of key and lock principle: enzyme acts on the protein only provided the surfaces of the protein and enzyme fit together like lock and key. Usually it is believed that the association of a geometric form to chemical compounds and the "join along boundaries" mechanism provide an easy short hand description, which is in principle derivable from the complete Schrödinger equations. TGD suggests that this is not be the case.

What is exciting that this kind of idea leads to a completely fresh approach to the understanding of bio-systems: the basic principles of the underlying the biochemistry could be formulated in terms of the 3-topology. The biological information processing could involve the manipulation of the 3-topology or more precisely: the manipulation of the boundary topology if "join along boundaries" is indeed the basic mechanism. It should noticed also that the emergence of the vacuum quantum numbers is purely TGD:eish feature and provides a possible means for realizing the Universe as Computer idea in biological systems. xc

2.4.3 3-topology and super-conductivity

The #-contacts (wormholes) feeding the gauge fluxes from a given sheet of the 3-space to a larger one, can be regarded as particles carrying classical charges defined by the gauge fluxes. These particles must be light, which suggests that #-contacts can form Bose-Einstein condensate or coherent state identifiable in terms of Higgs vacuum expectation value. This BE condensate provides a possible explanation of so called Comorosan effect [28] observed in organic molecules. A related effect is the formation of exotic atoms, when some valence electrons drop from the atomic space-time sheet to a larger space-time sheet. This process is accompanied by the generation of # contacts. The process leads to the effective lowering of the valence of the original atom and thus to "electronic alchemy".

The claimed peculiar properties of so called ORMES [77] could have explanation as exotic atoms as suggested in [J1, J2, J3].

I have also suggested that the basic mechanism of super-conductivity somehow involves quantum coherent states of wormhole contacts. This might be the case although not quite in the original sense. There are two poorly understood problems involved with super-conductivity.

1. Super-conductor is often modelled as a coherent state of Cooper pairs. The conceptual problem is that the electric charge of this state is not well-defined and this is definitely in conflict with the conservation of electromagnetic charge.

2. The massivation of photons is a second poorly understood basic aspect of super-conductivity. The obvious question is whether this process could be interpreted in terms of a vacuum expectation value of a charged Higgs field and whether the charge of the Higgs field resolve the paradox otherwise created by the non-conservation of electromagnetic charge.

The obvious guess is that superconductor corresponds to superposition of quantum states with a well-defined total em charge such that electronic electromagnetically charge of some electronic Cooper pairs has been transferred to neutral wormhole contacts having quantum numbers of charged left/right handed positron and neutral right/left handed neutrino so that some Cooper pairs themselves have been transmuted to neutrino Cooper pairs.

In ordinary phase a space-time sheet carrying N Cooper pairs would feed em charge to a larger space-time sheet by $2N$ wormhole contacts consisting of e^+e^- parton pair. Super-conducting phase would correspond to a superposition of states for which $2M \leq 2N$ wormhole contacts have become electromagnetically charged and $2M$ electrons have transformed to neutrinos. Coherent state would thus correspond to a superposition of states with $M \leq N$ neutrino pairs, $N-M$ Cooper pairs, and $2M$ charged wormhole contacts.

The presence of exotic W bosons mediating weak interactions in the scale of the space-time sheet would make possible this kind of states (which involved entanglement between wormhole contacts and Cooper pairs). The model would require that neutrinos and electrons in the superconducting phase have nearly identical masses and thus correspond to $p = M_{127}$, the largest Mersenne prime which corresponds to non-super-astronomical p-adic length scale. This conforms also with the absence of electro-weak symmetry breaking below the p-adic length scale characterizing the size of the Cooper pair. Also the quantum model for hearing [M6] requires that exotic neutrinos with mass very near to electron mass are involved. The TGD based model for atomic nucleus [F8] in turn predicts that quarks with mass near to electron mass appear at the ends of the color bonds connecting nucleons.

2.4.4 Macroscopic bodies as a topology of 3-space

The natural generalization of the foregoing ideas is that even the macroscopic bodies of the everyday world correspond to 3-surfaces, which have suffered topological condensation to the background 3-space. The outer surfaces of the macroscopic bodies would correspond to the boundaries of a particular space-time sheet. When macroscopic bodies touch each other, a partial join along boundaries would take place. We would live in the middle of a wild science fiction without realizing it!

Paradoxically, this new interaction is extremely familiar for us. The surface of the Earth corresponds to a boundary of a rather big 3-surface. At smaller length scales we see flowers, trees and all kinds of things and also these are 3-surfaces, which have joined along their boundaries to the surface of the Earth. Our biological bodies correspond to 3-surfaces having boundaries. We have however the special ability to cut this contact rather easily and to move quite freely although the gravitational force acting in the background 3- space takes care that the join along the boundaries with the surface of Earth is the usual state of affairs. When I touch the surface of the table by finger, a join along boundaries interaction takes place: we even recognize different objects just by touching them. We also smell and taste and at the microscopic level these senses are based on the join along boundaries interaction. Despite all this it has not been explicitly recognized that the formation of the join along boundaries bond might be a fundamental physical interaction!

What is also amusing that the implicit assumptions of any physical model of the macroscopic world is based on the assumptions about the geometric form of the physical objects and also the join along boundaries interaction is introduced implicitly into the description. For example, in order to describe solid state one draws lattice: one draws atoms in this lattice and bonds between the atoms. A second example is provided by the description of mechanical system consisting of rigid bodies.

In present picture this description is obtained by projecting the boundary of the 3- space to flat space E^3 : matter in the conventional sense corresponds to the shadow of the boundary-topology of 3-surface (for a 2-dimensional illustration see Fig.2.4.4). The fact that this kind of description is so obvious masks the fact that it is far from trivial whether one can actually deduce this kind of description starting from wave mechanics or QED.

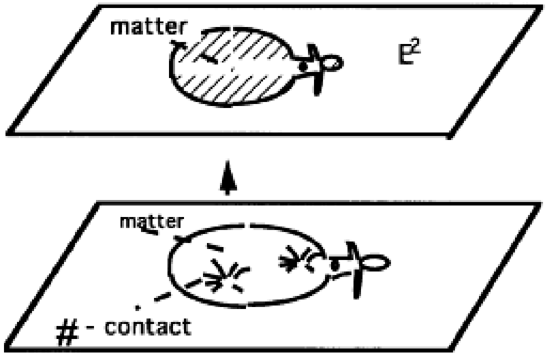

Figure 2.4: 3-dimensional matter as projection of the boundary of 3-surface to E^3: 2-dim. visualization

What is so exciting that we can deduce the rough features of the topology of the surrounding 3-space just by looking it in various scales! Single glance shows that this topology is extremely complicated and contains boundaries everywhere and in all scales. In any case, it is in principle possible to make a map of a 3-surface in H both by observation of the form of macroscopic bodies and by measuring the ordinary physical observables like electromagnetic fields. Note that the fractal properties of the world are in accordance with the prediction of RGI hypothesis that topological condensate has hierarchical structure containing 3-surfaces of all possible sizes.

To summarize, topological condensation seems to provide a purely topological description for the generation of structures. The concept of matter in topologically trivial, almost flat 3-space is replaced with an empty but topologically highly nontrivial 3-space. The idea leads to a concrete program of actually finding out what is the topology of a given form of matter and understanding the physical properties matter in terms of this topology! And it would surprising if this kind of understanding would not increase our abilities to control and manipulate the properties of the matter.

Topological field quantum as a coherent quantum system

There are several arguments suggesting that topological field quanta are good candidates for coherent quantum systems and that join along boundaries provides basic means for constructing larger quantum systems from smaller units.

1. The choice of the coordinates inside a given field quantum is analogous to the choice of the quantization axis. This suggests that the topological field quanta might provide a topological description of certain aspects of quantum phenomena. The choice of the quantization axis could indeed correspond to that taking place in quantum measurement. The fact that the quantization axes associated with different connected 3-surfaces need not be the same is in accordance with the idea that quantum coherence is possible for a connected 3-surface only. An exception is provided by a system consisting of several topological field quanta connected by "bridges" (join along boundaries bonds), for which quantization axis are same and which therefore can be be regarded as a coherent quantum system. As an example consider a spinning particle in a constant magnetic field. To describe the situation one must construct the imbedding of the

magnetic field on the particle 3-surface by requiring that the resulting 4-surfaces corresponds to a preferred extremals of Kähler action. The simplest manner to achieve this is to assume that the quantization axis defining the vacuum quantum numbers n_1 and n_2 is in the direction of the magnetic field so that one say that the external magnetic field fixes the quantization axis.

2. 3-surfaces consisting of several field quanta are in general unstable in accordance with that fact that the formation of macroscopic quantum systems is also a rare phenomenon. The argument goes as follows.
i) CP_2 coordinates tend to have discontinuous or have even infinite derivatives at the boundaries of the topological field quanta if one poses some rather sensible physical requirements like the requirement that the 3-surface provides an imbedding for the Kähler electric field created by the mass distribution. As a consequence, Einstein tensor contains delta function type singularities and this is not nice. The best manner to avoid the edges is to allow boundaries.
ii) The boundaries of a 3-surface consisting of several field quanta are in general carriers of surface Kähler (Z^0) charge as the following argument shows. The embedding of the Kähler electric field associated with a given matter distribution has certain critical radius, which corresponds to the boundary of a field quantum. In general, one cannot continue the imbedding to a neighboring field quantum without allowing infinite derivatives of CP_2 coordinates.
iii) The 3-surface consisting of several field quanta is not stable unless the condition $u = cos(\Theta) = \pm 1$ is satisfied on $r = \infty$ surfaces. The point is that the excitations of Φ coordinate in general imply discontinuity of 3-surface at the boundary unless they are strongly correlated for neighboring field quanta.

3. The gluing of topological field quanta is probably possible by the join along boundaries bonds. The tube $D^2 \times D^1$ or the "bridge" between the two topological field quanta corresponds to a topological field quantum. The most probable "hot spots", where the gluing is possible correspond to parts of the surface, where the normal component of the Kähler electric field is vanishing. Now however the stability of the join along boundaries bond is not obvious. It can also happen that the directions of the induced Kähler fields are same on some portions of the boundaries and in this case the gluing by joing along boundaries bond serving as a Kähler electric flux tube is possible: in this case the stability of the bond is obvious. The color electric flux tubes between valence quarks provide a good example of this.

Topological description of supra phases

The topological construction recipe of a supra phase could be following. Take volumes of ordinary phase with a size of order of coherence length ξ, topologically condense them to the background 3-space and construct "bridges" between the boundaries of these structures. Supra phase is destroyed if the bridges are cut either thermally or by external magnetic field: the introduction of an external magnetic field indeed destroys the bridge since it implies that the quantum numbers n_1 and n_2 become in general non-vanishing inside the field quanta and bridge so that the order parameter ψ becomes discontinuous on the boundaries of bridges.

In the ground state of the supra phase the order parameter describing the supra phase is covariantly constant. Since the topology of the join along boundaries condensate is extremely complicated, the first homotopy group of the condensate is nontrivial. This means that one in general cannot find a global gauge transformation gauging the gauge potential associated with a vanishing magnetic field away. This implies that the phase increment of the order parameter along a closed homotopically nontrivial loop is in general nontrivial. These increments obviously contain information coded into the order parameter about the topology of the join along boundaries condensate.

The BE condensate of the charged # contacts, giving rise to pseudo super conductivity, playd a key role in the earlier TGD inspired model of brain as a macroscopic quantum system. In the model discussed in this chapter the coherent state of Cooper pairs is replaced with an entangled state involving product states of $2M$ charged wormhole contacts, $N-M$ electronic Cooper pairs, and M neutrino cooper pairs. One can also ask whether the vacuum quantum numbers might provide a realization for the idea about Universe as Computer. Biological information processing might be based on the manipulation of the vacuum quantum numbers. These ideas will be developed in some detail in the last part of the book.

Topological description of dissipation

The previous topological ideas lead to a general ideas about how structures are generated at macroscopic level. There is however a standard approach to the description of the generation of structures [59] and in this approach dissipative mechanisms play central role. The basic idea is that dissipation takes care that an open system ends up to some asymptotic state, which need not be thermal equilibrium but can be a complicated dynamic, non-equilibrium state.

The topological definition of the quantum coherence suggests that these approaches are in fact very closely related. Dissipation means certainly a loss of quantum coherence since for a coherent quantum system density matrix develops unitarily so that dissipation is impossible. Quantum coherence is lost at a given level of condensation hierarchy if the condensate consists of several 3-surfaces interacting through standard interactions only. The formation of the join along boundaries bonds however creates quantum coherence. Therefore the breaking of the join along boundaries bonds provides a good candidate for a fundamental dissipation mechanism.

To make the idea more concrete consider as an example liquid flow, assuming that there is a velocity gradient in a direction orthogonal to the velocity. What one wants to understand is the friction or how the energy of the liquid is dissipated. Liquid molecules have typically join along boundaries contacts (tube $D^2 \times D^1$) with the neighboring molecules (and due to thermal motion these contacts are continuously splitting and rejoining. The average age of a typical contact is much smaller than the time scale associated with the motion of a liquid so that the contact between two neighboring molecules suffers several thermally induced splittings and re-joinings, when the neighboring molecule pass by. A natural assumption is that the contact between two neighboring molecules is like a rubber band: energy is needed to stretch it. Assume that contact is formed between neighboring atoms moving with certain relative velocity so that the contact gets longer and splits after certain average time. The energy needed to stretch the contact longer is taken from the energy of the translational motion so that the relative motion becomes slightly slower.

As a second example, consider the understanding of the finite conductivity in metals. The neighboring atoms in the metal form a lattice and there are contacts between the neighboring atoms. These contacts are not completely stable but suffer splittings now and then. The large conductivity of the metal results from these contacts since they provide for the conduction electrons the bridges to move from one atomic 3-surface to a another one. The finiteness of the conductivity results from the fact that now and then a bridge between two neighboring atoms is broken. In the last part of the book it will be found that this kind of argument leads to a correct order of magnitude estimate for the metallic conductivity using a TGD inspired modification of the Drude model.

The concept of topological condensate affords also a second new point of view concerning the description of dissipation. The standard description of dissipation is in terms of inelastic collisions of particles. This description generalizes: particles at the condensate level n correspond to topological field quanta of level $n-1$ with typical size $L(n-1)$. In inelastic collisions of these particles join along boundaries contacts are created and split and part of kinetic energy is transferred to the kinetic energy of topological field quanta of level $n-2$ condensed on level $n-1$ field quanta. This mechanism makes possible the gradual transfer of the kinetic energy to the atomic length scales, where the collisions of ordinary particles take care of the further dissipation. Some potential applications of this picture are provided by hydrodynamics: ordinary hydrodynamics generalizes to a hierarchy of hydrodynamics, one for each condensate level plus a model for the energy and momentum transfer between two subsequent levels.

2.5 Topological condensation and color confinement

In this section a simple semiclassical model of color confinement is constructed as an application of the previous ideas. Also a view about color confinement being based on the same mechanism as the generation of macroscopic and macro-temporal quantum coherence (crucial for the TGD inspired theory of consciousness [K2] is discussed. These two arguments are separated by a temporal distance longer than decade and their different style reflects the development of my own thinking about TGD.

2.5.1 Explanation of color confinement using quantum classical correspondence

One can understand color confinement from the properties of the Kähler action by applying quantum classical correspondence.

1. The classical color gauge field is proportional to $H^A J_{\alpha\beta}$, where H^A is color Hamiltonian. This implies that the color holonomy group is Abelian. This suggests strongly that the physical states correspond states of color multiplets having vanishing color hyper charge and isospin. This would mean a weak form of color confinement.

2. The proportionality of the gluon field to the induced Kähler field, approximately satisfying free Maxwell equations, implies that the direction of the classical color field in M^4 is not random and that gluon field behaves in this sense as a massless field giving rise to long range interactions. The approximate canonical invariance of the Maxwell phase, which corresponds to the exact canonical gauge invariance of the configuration space geometry, is realized as approximately local $U(1)$ transformations which become constant color rotations below a cutoff scale identifiable as the size of space-time sheet carrying color charge.

3. The fact that the classical color field is proportional to a color Hamiltonian and Kähler field implies that the direction of the gluon field in the color algebra is random above the cutoff length scale so that color cannot propagate in length scales longer than the cutoff scale. Since color gauge currents are conserved for CP_2 type extremals representing wormhole contacts, color gauge flux is conserved in wormhole contacts which are therefore color neutral as particles so that colored variant of Higgs mechanism is not possible. The finite range of color interaction therefore leaves only the possibility that the net color charge of the elementary particles topologically condensed at the hadronic space-time sheet vanishes.

2.5.2 Hadrons as color magnetic/electric flux tubes

In this model quarks and gluons correspond to small M^4 type surfaces containing topologically condensed CP_2 type extremals and these surfaces are in turn condensed on a larger hadronic M^4 type surface. Valence quarks (at least) are connected by color electric or magnetic flux tubes (join along boundaries bonds) to form color singlets.

At elementary particle level, topological condensation means the condensation of the CP_2 type extremals around M^4 type surfaces. The condensed CP_2 type extremals perform zitterbewegung with a velocity of light although cm is at rest. The 3-space surrounding the condensed elementary particle has a finite size of the order of Compton radius (natural guess at this stage). At length scales $r << r_c$ (r_c denotes the Compton radius of the particle), condensed particles look essentially like massless particles whereas at length scales $r >> r_C$ they look like pieces of M^4 condensed to the background and moving with a velocity smaller than light velocity. CP_2 type extremals can be regarded as Kähler magnetic monopoles, whose magnetic flux runs in the internal degrees of freedom so that no long range $1/r^2$ magnetic field is generated. The fact that elementary particles are in a well defined sense Kähler magnetic monopoles supports criticality hypothesis: the strong Kähler coupling phase for the electric charges must be identical with the weak coupling phase for the magnetic monopoles and therefore Kähler action must correspond to a fixed point of the coupling constant evolution (this does not exclude the p-adic coupling constant evolution with respect to the zero modes of the Kähler metric).

The construction of the configuration space geometry and of quantum TGD lead to the conclusion that the description of the non-perturbative aspects of the color interaction must be based on the flux variables defined by the induced Kähler form. These variables include as a special case the generalized classical color fluxes. Since the low energy limit of TGD is expected to be more or less equivalent with the standard model, one can ask whether color confinement is signalled also by the divergence of the color coupling strength at low energies. p-Adic length scale hypothesis makes it possible to quantitative understand the confinement scale.

There are good reasons to expect that the quantum average space-time associated with a hadron could be regarded as an orbit of a 3-surface obtained by connecting the 3-surfaces (of size smaller than hadronic size) associated with the valence quarks with color electric flux tubes to get a color singlet state. Color singletness results from the randomness of the direction of the color field above hadronic length scales implying that the average radial color gauge flux emanating from the hadron vanish. This structure in turn has suffered a topological condensation on a larger hadronic 3-surface. The cutting of one or more color electric flux tube leads automatically to a generation of compensating color charges so that only color singlets can be created in the decays of the hadron. Also the topological evaporation of only color singlet objects is possible.

Color magnetic or electric flux tubes or both?

Both color magnetic and electric flux tubes have been used to model hadrons in TGD framework as well as in QCD, and one might wonder which of these options is the correct one. For absolute minimization of Kähler action Kähler electric fields are favored so that color electric flux tubes would be in a preferred position as models of hadron. For the more general variational principle discussed in [E2] the absolute value of Kähler action for space-time region with a definite sign of action density is either minimized or maximized (these options define dual dynamics and are consistent with the fact that 3-surfaces rather than 4-surfaces are fundamental dynamical objects). Therefore both Kähler magnetic and electric flux tubes are possible so that both color electric and magnetic models can be said to be correct.

The simplest model for the color flux tube connecting two quarks is based on the following picture.

1. The CP_2 type extremals with quark quantum numbers are topologically condensed at M^4 type 3-surfaces with size smaller than the hadronic size. These 2-surfaces are in turn condensed on the hadronic 3-surface. Quark like 3-surfaces are connected by join along boundaries contacts, which are color flux tubes connecting the boundaries of the quark 3-surfaces. These color flux tubes are the counterparts of the hadronic string.

2. The color magnetic/electric flux tube is a deformation of a vacuum extremal of type $M^2 \times D^2$ ("spring"), where D^2 is a disk orthogonal to M^2. This surface indeed looks like a tube of cross section D^2. The disk has an area of order $1/T$, where T is hadronic string tension.

3. The quarks at the ends of the flux tube serve as sources of approximately constant Kähler magnetic/electric fields (giving rise to chromo-electic fields of confining type), which generate the hadronic string tension. Since color field is proportional to Kähler field, also the Kähler charge of quark and gluon is of order $q \simeq 1$. The proportionality of the induced Kähler field and classical color field implies that hadrons can be regarded as chromo-electric flux tubes. Also QCD [38, 32] affords this kind of descriptions for color confinement.

A model for color electric flux tube

Consider now in a more detail the model for the Kähler electric flux tube understood as a preferred extremal of the Kähler action. Since the actual situation is rather complicated it is useful to consider a simplified situation that is solution of the field equations with essentially constant Kähler electric field in the axal direction inside a cylinder of M^4.

The join along boundaries contact (color electric flux tube) corresponds to a surface of representable as a map from $M^4 = M^2 \times D^2$ to the homologically nontrivial geodesic sphere of type II. Here D^2 is a disk corresponding to the transversal section of the color flux tube and has size not much smaller than a typical hadronic length. One expects the Kähler action to be lowered by the generation of the Kähler electric fields. Field equations for the small deformations reduce in the lowest order to free Maxwell equations

$$D_\beta J^{\alpha\beta} = 0 \ . \tag{2.5.1}$$

Topologically condensed valence quarks at the ends of the flux tube serve as sources for the Kähler electric field.

The solution ansatz describing a constant Kähler electric field is obtained as a map from $M^4 = M^2 \times D^2$ to the geodesic sphere of type II:

$$\begin{aligned} cos(\Theta) &= u(z) \ , \\ \Phi &= \omega t \ . \end{aligned} \tag{2.5.2}$$

The interesting components of the induced metric and induced Kähler form are given by the expressions

$$
\begin{aligned}
g_{tt} &= 1-\frac{R^2\omega^2}{4}(1-u^2) \ , \\
g_{zz} &= -1-\frac{R^2}{4}\frac{u_{,z}^2}{(1-u^2)} \ , \\
J_{tz} &= \frac{u_{,z}\omega}{4} \ .
\end{aligned} \tag{2.5.3}
$$

Field equations are obtained from the conservation of four-momentum and the conservation condition for the z-component of momentum gives

$$
u_{,z}^2(g_{zz}^3 g_{tt})^{-1/2} = \frac{E}{\omega^2} \ , \tag{2.5.4}
$$

where E can be interpreted as the constant field strength.

The lowest order solution is obtained by approximating the induced metric with a flat metric so that one has

$$
\Theta = arccos(\frac{Ez}{\omega}) \ . \tag{2.5.5}
$$

The solution obtained is well defined only for the values of z having absolute value smaller that $2\pi/E$ and the g_{zz} component of the induced metric becomes infinite at the critical values of z. One might think that the appearance of the singularity is an artefact of the approximation used but this is not the case. The closer examination of the field equations shows that the singularity is unavoidable and results from the compactness of CP_2 (vector potential is proportional to $u = cos(\Theta)$) and that one cannot continue the solution in any manner for larger values of z. The nice thing is that boundary conditions are satisfied due to the singularity of the metric in the direction of the Kähler electric field. The result implies that the length of the string, and therefore the size of the hadron, is of order

$$
L \sim \frac{2\pi\omega}{E} \ .
$$

The hadronic string tension is generated dynamically. One can obtain an estimate for the string tension by noticing that the situation is to a good approximation one-dimensional. This means that the Kähler electric field of the point charge is constant. Since the Kähler charges of quarks serve as sources of the Kähler field the order of magnitude for the Kähler electric field is given from Gauss theorem

$$
E = \frac{q}{S} \ . \tag{2.5.6}
$$

where $q \simeq 1$ is the Kähler charge of quark and S is the transverse area of the string. The order of magnitude estimate $q \simeq 1$ follows from the requirement that the color charges for quarks have this order of magnitude and from the fact that classical gluon field is proportional to the Kähler field. Hadronic string tension is obtained by integrating the energy momentum density over the transversal degrees of freedom

$$
T \simeq \frac{1}{8\pi\alpha_K}\int E^2 dS \simeq \frac{1}{8\pi\alpha_K}\frac{q^2}{S} \ . \tag{2.5.7}
$$

This implies that the transversal size of the hadronic string is of the order of $S \simeq 1/GeV^2$. For ground state hadrons the length of the string is therefore of same order as the transversal size of the string. Despite this, hadrons are string like objects in a well defined sense: their topology is $D^1 \times S^2$ instead of $D^1 \times D^2$.

As already found, the imbedding of the constant Kähler electric electric field associated with the flux tube becomes singular for values $z = \pm 2\pi\omega/E$ of the coordinate variable z in the direction of E (ω is the frequency associated with the solution). The study of the spherically symmetric extremal revealed that the parameter ω has value of order $10^{-4}m_{Pl}$ in long length scales. For the hadronic space-time sheet ω must of the order $\omega \sim 1/L$, where L is a typical hadronic length in order to get reasonable length for the string like object.

2.5.3 Color confinement and generation of macro-temporal quantum coherence

How macroscopic quantum coherence is possible in macroscopic time scales? This pressing problem of quantum consciousness theories involves both the question what coherence and de-coherence really mean and what really happens in quantum jump, as well as the question how the de-coherence times in living matter could be much longer than predicted by standard physics. Color confinement is the pressing problem of particle physics apparently put under the rug during last two decades. There might be a close connection between these seemingly totally un-related puzzles as the following little argument tends to show.

Classical argument: the time spent in color bound states is very long

The TGD based solution to the problem how to achieve macro-temporal quantum coherence relies on the new physics predicted by quantum TGD. The decisive factor is the gigantic almost degeneracy of states due to the fact that CP_2 canonical transformations, which effectively act as $U(1)$ gauge transformations, are approximate symmetries of the Kähler action broken only by the classical gravitation.

The argument goes as follows.

1. The increment of the psychological time in single quantum jump is estimated to be about CP_2 time, that is about 10^4 Planck times. During this time interval quantum coherence is destroyed in zero mode degrees freedom representing macroscopic degrees of freedom as well as in all degrees of freedom in which there is no bound state entanglement. This time interval is extremely brief as compared to the actual de-coherence times, which standard quantum theory allows to estimate.

2. The formation of bound states can save the situation since bound state entanglement is not reduced during state preparation phase of the quantum jump consisting of self measurements. The transformation of the zero modes (macroscopic classical degrees of freedom in which localization occurs in each quantum jump) to quantum fluctuating degrees of freedom, when join along boundaries bonds are formed between two space-time sheets representing binding systems accompanies the formation of bound states. The reason is that only over all center of mass zero modes remain zero modes. This means that the generation of macroscopic quantum fluctuating degrees of freedom and the formation of bound states accompany each other.

3. When bound state entanglement is generated, state function reduction and state preparation cease to occur in these degrees of freedom and one has macro-temporal quantum coherence. The sequence of quantum jumps effectively binds to a single quantum jump just like elementary particles bind to form atom behaving effectively as single elementary particle. The lifetime of the bound state defines the de-coherence time.

4. This does not yet explain why the lifetimes of the bound states, or more precisely, why the time spent in bound states, is much longer than predicted by the standard physics. New physics is required for this, and spin glass degeneracy provides it. What happens is following. When a bound state is formed, the space-time sheets representing the free particles are connected by join along boundaries bonds. By quantum spin glass degeneracy the number of bound states is huge as compared to the number of free states, since there is extremely large number of join along boundaries bond configurations and differing only by the classical gravitational energy. Accordingly, the time spent in bound states, and thus also de-coherence time, is much longer than that predicted by standard physics.

How could one understand color confinement in this picture? The idea is simple: when quarks form color bound states, they are connected by color flux tubes (this is the aspect of confinement which goes outside QCD). Also color flux tubes possess huge spin glass degeneracy. Free quark states do not possess this degeneracy since join along boundaries bonds are absent. Thus the time spent in free states in which color flux tubes are absent is negligible to the time time spent in color bound states so that the states consisting of free quarks are unobservable. If this picture is correct, the divergence of the color coupling strength in confinement length scale reflects mathematically the fact that number of bound states is overwhelmingly large as compared that for the free states.

Color confinement from unitarity and spin glass degeneracy

A more precise phrasing of the idea about the connection between spin glass degeneracy and color confinement relies on unitarity conditions and the assumptions $T_{MN} \simeq T$ and $T_{Mr} \simeq T_r$. Here capital subscripts refer to degenerate hadronic states and small letter subscripts to free many-quark states. In this idealization hadronic degenerate states are stable against decay to free many-quark states with only single exception. The exceptional state should act as a doorway making possible the transition to quark-gluon plasma phase.

The S-matrix can be written as sum of unit matrix and reaction matrix T: $S = 1 + iT$.

1. The unitarity conditions $SS^{\dagger} = 1$ read in terms of T-matrix as

$$i(T - T^{\dagger}) = TT^{\dagger} \quad . \tag{2.5.8}$$

   For diagonal elements one has

$$2 \times Im(T_{mm}) = \sum_r |T_{mr}|^2 \geq 0 \quad . \tag{2.5.9}$$

   What is essential that the right hand side is non-negative and closely related to the total rate of transitions. If this rate is high also the imaginary part at the left hand side of the equation is large and therefore also the rate for the diagonal transition. For instance, in the case of low energy strong interactions this implies that the total reaction rates are high but transitions occur mostly in the forward direction. In this case the mere large number of final many-hadron states implies that most transitions occur in the forward direction.

   In the recent case one must consider both free many quark states and their bound states. Let us use capitals M, N as labels for bound states and small letters m, n as labels for free states.

2. The diagonal unitarity conditions can be written for both of these states as

$$\begin{aligned} 2Im(T_{mm}) &= \sum_r |T_{mr}|^2 + \sum_R |T_{mR}|^2 \geq 0 \quad , \\ 2Im(T_{MM}) &= \sum_R |T_{MR}|^2 + \sum_r |T_{Mr}|^2 \geq 0 \quad . \end{aligned} \tag{2.5.10}$$

   In both cases there is a large number of the degenerate states involved at the right hand side so that one expects that the right hand side has a large value. For bound states the number of degenerate states is much higher due to the additional degeneracy brought in by the join along boundaries bonds (color flux tubes). Thus the lifetime and de-coherence time should be considerably longer than expected on basis of standard physics.

3. For the non-diagonal transitions from bound states to free states one has

$$i(T_{Mm} - \overline{T}_{mM}) = \sum_r T_{Mr}\overline{T}_{mr} + \sum_R T_{MR}\overline{T}_{mR} \ . \tag{2.5.11}$$

   The right hand side is not positive definite and since a large number of amplitudes between widely different free and bound states of quarks are involved, one expects that a destructive interference occurs. This is consistent with a small value of the non-diagonal amplitudes T_{Mm} and with the long lifetime of bound states.

4. What happens for non-diagonal transitions between degenerate states? The unitarity conditions read as

$$\begin{aligned} i(T_{mn} - \overline{T}_{nm}) &= \sum_r T_{mr}\overline{T}_{nr} + \sum_r T_{mR}\overline{T}_{nR} \ , \\ i(T_{MN} - \overline{T}_{NM}) &= \sum_R T_{MR}\overline{T}_{NR} + \sum_r T_{Mr}\overline{T}_{Nr} \ . \end{aligned} \tag{2.5.12}$$

   The right hand side is not anymore positive definite and there is a very large number of summands present. Hence a destructive interference could occur and the amplitude would be very strongly restricted in the forward direction. This need not however be true in the case of degenerate states since they are expected to be very similar to each other.

5. One can indeed play with the idealization that the transition amplitudes between degenerate states are identical $T_{MN} = T$ and that the amplitudes T_{Mr} are independent of M and given by $T_{Mr} = T_r$.

   In this case T-matrix would have the form $T = t \times X$, where X is a matrix for which all elements are equal to one. t can be written as $|t|exp(i\phi)$. T-matrix is maximally degenerate and the diagonalized form T^D of T-matrix has only a single non-vanishing element equal to Nt, N the number of degenerate states. t must satisfy the unitarity condition $|t| = 2 \times sin(\phi)/N$. S-matrix would reduce to an almost unit matrix for the diagonalized bound states.

   What about the stability of the bound states in this case? The decay amplitudes for bound states corresponding to the vanishing eigen values of T are given by $T^D(M,r) = \sum c_M T_{Mr} = \sum_M c_M \times T_r = 0$ by the orthogonality of these states with the state with a non-vanishing eigen value. Thus the lifetimes of all bound states expect the one with the non-vanishing eigen value of T are infinitely long in this idealization.

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Chapter 3

General View About Physics in Many-Sheeted Space-Time: Part II

3.1 Introduction

In previous chapter "General View About Physics in Many-Sheeted Space-Time" the notion of many-sheeted space-time concept and the understanding of coupling constant evolution at space-time level were discussed without reference to the newest developments in quantum TGD. In this chapter this picture is completed by a summary of the new rather dramatic developments in TGD that have occurred during last few years (the year I am writing this is 2007). The most important steps of progress are following ones.

3.1.1 Parton level formulation of quantum TGD

The formulation of quantum TGD at partonic level identifying fundamental objects as light-like 3-surfaces having also interpretation as random light-like orbits of 2-D partons having arbitrarily large size. This picture reduces quantum TGD to an almost-topological quantum field theory and leads to a dramatic understanding of S-matrix. A generalization of Feynman diagrams emerges obtained by replacing lines of Feynman diagram with light-like 3-surfaces meeting along their ends at vertices. This picture is different from that of string models and means also a generalization of the view about space-time and 3-surface since these surfaces cannot be assumed to be a smooth manifold anymore.

Extended super-conformal invariance involving the fusion of ordinary Super-Kac Moody symmetries and so called super-symplectic invariance generalizing the Kac-Moody algebra by replacing the Lie algebra of finite-dimensional Lie group with that for symplectic transformations of $\delta M^4_\pm \times CP_2$ plays a key role in this framework. The help of professionals in this branch of mathematics would be badly needed in order to develop a detailed understanding about the predicted particle spectrum.

3.1.2 Zero energy ontology

The notion of zero energy ontology emerged implicitly in cosmological context from the observation that the imbeddings of Robertson-Walker metrics are always vacuum extremals. In fact, practically all solutions of Einstein's equations have this property very naturally. The explicit formulation emerged with the progress in the formulation of quantum TGD. In zero energy ontology physical states are creatable from vacuum and have vanishing net quantum numbers, in particular energy. Zero energy states can be decomposed to positive and negative energy parts with definite geometro-temporal separation, call it T, and having interpretation in terms of initial and final states of particle reactions. Zero energy ontology is consistent with ordinary positive energy ontology at the limit when the time scale of the perception of observer is much shorter than T. One of the implications is a new view about fermions and bosons allowing to understand Higgs mechanism among other things.

Zero energy ontology leads to the view about S-matrix as a characterizer of time-like entanglement associated with the zero energy state and a generalization of S-matrix to what might be called M-matrix emerges. M-matrix is complex square root of density matrix expressible as a product of real valued "modulus" and unitary matrix representing phase and can be seen as a matrix valued generalization of Schrödinger amplitude. Also thermodynamics becomes an inherent element of quantum theory in this approach.

3.1.3 Fusion of real and p-adic physics to single one

The fusion of p-adic physics and real physics to single coherent whole requires generalization of the number concept obtained by gluing reals and various p-adic number fields along common algebraic numbers. This leads to a completely new vision about how cognition and intentionality make themselves visible in real physics via long range correlations realized via the effective p-adicity of real physics. The success of p-adic length scale hypothesis and p-adic mass calculations suggest that cognition and intentionality are present already at elementary particle level. This picture leads naturally to an effective discretization of the real physics at the level of S-matrix and relying on the notion of umber theoretic braid.

3.1.4 Dark matter hierarchy and hierarchy of Planck constants

The idea about hierarchy of Planck constants relying on generalization of the imbedding space was inspired both by empirical input (Bohr quantization of planetary orbits and anomalies of biology) and by the mathematics of hyper-finite factors of type II_1 combined with the quantum classical correspondence. Consider first the mathematical structure in question.

1. The Clifford algebra of World of Classical Worlds (WCW) creating many fermion states is a standard example of an algebra expressible as a direct integral of copies of von Neumann algebras known as hyper-finite factor of type II_1 (HFFs). The inclusions of HFFs relate very intimately to the notion of finite measurement resolution. There is a canonical hierarchy of Jones inclusions [18] labeled by finite subgroups of SU(2) [17]. Quantum classical correspondence suggests that these inclusions have space-time correlates [C6, A9] and the generalization of imbedding space would provide these correlates.

2. The space $CD\times CP_2$, where $CD\subset M^4$ is so called causal diamond identified as the intersection of future and past directed light-cones defines the basic geometric structure in zero energy ontology. The positive (negative) energy part of the zero energy state is located to the lower (upper) light-like boundaries of $CD\times CP_2$ and has interpretation as the initial (final) state of the physical event in standard positive energy ontology. p-Adic length scale hypothesis follows if one assumes that the temporal distance between the tips of CD comes as an octave of fundamental time scale defined by the size of CP_2. The "world of classical worlds" (WCW) is union of sub-WCWs associated with spaces $CD\times CP_2$ with different locations in $M^4\times CP_2$.

3. One can say that causal diamond CD and the space CP_2 appearing as factors in $CD\times CP_2$ forms the basic geometric structure in zero energy ontology, is replaced with a book like structure obtained by gluing together infinite number of singular coverings and factor spaces of CD *resp.* CP_2 together. The copies are glued together along a common "back" $M^2\subset M^2$ of the book in the case of CD. In the case of CP_2 the most general option allows two backs corresponding to the two non-isometric geodesic spheres S^2_i, $i=I,II$, represented as sub-manifolds $\xi^1=\overline{\xi}^2$ and $\xi^1=\xi^2$ in complex coordinates transforming linearly under $U(2)\subset SU(3)$. Color rotations in CP_2 produce different choices of this pair.

4. The selection of geodesic spheres S^2 and M^2 is an imbedding space correlate for the fixing of quantization axes and means symmetry breaking at the level of imbedding space geometry. WCW is union over all possible choices of CD and pairs of geodesic spheres so that at the level no symmetry breaking takes place. The points of M^2 and S^2 have a physical interpretation in terms of quantum criticality with respect to the phase transition changing Planck constant (leakage to another page of the book through the back of the book).

5. The pages of the singular coverings are characterized by finite subgroups G_a and G_b of $SU(2)$ and these groups act in covering or leave the points of factor space invariant. The pages are labeled by Planck constants $\hbar(CD)=n_a\hbar_0$ and $\hbar(CP_2)=n_b\hbar_0$, where n_a and n_b are integers

characterizing the orders of maximal cyclic subgroups of G_a and G_b. For singular factor spaces one has $\hbar(CD) = \hbar_0/n_a$ and $\hbar(CP_2) = \hbar_0/n_b$. The observed Planck constant corresponds to $\hbar = (\hbar(CD)/\hbar(CP_2)) \times \hbar_0$. What is also important is that $(\hbar/\hbar_0)^2$ appears as a scaling factor of M^4 covariant metric so that Kähler action via its dependence on induced metric codes for radiative corrections coming in powers of ordinary Planck constant: therefore quantum criticality and vanishing of radiative corrections to functional integral over WCW does not mean vanishing of radiative corrections.

The interpretation in terms of dark matter comes as follows.

1. Large values of $\hbar$ make possible macroscopic quantum phase since all quantum scales are scaled upwards by $\hbar/\hbar_0$. Anyonic and charge fractionization effects allow to "measure" $\hbar(CD)$ and $\hbar(CP_2)$ rather than only their ratio. $\hbar(CD) = \hbar(CP_2) = \hbar_0$ corresponds to what might be called standard physics without any anyonic effects and visible matter is identified as this phase.

2. Particle states belonging to different pages of the book can interact via classical fields and by exchanging particles, such as photons, which leak between the pages of the book. This leakage means a scaling of frequency and wavelength in such a manner that energy and momentum of photon are conserved. Direct interactions in which particles from different pages appear in the same vertex of generalized Feynman diagram are impossible. This seems to be enough to explain what is known about dark matter. This picture differs in many respects from more conventional models of dark matter making much stronger assumptions and has far reaching implications for quantum biology, which also provides support for this view about dark matter.

All this is a work in progress and there are many uncertainties involved. Despite this it seems that it is good to sum up the recent view in order to make easier to refer to the new developments in the existing chapters.

3.2 The new developments in quantum TGD

This section summarizes the developments in quantum TGD which have taken place during last few years.

3.2.1 Reduction of quantum TGD to parton level

It took surprisingly long time before the realization that quantum TGD can be reduced to parton level in the sense that fundamental objects are light-like 3-surfaces (of arbitrary size). This identification follows from 4-D general coordinate invariance. Light-likeness in turn implies effective 2-dimensionality of the fermionic dynamics. 4-D space-time sheets are identified as preferred extrema of Kähler action. A stronger form of holography is that modified Dirac action and Chern-Simons action for light-like partonic 3-surfaces defined the Kähler action as a logarithm of the fermionic determinant.

Magic properties of 3-D light-like surfaces and generalization of super-conformal symmetries

The very special conformal properties of both boundary $\delta M^4_\pm$ of 4-D light-cone and of light-like partonic 3-surfaces X^3 imply a generalization and extension of the super-conformal symmetries of super-string models to 3-D context [B2, B3, C1]. Both the Virasoro algebras associated with the light-like coordinate r and to the complex coordinate z transversal to it define super-conformal algebras so that the structure of conformal symmetries is much richer than in string models.

1. The symplectic transformations of $\delta M^4_\pm \times CP_2$ give rise to an infinite-dimensional symplectic/symplectic algebra having naturally a structure of Kac-Moody type algebra with respect to the light-like coordinate of $\delta M^4_\pm = S^2 \times R_+$ and with finite-dimensional Lie group G replaced with the symplectic group. The conformal transformations of S^2 localized with respect to the light like coordinate act as conformal symmetries analogous to those of string models. The super-symplectic algebra, call it SC, made local with respect to partonic 2-surface can be regarded as a Kac-Moody algebra associated with an infinite-dimensional Lie algebra.

2. The light-likeness of partonic 3-surfaces is respected by conformal transformations of H made local with respect to the partonic 3-surface and gives to a generalization of bosonic Kac-Moody algebra, call it KM, Also now the longitudinal and transversal Virasoro algebras emerge. The commutator $[KM, SC]$ annihilates physical states.

3. Fermionic Kac-Moody algebras act as algebras of left and right handed spinor rotations in M^4 and CP_2 degrees of freedom. Also the modified Dirac operator allows super-conformal symmetries as gauge symmetries of its generalized eigen modes.

Quantum TGD as almost topological quantum field theory at parton level

The original belief was that the light-like character of basic dynamical objects X_l^3 at which the signature of the induced metric changes implies that Chern-Simons action for the induced Kähler gauge potential of CP_2 determines the classical dynamics of partonic 3-surfaces [B4]. This turned out to be a wrong guess: Kähler action and corresponding modified Dirac action is enough.

1. Number theoretical compactification and the properties of known extremals of Kähler action suggests strongly the slicing of space-time surface by 3-D light-like surfaces Y_l^3 parallel to X_l^3. The surfaces Y_l^3 behave as independent dynamical units in the sense that conserved currents flow along them so that quantum holography is realized. Number theoretic compactification allows also dual slicings of $X^4(X_l^3)$ by string world sheets Y^2 and partonic 2-surfaces X^2.

2. The modified Dirac action obtained as the super-symmetric counterpart Kähler action fixes the dynamics of the second quantized free fermionic fields in terms of which configuration space gamma matrices and configuration space spinors can be constructed. The essential difference to the ordinary massless Dirac action is that induced gamma matrices are replaced by the contractions of the symplectic momentum densities Kähler action with imbedding space gamma matrices. Therefore the effective metric defined by the modified gamma matrices replaces ordinary gamma matrices and the corresponding effective metric can be non-singular even when induced metric is degenerate. Effective 3-dimensionality means that the modes of the induced spinor field are constant with respect to the light-like coordinate labeling the slices Y_l^3.

3. Modified Dirac action is consistent with the symmetries of Kähler action provided its first variation with respect to H coordinates vanishes - or equivalently- the second variation of Kähler action varies. This would realize quantum criticality at space-time level. One can consider also the possibility that second variation vanishes only for those deformations which correspond to conserved currents.

4. Modified Dirac operator decomposes as $D_K = D_K(Y^2) + D_K(X^2)$ and its zero modes for effectively 3-D solutions can be chosen to be generalized eigenmodes of $D_K(X^2)$. The product of the generalized eigenvalues of $D_K(X^2)$ defines the exponent of Kähler function conjectured to reduce to Kähler action for the preferred extremal.

Fermionic statistics is geometrized in terms of spinor geometry of WCW since gamma matrices are linear combinations of fermionic oscillator operators identifiable also as super-symplectic generators [B4]. Only the light-likeness property involving the notion of induced metric breaks the topological QFT property of the theory so that the theory is as close to a physically trivial theory as it can be.

The resulting generalization of $N = 4$ super-conformal symmetry [27] involves super-symplectic algebra (SC)and super Kac-Moody algebra (SKM) [C1] There are considerable differences as compared to string models. Super generators carry fermion number, no sparticles are predicted (at least super Poincare invariance is not obtained), SKM algebra and corresponding Virasoro algebra associated with light-like coordinates of X^3 and $\delta M^4_\pm$ do not annihilate physical states which justifies p-adic thermodynamics used in p-adic mass calculations, four-momentum does not appear in Virasoro generators so that there are no problems with Lorentz invariance, and mass squared is p-adic thermal expectation of conformal weight.

3.2.2 Quantum measurement theory with finite measurement resolution

Infinite-dimensional Clifford algebra of CH can be regarded as a canonical example of a von Neumann algebra known as a hyper-finite factor of type II_1 [16, 17](shortly HFF) characterized by the defining condition that the trace of infinite-dimensional unit matrix equals to unity: $Tr(Id) = 1$. In TGD framework the most obvious implication is the absence of fermionic normal ordering infinities whereas the absence of bosonic divergences is guaranteed by the basic properties of the configuration space Kähler geometry, in particular the non-locality of the Kähler function as a functional of 3-surface.

The special properties of this algebra, which are very closely related to braid and knot invariants [17, 26], quantum groups [19, 17], non-commutative geometry [23], spin chains, integrable models [21], topological quantum field theories [22], conformal field theories, and at the level of concrete physics to anyons [20], generate several new insights and ideas about the structure of quantum TGD.

Jones inclusions $\mathcal{N} \subset \mathcal{M}$ [18, 17] of these algebras lead to quantum measurement theory with a finite measurement resolution characterized by $\mathcal{N}$ [C6, A9]. Quantum Clifford algebra $\mathcal{M}/\mathcal{N}$ interpreted as $\mathcal{N}$-module creates physical states modulo measurement resolution. Complex rays of the state space resulting in the ordinary state function reduction are replaced by $\mathcal{N}$-rays and the notions of unitarity, hermiticity, and eigenvalue generalize [A9, C2].

The notion of entanglement generalizes so that entanglement coefficients are N-valued. Generalized eigenvalues are in turn N-valued hermitian operators. S- and U-matrices become N valued and probabilities are obtained from N-valued probabilities as traces.

Non-commutative physics would be interpreted in terms of a finite measurement resolution rather than something emerging below Planck length scale. An important implication is that a finite measurement sequence can never completely reduce quantum entanglement so that entire universe would necessarily be an organic whole. Topologically condensed space-time sheets could be seen as correlates for sub-factors which correspond to degrees of freedom below measurement resolution. Topological condensation in turn corresponds to the inclusion $\mathcal{N} \subset \mathcal{M}$. This is however not the only possible interpretation.

3.2.3 Hierarchy of Planck constants

The idea about hierarchy of Planck constants relying on generalization of the imbedding space was inspired both by empirical input (Bohr quantization of planetary orbits) and by the mathematics of hyper-finite factors of type II_1 combined with the quantum classical correspondence.

The generalization of imbedding space concept and hierarchy of Planck constants

Quantum classical correspondence suggests that Jones inclusions [18] have space-time correlates [C6, A9]. There is a canonical hierarchy of Jones inclusions labeled by finite subgroups of SU(2)[17] This leads to a generalization of the imbedding space obtained by gluing an infinite number of copies of H regarded as singular bundles over $H/G_a \times G_b$, where $G_a \times G_b$ is a subgroup of $SU(2) \times SU(2) \subset SL(2,C) \times SU(3)$. Gluing occurs along a factor for which the group is same. The generalized imbedding space has clearly a book like structure with pages of books intersecting along 4-D sub-manifold $M^2 \times S^2$, S^2 a geodesic sphere of CP_2 characterizing the choice of quantization axies. Entire configuration space is union over "books" corresponding to various choices of this sub-manifold.

The groups in question define in a natural manner the direction of quantization axes for for various isometry charges and this hierarchy seems to be an essential element of quantum measurement theory. Ordinary Planck constant, as opposed to Planck constants $\hbar_a = n_a \hbar_0$ and $\hbar_b = n_b \hbar_0$ appearing in the commutation relations of symmetry algebras assignable to M^4 and CP_2, is naturally quantized as $\hbar = (n_a/n_b)\hbar_0$, where n_i is the order of maximal cyclic subgroup of G_i. The hierarchy of Planck constants is interpreted in terms of dark matter hierarchy [A9]. What is also important is that $(n_a/n_b)^2$ appear as a scaling factor of M^4 metric so that Kähler action via its dependence on induced metric codes for radiative corrections coming in powers of ordinary Planck constant: therefore quantum criticality and vanishing of radiative corrections to functional integral over WCW does not mean vanishing of radiative corrections.

G_a would correspond directly to the observed symmetries of visible matter induced by the underlying dark matter [A9]. For instance, in living matter molecules with 5- and 6-cycles could directly reflect the fact that free electron pairs associated with these cycles correspond to $n_a = 5$ and $n_a = 6$ dark matter possibly responsible for anomalous conductivity of DNA [A9, J1] and recently reported strange properties of graphene [75]. Also the tedrahedral and icosahedral symmetries of water molecule clusters could have similar interpretation [53, F9].

A further fascinating possibility is that the observed indications for Bohr orbit quantization of planetary orbits [30] could have interpretation in terms of gigantic Planck constant for underlying dark matter [D6] so that macroscopic and -temporal quantum coherence would be possible in astrophysical length scales manifesting itself in many manners: say as preferred directions of quantization axis (perhaps related to the CMB anomaly) or as anomalously low dissipation rates.

Since the gravitational Planck constant is proportional to the product of the gravitational masses of interacting systems, it must be assigned to the field body of the two systems and characterizes the interaction between systems rather than systems themselves. This observation applies quite generally and each field body of the system (em, weak, color, gravitational) is characterized by its own Planck constant.

In the gravitational case the order of G_a is gigantic and at least GM_1m/v_0, $v_0 = 2^{-11}$ the favored value. The natural interpretation is as a discrete rotational symmetry of the gravitational field body of the system having both gravimagnetic and gravi-electric parts. The subgroups of G_a for which order is a divisor of the order of G_a define broken symmetries at the lower levels of dark matter hierarchy, in particular symmetries of visible matter.

The number theoretically simple ruler-and-compass integers having as factors only first powers of Fermat primes and power of 2 would define a physically preferred sub-hierarchy of quantum criticality for which subsequent levels would correspond to powers of 2: a connection with p-adic length scale hypothesis suggests itself. Ruler and compass hypothesis implies that besides p-adic length scales also their 3- and 5- multiples should be important. Note that in the structure of chromosomes p-adic length scale $L(151) \simeq 10$ characterizes beads-on-string structure of DNA whereas the length scale $3L(151)$ appears in the coiling of this structure.

Implications of dark matter hierarchy

The basic implication of dark matter hierarchy is hierarchy of macroscopic quantum coherent systems covering all length scales. The presence of this hierarchy is visible as exact discrete symmetries of field bodies reflecting at the level of visible matter as broken symmetries. In case of gravitational interaction these symmetries are highest and also the scale of quantum coherence is astrophysical. Together with ruler-and-compass hypothesis and p-adic length scale hypothesis this leads to very powerful predictions and p-adic length scale hypothesis might reduce to the ruler-and-compass hypothesis.

At the level of condensed matter one application is nuclear string model explaining also the selection rules of cold fusion and predicting that dark copy of weak physics with atomic scale defining the range of weak interaction is involved. Note that cold fusion has recently gained considerable support. High T_c super-conductivity is second application of dark matter hierarchy.

The 5- and 6-fold symmetries of the sugar backbone of DNA suggest that corresponding cyclic groups or cyclic groups having these groups as factors are symmetries of dark matter part of DNA presumably consisting of what is called as free electron pairs assignable to 5- and 6-cycles. The model allows to understand the observed high conductivity of DNA not consistent with the insulator property of DNA at the level of visible matter.

One also ends up with a speculative notion of N-atom providing a mechanism for the emergence of symbolic representations at the level of bio-molecules and a general mechanism of bio-catalysis.

Dark matter and bio-control

The hierarchy of dark matters provides rather concrete realization for the vision about living matter as quantum critical system. This vision will be discussed in more detail later.

The large Planck constants characterize various field bodies of physical system. This gives justification to the notion of (magnetic) field body which plays key role in TGD inspired model of living matter serving as intentional agent controlling the behavior of field body. For instance, the model of EEG relies and of bio-control relies on this notion. The large value of the Planck constant is absolutely essential since for a given low frequency it allows to have gauge boson energy above thermal threshold. Large value of Planck constant is essential for time mirror mechanism which is behind the models of metabolism, long term memory, and intentional action.

The huge values of gravitational Planck constant supports the vision of Penrose [54] about the special role of quantum gravitation in living matter. In TGD framework the proposal of Penrose and

Hameroff for the emergence of consciousness known as Orch-Or (Orchestrated Objective Reduction [55]) is however too restricted since it gives a very special role to micro-tubules.

A reasonable guess - based on the hypothesis that transition to dark matter phase occurs when perturbation theory for standard value of Planck constant fails - is that $GMm > 1$ is the criterion for the transition to dark phase for the gravitational field body characterizing the interaction between the two masses so that Planck mass becomes the critical mass for this transition. For the density of water this means size scale of .1 mm, the size of large neuron.

3.2.4 Zero energy ontology

Zero energy ontology has roots in TGD inspired cosmology [D5]. The problem has been that the imbeddings of Robertson-Walker cosmologies have vanishing densities of Poincare momenta identified as inertial momenta whereas gravitational energy density is non-vanishing. This led to the conclusion that one must allow space-time sheets with both time orientations such that the signs of Poincare energies are different for them and total density of inertial energy vanishes. Gravitational momenta can be identified as difference of the Poincare momenta and need not be conserved.

Construction of S-matrix and zero energy ontology

The construction of S-matrix allows to formulate this picture more sharply. Zero energy states have positive and negative energy parts located in geometric past and future and S-matrix can be identified as time-like entanglement coefficients between these states. Positive energy ontology is a good approximation in time scales shorter than the temporal distance between positive and negative energy states. This picture leads also to a generalization of Feynman graphs obtained by gluing light-like partonic 3-surfaces together along their ends at vertices. These Feynman cobordisms become a basic element of quantum TGD having interpretation as almost topological QFT and category theoretical formulation of quantum TGD emerges.

Elementary particles and zero energy ontology

At the level of elementary particles zero energy ontology means that fermionic quantum numbers are located at the light-like throats of wormhole contacts connecting CP_2 type extremals with Euclidian signature of induced metric to space-time sheets with Minkowskian signature of induced metric. Gauge bosons in turn correspond to pieces of CP_2 type extremals connecting positive and negative energy space-time sheets with fermion and antifermion quantum numbers at the throats of the wormhole contact. Depending on the sign of net energy one has ordinary boson or its phase conjugate. Gravitons correspond to pairs of fermion or gauge boson pair with particle and antiparticle connected by flux tube. This string picture emerges automatically if one assumes that the fermions of the conformal field theory associated with partonic 3-surface are free. It is also possible to have gauge bosons corresponding to single wormhole throat: these particles correspond to bosonic generators of super-symplectic algebra and excitations which correspond to genuine configuration space degrees of freedom so that description in terms of quantum field theory in fixed background space-time need not work.

3.2.5 U- and S-matrices

In quite early stage physical arguments led to the conclusion that the universal U-matrix associated with quantum jump must be distinguished from the S-matrix characterizing the rates of particle reactions. The notion of zero energy ontology was however needed before it became possible to characterize the difference between these matrices in a more precise manner.

Some distinctions between U- and S-matrices

The distinctions between U- and S-matrices have become rather clearer.

1. U-matrix is the universal unitary matrix assignable to quantum jump between zero energy states whereas S-matrix can be identified as time-like entanglement coefficients between positive and negative energy parts of the zero energy state. Thus S-matrix characterizes zero energy states.

2. U-matrix is always between zero energy states and the corresponding state function reduction reduces entanglement between zero energy states. State function reduction for S-matrix elements reduces the entanglement between positive and negative energy parts of a given zero energy state and is completely analogous to ordinary quantum measurement reducing entanglement between systems having space-like separation.

3. U-matrix is unitary whereas S-matrix can be unitary only for HFFs of type II_1. In the most general case S-matrix can be regarded as a "square" root of the density matrix assignable to time like entanglement: this hypothesis would unify the notions of S-matrix and density matrix and one could regard quantum states as matrix analogs of Schrö;dinger amplitudes expressible as products of its modulus (square root of probability density replaced with square root of density matrix) and phase (possibly universal unitary S-matrix). Thermal S-matrices define an important special case and thermodynamics becomes an integral part of quantum theory in zero energy ontology.

4. U-matrix can have elements between different number fields. In this case one must however assume number theoretical universality meaning that U-matrix has rational or at most algebraic matrix elements. In the case of HFFs of type II_1 this might imply triviality. U-matrix between p-adic and real number fields would relate to intentional action and the almost triviality would be a blessing meaning that the realization of intentional action occurs in a very precise manner and is restricted only by cutoff due to the algebraic character of number theoretic braids.

   S-matrix as time-like entanglement matric is diagonal with respect to number field and number theoretical universality is not absolutely essential for its definition.

Number theoretic universality and S-matrix

The fact that zero energy states are created by p-adic to-real transitions and must be number theoretically universal suggests strongly that the data about partonic 2-surfaces contributing to S-matrix elements come from the intersection of real partonic 2-surface and its p-adic counterpart satisfying same algebraic equations. The intersection consists of algebraic points and contains as subset number theoretic braids central for the proposed construction of S-matrix.

The question is whether also states for which S-matrix receives data from non-algebraic points should be allowed or whether the data can come even from continuous string like structures at partonic 2-surfaces as standard conformal field theory picture would suggest. If also S-matrix is algebraic, one can wonder whether there is any difference between p-adic and real physics at all. The latter option would mean that intentional action is followed by a unitarity process U analogous to a dispersion of completely localized particle implied by Schröndinger equation.

The algebraic universality of S-matrix could mean that S-matrix is obtained as algebraic continuation of rational S-matrix by replacing incoming momenta and other continuous quantum numbers with real ones. Similar continuation should make sense in p-adic sector. S-matrix and U-matrix in a given algebraic extension of rationals or p-adics are not in general diagonalizable. Thus number theory would allows to avoid the paradoxical conclusion that S-matrix is always diagonal in a suitable basis.

3.2.6 Number theoretic ideas

p-Adic physics emerged roughly at the same time via p-adic mass calculations. The interpretation of p-adic physics as physics of cognition and intentionality emerged. The basic idea was that bosonic p-adic space-time sheets provide representations for intentions and the transformation of intention to action corresponds to a transformation of p-adic space-time sheet to a real one. Gauge bosons identified as pairs of wormhole throats carrying fermion and antifermion numbers so that a a more precise characterization of "bosonic" would be as "purely bosonic" meaning wormhole throat associated with CP_2 type extremal. These bosons would be exotic and correspond to states of super-symplectic representations. If one accepts the hypothesis that fermionic Fock algebra represents Boolean cognition, one ends up the idea that fermions and their p-adic counterparts appear as pairs and that p-adic partonic 2-surface has interpretation as cognitive representation of fermion. This picture conforms nicely with interpretation in terms of infinite primes.

Cognition and intentionality would be present already at elementary particle level and p-adic fractality would be the experimental signature of it making itself visible in elementary particle mass spectrum among other things. The success of p-adic mass calculations provides strong siupport for the hypothesis.

This led gradually to the vision about physics as generalized number theory. It involves three separate aspects.

1. The p-adic approach led eventually to the program of fusing real physics and various p-adic physics to a single coherent whole by generalizing the number concept by gluing reals and various p-adics to a larger structure along common rationals and algebraics. This inspired the notion of algebraic universality stating that for instance S-matrix should result by algebraic continuation from rational or at most algebraic valued S-matrix.

   The notion of number theoretic braid belonging to the algebraic intersection of real and p-adic partonic 2-surface obeying same algebraic equations emerged also and gives a further connection with topological QFT:s. The perturbation theoretic definition of S-matrix is definitely excluded in this approach and TGD indeed leads to the understanding of coupling constant evolution at the level of "free" theory as a discrete p-adic coupling constant evolution so that radiative corrections are not needed for this purpose.

2. Also the classical number fields relate closely to TGD and the vision is that imbedding space M^4xCP_2 emerges from the physics based on hyper-octonionic 8-space with associativity as the fundamental dynamical principle both at classical and quantum level. Hyper-octonion space M^8 with space-time surface identified as hyper-quanternionic sub-manifolds or their duals and M^4xCP_2 would provide in this framework dual manners to describe physics and this duality would provide TGD counterpart for compactication.

3. The construction of infinite primes is analogous to repeated second quantization of super-symmetric arithmetic quantum field theory. This notion implies a further generalization of real and p-adic numbers allowing space-time points to have infinitely complex number theoretic structure not visible at the level of real physics. The idea is that space-time points define the Platonia able to represent in its structure arbitrarily complex mathematical structures and that space-time points could be seen as evolving structures becoming quantum jump by quantum jump increasingly complex number theoretically. Even the world of classical worlds (light-like 3-surfaces) and quantum states of Universe might be represented in terms of the number theoretic anatomy of space-time points (number theoretic Brahman=Atman and algebraic holography).

S-matrix as a functor and the groupoid structure formed by S-matrices

In zero energy ontology S-matrix can be seen as a functor from the category of Feynman cobordisms to the category of operators. S-matrix can be identified as a "square root" of the positive energy density matrix $S = \rho_+^{1/2} S_0$, where S_0 is a unitary matrix and ρ_+ is the density matrix for positive energy part of the zero energy state. Obviously one has $SS^\dagger = \rho_+$. $S^\dagger S = \rho_-$ gives the density matrix for negative energy part of zero energy state. Clearly, S-matrix can be seen as matrix valued generalization of Schrödinger amplitude. Note that the "indices" of the S-matrices correspond to configuration space spinors (fermions and their bound states giving rise to gauge bosons and gravitons) and to configuration space degrees of freedom (world of classical worlds). For hyper-finite factor of II_1 it is not strictly speaking possible to speak about indices since the matrix elements are traces of the S-matrix multiplied by projection operators to infinite-dimensional subspaces from right and left.

The functor property of S-matrices implies that they form a multiplicative structure analogous but not identical to groupoid [30]. Recall that groupoid has associative product and there exist always right and left inverses and identity in the sense that ff^{-1} and $f^{-1}f$ are always defined but not identical and one has $fgg^{-1} = f$ and $f^{-1}fg = g$.

The reason for the groupoid like property is that S-matrix is a map between state spaces associated with initial and final sets of partonic surfaces and these state spaces are different so that inverse must be replaced with right and left inverse. The defining conditions for groupoid are replaced with more general ones. Also now associativity holds but the role of inverse is taken by hermitian conjugate. Thus one has the conditions $fgg^\dagger = f\rho_{g,+}$ and $f^\dagger fg = \rho_{f,-}g$, and the conditions $ff^\dagger = \rho_+$ and $f^\dagger f = \rho_-$ are satisfied. Here $\rho_\pm$ is density matrix associated with positive/negative energy parts of zero energy state. If the inverses of the density matrices exist, groupoid axioms hold true since $f_L^{-1} = f^\dagger \rho_{f,+}^{-1}$ satisfies $ff_L^{-1} = Id_+$ and $f_R^{-1} = \rho_{f,-}^{-1} f^\dagger$ satisfies $f_R^{-1} f = Id_-$.

There are good reasons to believe that also tensor product of its appropriate generalization to the analog of co-product makes sense with non-triviality characterizing the interaction between the systems of the tensor product. If so, the S-matrices would form very beautiful mathematical structure bringing in mind the corresponding structures for 2-tangles and N-tangles. Knowing how incredibly powerful the group like structures have been in physics, one has good reasons to hope that groupoid like structure might help to deduce a lot of information about the quantum dynamics of TGD.

A word about nomenclature is in order. S has strong associations to unitarity and it might be appropriate to replace S with some other letter. The interpretation of S-matrix as a generalized Schrödinger amplitude would suggest Ψ-matrix. Since the interaction with Kea's M-theory blog (with M denoting Monad or Motif in this context) was crucial for the realization of the the connection with density matrix, also M-matrix might work. S-matrix as a functor from the category of Feynman cobordisms in turn suggests C or F. Or could just Matrix denoted by M in formulas be enough?

Number theoretic braids

The notion of number theoretic braid has gradually evolved to a fundamental notion in quantum TGD and both number theoretical universality (p-adicization), TGD as almost-TQFT, and the notion of finite measurement resolution lead to this notion. The decisive proof of the notion came from the observation that the special properties of Kähler action imply this concept. In the quantization of induced spinor fields the number of fermionic oscillators is finite so that anti-commutation relations can hold true only for a finite point set defining the points of the number theoretic braid. The natural identification of the number theoretic braid is as the intersection of M^4 (CP_2) projection of X_l^3 with the back M^2 of M^4 book (back S_i^2, $i = I, II$, of CP_2 book) so that the points of braid would be always quantum critical. Both homologically trivial ($i = I$) and non-trivial geodesic sphere ($i = II$) can be considered in the case of CP_2 so that there would be three possibly equivalent braidings defining kind of holy trinity.

The notion of number theoretic braid is especially interesting from the point of view of quantum biology. Generalized Feynman diagrams obtained by gluing light-like partonic 3-surfaces (whose sizes can be arbitrarily large) along their ends and define what might be called Feynman cobordisms. The first expectation was that number theoretic braids replicate in the vertices identifiable as partonic 2-surfaces at which the incoming and outgoing lines of generalized Feynman diagram meet. This would be nice but is not the case since by the lacking anti-commutatitivity of the incoming and outgoing oscillator operators the lines need not meet in this manner. This suggested an attractive information theoretic interpretation of generalized Feynman diagrams. Incoming and outgoing "lines" would give rise to topological quantum computations characterized by corresponding M-matrices, vertices would represent the replication of number theoretic braids analogous to DNA replication, and internal lines would be analogous to quantum communications. One could of generalize this simple view about computation by allowing creation of new strands instead of mere replication.

Number theoretic braids are associated with light-like 3-surfaces and can be said to have both dynamical and static characteristics. Partonic 2-surfaces as sub-manifolds of space-like 3-surface can also become linked and knotted and would naturally define space-like counterparts of tangles. Number theoretic braids could define dynamical topological quantum computation like operations whereas partonic 2-surfaces associated with say RNA could define as their space-like counterparts tangles and in the special case braids analogous to printed quantum programs so that there is duality between space-like and light-like braids [E10]. In terms of dance metaphor the dynamical braiding defined by the light like braid points interpreted as dancers has as a dual space-like braiding resulting as the threads connecting the feet of the dancers get tangled. An interesting question is how light-like and space-like braidings are transformed to each other: could this process correspond to a conscious reading like process and how closely DNA relates to language so that reading and writing would be fundamental processes appearing in all scales.

It came as a pleasant surprise that the idea about duality of space-like and light-like braidings inspired by DNA as topological quantum computer model [E10] is realized at the level of basic quantum TGD [B4]. The dual slicings of $X^4(X_l^3)$ to string world sheets Y^2 and partonic 2-surfaces X^2 generalize the original picture in the sense that one can speak either about partons or string world sheets as basic objects. The strings connecting points of braid strands in X_l^3 would define space-like braidings whereas time like braidings are associated with X_l^3. The light-like braiding at X_l^3 induces the space-like braiding of strings connecting the points of the strands to the strands of other braids.

Dark matter hierarchy and hierarchy of quantum critical systems in modular degrees of freedom

Dark matter hierarchy corresponds to a hierarchy of conformal symmetries Z_n of partonic 2-surfaces with genus $g \geq 1$ such that factors of n define subgroups of conformal symmetries of Z_n. By the decomposition $Z_n = \prod_{p|n} Z_p$, where $p|n$ tells that p divides n, this hierarchy corresponds to an hierarchy of increasingly quantum critical systems in modular degrees of freedom. For a given prime p one has a sub-hierarchy Z_p, $Z_{p^2} = Z_p \times Z_p$, etc... such that the moduli at n+1:th level are contained by n:th level. In the similar manner the moduli of Z_n are sub-moduli for each prime factor of n. This mapping of integers to quantum critical systems conforms nicely with the general vision that biological evolution corresponds to the increase of quantum criticality as Planck constant increases. This hierarchy would also define a hierarchy of conscious entities and could relate directly to mathematical cognition.

The group of conformal symmetries could be also non-commutative discrete group having Z_n as a subgroup. This inspires a very short-lived conjecture that only the discrete subgroups of SU(2) allowed by Jones inclusions are possible as conformal symmetries of Riemann surfaces having $g \geq 1$. Besides Z_n one could have tedrahedral and icosahedral groups plus cyclic group Z_{2n} with reflection added but not Z_{2n+1} nor the symmetry group of cube. The conjecture is wrong. Consider the orbit of the subgroup of rotational group on standard sphere of E^3, put a handle at one of the orbits such that it is invariant under rotations around the axis going through the point, and apply the elements of subgroup. You obtain a Riemann surface having the subgroup as its isometries. Hence all discrete subgroups of SU(2) can act even as isometries for some value of g.

The number theoretically simple ruler-and-compass integers having as factors only first powers of Fermat primes and power of 2 would define a physically preferred sub-hierarchy of quantum criticality for which subsequent levels would correspond to powers of 2: a connection with p-adic length scale hypothesis suggests itself.

Spherical topology is exceptional since in this case the space of conformal moduli is trivial and conformal symmetries correspond to the entire $SL(2,C)$. This would suggest that only the fermions of lowest generation corresponding to the spherical topology are maximally quantum critical. This brings in mind Jones inclusions for which the defining subgroup equals to $SU(2)$ and Jones index equals to $\mathcal{M}/\mathcal{N} = 4$. In this case all discrete subgroups of $SU(2)$ label the inclusions. These inclusions would correspond to fiber space $CP_2 \rightarrow CP_2/U(2)$ consisting of geodesic spheres of CP_2. In this case the discrete subgroup might correspond to a selection of a subgroup of $SU(2) \subset SU(3)$ acting non-trivially on the geodesic sphere. Cosmic strings $X^2 \times Y^2 \subset M^4 \times CP_2$ having geodesic spheres of CP_2 as their ends could correspond to this phase dominating the very early cosmology.

3.3 Identification of elementary particles and the role of Higgs in particle massivation

The development of the recent view about the identification of elementary particles and particle massivation has taken fifteen years since the discovery of p-adic thermodynamics around 1993. p-Adic thermodynamics worked excellently from the beginning for fermions. Only the understanding of gauge boson masses turned out to be problematic and group theoretical arguments led to the proposal that Higgs boson should be present and give the dominating contribution to the masses of gauge bosons whereas the contribution to fermion masses should be small and even negligible. The detailed understanding of quantum TGD at partonic level eventually led to the realization that the coupling to Higgs is not needed after all. The deviation Δh of the ground state conformal weight from negative integer has interpretation as effective Higgs contribution since Higgs vacuum expectation is naturally proportional to Δh but the coupling to Higgs does not cause massivation. In the following I summarize the basic identification of elementary particles and massivation.

3.3.1 Identification of elementary particles

The developments in the formulation of quantum TGD which have taken place during the period 2005-2007 [C1, C2] suggest dramatic simplifications of the general picture discussed in the earlier version of this chapter. p-Adic mass calculations [F3, F4, F5] leave a lot of freedom concerning the detailed identification of elementary particles.

Elementary fermions and bosons

The basic open question is whether the *theory is on some sense free at parton level* as suggested by the recent view about the construction of S-matrix (actually its generalization M-matrix) and by the almost topological QFT property of quantum TGD at parton level [C2]. If partonic 2-surfaces at elementary particle level carry only free many-fermion states, no bi-local composites of second quantized induced spinor field would be needed in the construction of the quantum states and this would simplify the theory enormously.

If this is the case, the basic conclusion would be that light-like 3-surfaces - in particular the ones at which the signature of induced metric changes from Minkowskian to Euclidian - are carriers of fermionic quantum numbers. These regions are associated naturally with CP_2 type vacuum extremals identifiable as correlates for elementary fermions if only fermion number ± 1 is allowed for the stable states. The question however arises about the identification of elementary bosons.

Wormhole contacts with two light-like wormhole throats carrying fermion and anti-fermion quantum numbers are the first thing that comes in mind. The wormhole contact connects two space-time sheets with induced metric having Minkowski signature. Wormhole contact itself has an Euclidian metric signature so that there are two wormhole throats which are light-like 3-surfaces and would carry fermion and anti-fermion number. In this case a delicate question is whether the space-time sheets connected by wormhole contacts have opposite time orientations or not. If this the case the two fermions would correspond to positive and negative energy particles.

I considered first the identification of only Higgs as a wormhole contact but there is no reason why this identification should not apply also to gauge bosons (certainly not to graviton). This identification would imply quite a dramatic simplification since the theory would be free at single parton level and the only stable parton states would be fermions and anti-fermions.

This picture allows to understand the difference between fermions and gauge bosons and Higgs particle. For fermions topological explanation of family replication predicts three fermionic generations [F1] corresponding to handle numbers $g = 0, 1, 2$ for the partonic 2-surface. In the case of gauge bosons and Higgs this replication is not visible. This could be due to the fact that gauge bosons form singlet and octet representation of the dynamical $SU(3)$ group associated with the handle number $g = 0, 1, 2$ since bosons correspond to pairs of handles. If octet representation is heavy the experimental absence of family replication for bosons can be understood.

Graviton and other stringy states

Fermion and anti-fermion can give rise to only single unit of spin since it is impossible to assign angular momentum with the relative motion of wormhole throats. Hence the identification of graviton as single wormhole contact is not possible. The only conclusion is that graviton must be a superposition of fermion-anti-fermion pairs and boson-anti-boson pairs with coefficients determined by the coupling of the parton to graviton. Graviton-graviton pairs might emerge in higher orders. Fermion and anti-fermion would reside at the same space-time sheet and would have a non-vanishing relative angular momentum. Also bosons could have non-vanishing relative angular momentum and Higgs bosons must indeed possess it.

Gravitons are stable if the throats of wormhole contacts carry non-vanishing gauge fluxes so that the throats of wormhole contacts are connected by flux tubes carrying the gauge flux. The mechanism producing gravitons would the splitting of partonic 2-surfaces via the basic vertex. A connection with string picture emerges with the counterpart of string identified as the flux tube connecting the wormhole throats. Gravitational constant would relate directly to the value of the string tension.

The development of the understanding of gravitational coupling has had many twists and it is perhaps to summarize the basic misunderstandings.

1. CP_2 length scale R, which is roughly $10^{3.5}$ times larger than Planck length $l_P = \sqrt{\hbar G}$, defines a fundamental length scale in TGD. The challenge is to predict the value of Planck length $\sqrt{\hbar G}$. The outcome was an identification of a formula for $R^2/\hbar G$ predicting that the magnitude of Kähler coupling strength α_K is near to fine structure constant in electron length scale (for ordinary value of Planck constant should be added here).

2. The emergence of the parton level formulation of TGD finally demonstrated that G actually appears in the fundamental parton level formulation of TGD as a fundamental constant characterizing the M^4 part of CP_2 Kähler gauge potential [B4, F12]. This part is pure gauge in the sense of standard gauge theory but necessary to guarantee that the theory does not reduce to topological QFT. Quantum criticality requires that G remains invariant under p-adic coupling constant evolution and is therefore predictable in principle at least.

3. The TGD view about coupling constant evolution predicts the proportionality $G \propto L_p^2$, where L_p is p-adic length scale. Together with input from p-adic mass calculations one ends up to two conclusions. The correct conclusion was that Kähler coupling strength is equal to the fine structure constant in the p-adic length scale associated with Mersenne prime $p = M_{127} = 2^{127}-1$ assignable to electron. I have considered also the possibility that α_K would be equal to electro-weak $U(1)$ coupling in this scale.

4. The additional - wrong- conclusion was that gravitons must always correspond to the p-adic prime M_{127} since G would otherwise vary as function of p-adic length scale. As a matter fact, the question was for years whether it is G or g_K^2 which remains invariant under p-adic coupling constant evolution. I found both options unsatisfactory until I realized that RG invariance is possible for both g_K^2 and G! The point is that the exponent of the Kähler action associated with the piece of CP_2 type vacuum extremal assignable with the elementary particle is exponentially sensitive to the volume of this piece and logarithmic dependence on the volume fraction is enough to compensate the $L_p^2 \propto p$ proportionality of G and thus guarantee the constancy of G.

The explanation for the small value of the gravitational coupling strength serves as a test for the proposed picture. The exchange of ordinary gauge boson involves the exchange of single CP_2 type extremal giving the exponent of Kähler action compensated by state normalization. In the case of graviton exchange two wormhole contacts are exchanged and this gives second power for the exponent of Kähler action which is not compensated. It would be this additional exponent that would give rise to the huge reduction of gravitational coupling strength from the naive estimate $G \sim L_p^2$.

Gravitons are obviously not the only stringy states. For instance, one obtains spin 1 states when the ends of string correspond to gauge boson and Higgs. Also non-vanishing electro-weak and color quantum numbers are possible and stringy states couple to elementary partons via standard couplings in this case. TGD based model for nuclei as nuclear strings having length of order $L(127)$ [F8] suggests that the strings with light M_{127} quark and anti-quark at their ends identifiable as companions of the ordinary graviton are responsible for the strong nuclear force instead of exchanges of ordinary mesons or color van der Waals forces.

Also the TGD based model of high T_c super-conductivity involves stringy states connecting the space-time sheets associated with the electrons of the exotic Cooper pair [J1, J2]. Thus stringy states would play a key role in nuclear and condensed matter physics, which means a profound departure from stringy wisdom, and breakdown of the standard reductionistic picture.

Spectrum of non-stringy states

The 1-throat character of fermions is consistent with the generation-genus correspondence. The 2-throat character of bosons predicts that bosons are characterized by the genera (g_1, g_2) of the wormhole throats. Note that the interpretation of fundamental fermions as wormhole contacts with second throat identified as a Fock vacuum is excluded.

The general bosonic wave-function would be expressible as a matrix M_{g_1,g_2} and ordinary gauge bosons would correspond to a diagonal matrix $M_{g_1,g_2} = \delta_{g_1,g_2}$ as required by the absence of neutral flavor changing currents (say gluons transforming quark genera to each other). 8 new gauge bosons are predicted if one allows all 3×3 matrices with complex entries orthonormalized with respect to trace meaning additional dynamical $SU(3)$ symmetry. Ordinary gauge bosons would be $SU(3)$ singlets in this sense. The existing bounds on flavor changing neutral currents give bounds on the masses of the boson octet. The 2-throat character of bosons should relate to the low value $T = 1/n \ll 1$ for the p-adic temperature of gauge bosons as contrasted to $T = 1$ for fermions.

If one forgets the complications due to the stringy states (including graviton), the spectrum of elementary fermions and bosons is amazingly simple and almost reduces to the spectrum of standard model. In the fermionic sector one would have fermions of standard model. By simple counting leptonic wormhole throat could carry $2^3 = 8$ states corresponding to 2 polarization states, 2 charge states, and sign of lepton number giving 8+8=16 states altogether. Taking into account phase conjugates gives 16+16=32 states.

In the non-stringy boson sector one would have bound states of fermions and phase conjugate fermions. Since only two polarization states are allowed for massless states, one obtains $(2+1) \times (3+1) = 12$ states plus phase conjugates giving 12+12=24 states. The addition of color singlet states for quarks gives 48 gauge bosons with vanishing fermion number and color quantum numbers. Besides 12 electro-weak bosons and their 12 phase conjugates there are 12 exotic bosons and their 12 phase conjugates. For the exotic bosons the couplings to quarks and leptons are determined by the orthogonality of the coupling matrices of ordinary and boson states. For exotic counterparts of W bosons and Higgs the sign of the coupling to quarks is opposite. For photon and Z^0 also the relative magnitudes of the couplings to quarks must change. Altogether this makes 48+16+16=80 states. Gluons would result as color octet states. Family replication would extend each elementary boson state into $SU(3)$ octet and singlet and elementary fermion states into $SU(3)$ triplets.

What about light-like boundaries and macroscopic wormhole contacts?

Light-like boundaries of the space-time sheet as also wormhole throats can have macroscopic size and can carry free many-fermion states but not elementary bosons. Number theoretic braids and anyons might be assignable to these structures. Deformations of cosmic strings to magnetic flux tubes with a light-like outer boundary are especially interesting in this respect.

If the ends of a string like object move with light velocity as implied by the usual stringy boundary conditions they indeed define light-like 3-surfaces. Many-fermion states could be assigned at the ends of string. One could also connect in pairwise manner the ends of two time-like strings having opposite time orientation using two space-like strings so that the analog of boson state consisting of two wormhole contacts and analogous to graviton would result. "Wormhole throats" could have arbitrarily long distance in M^4.

Wormhole contacts can be regarded as slightly deformed CP_2 type extremals only if the size of M^4 projection is not larger than CP_2 size. The natural question is whether one can construct macroscopic wormhole contacts at all.

1. The throats of wormhole contacts cannot belong to vacuum extremals. One might however hope that small deformations of macrosopic vacuum extremals could yield non-vacuum wormhole contacts of macroscopic size.

2. A large class of macroscopic wormhole contacts which are vacuum extremals consists of surfaces of form $X^2_1 \times X^2_2 \subset (M^1 \times Y^2) \times E^3$, where Y^2 is Lagrangian manifold of CP_2 (induced Kähler form vanishes) and $M^4 = M^1 \times E^3$ represents decomposition of M^1 to time-like and space-like sub-spaces. X^2_2 is a stationary surface of E^3. Both $X^2_1 \subset M^1 \times CP_2$ and X^2_2 have an Euclidian signature of metric except at light-like boundaries $X^1_a \times X^2_2$ and $X^1_b \times X^2_2$ defined by ends of X^2_1 defining the throats of the wormhole contact.

3. This kind of vacuum extremals could define an extremely general class of macroscopic wormhole contacts as their deformations. These wormhole contacts describe an interaction of wormhole throats regarded as closed strings as is clear from the fact that X^2 can be visualized as an analog of closed string world sheet X^2_1 in $M^1 \times Y^2$ describing a reaction leading from a state with a given number of incoming closed strings to a state with a given number of outgoing closed strings which correspond to wormhole throats at the two space-time sheets involved.

If one accepts the hierarchy of Planck constants [A9] leading to the generalization of the notion of imbedding space, the identification of anyonic phases in terms of macroscopic light-like surfaces emerges naturally. In this kind of states large fermion numbers are possible. Dark matter would correspond to this kind of phases and "partonic" 2-surfaces could have even astrophysical size. Also black holes can be identified as dark matter at light-like 3-surfaces analogous to black hole horizons and possessing gigantic value of Planck constant [F12].

3.3.2 New view about the role of Higgs boson in massivation

The proposed identifications challenge the standard model view about particle massivation.

1. The standard model inspired interpretation would be that Higgs vacuum expectation associated with the coherent state of neutral Higgs wormhole contacts generates gauge boson mass. Higgs could not however contribute to fermion mass since Higgs condensate cannot accompany fermionic space-time sheets. Fermionic mass would be solely to p-adic thermodynamics. This assumption is consistent with experimental facts but means asymmetry between fermions and bosons.

2. The alternative interpretation inspired by p-adic thermodynamics. Besides the thermodynamical contribution to the particle mass there can be a small contribution from the ground state conformal weight unless this weight is not negative integer. Gauge boson mass would correspond to the ground state conformal weight present in both fermionic and bosonic states and in the case of gauge bosons this contribution would dominate due to the small value of p-adic temperature. For fermions p-adic thermodynamics for super Virasoro algebra would give the dominating contribution to the mass. Higgs vacuum expectation value would be proportional to the square root of ground state conformal weight for the simple reason that it is the only natural dimensional parameter available. Therefore the causal relation between Higgs and massivation would have been misunderstood in standard model inspired framework. As will be found, the generalized eigen values of the modified Dirac operator having dimension of mass have a natural interpretation as square roots of ground state conformal weight and eigenvalues reflect directly the dynamics of Kähler action.

3. The remaining problem is to understand how the negative value of the ground state conformal weight emerges. This negative conformal weight compensated by the action of Super Virasoro generators is necessary for the success of p-adic mass calculations. Also this problem finds a natural solution. The generalized eigenvalues of the modified Dirac operator are purely imaginary if the effective metric associated with the modified Dirac operator has Euclidian signature. Ground state conformal would be negative and if it is not integer, an effective Higgs contribution to the mass squared is implied. For fermions the deviation from negative integer would be small. Hence p-adic thermodynamics is able to describe the massivation without the introduction of coupling to Higgs, which in TGD framework would be necessarily only a phenomenological description.

3.3.3 Microscopic identification of Weinberg angle

Only after the discovery how the information about preferred extremal of Kähler action can be feeded to the spectrum of modified Dirac operator (see the discussion about modified Dirac action), a real understanding of TGD invariant of Higgs mechanism emerged.

1. The generalized eigenvalues of the transverse part $D_K(X^2)$ of the modified Dirac operator D_K are simply square roots of ground state conformal weights and by analogy with cyclotron energies the conformal weights are in reasonable approximation given by $h = -n - 1/2$ giving the desired $h \simeq -1/2$ for lowest state plus finite number of additional ground states. The deviation Δh of h from half odd integer value cannot be compensated by the action of Virasoro generators and it is this contribution which has interpretation as Higgs contribution to mass squared. Higgs zero phase thus corresponds to integer value for h which is highly improbable since the induced ew magnetic field at X_l^3 does not correspond exactly to constant magnetic field. Δh is present for both fermions and bosons, should be small for fermions and dominate for gauge bosons. The vacuum expectation of Higgs is indeed naturally proportional to Δh but the presence of Higgs condensate does not cause the massivation.

2. One must also understand the relationship $M_W^2 = M_Z^2 cos^2(\theta_W)$ requiring $\Delta h(W)/\Delta h(Z) = cos^2(\theta_W)$. Essentially, one should understand the dependence of the quantum averaged the

spectrum of modified Dirac operator on the quantum numbers of elementary particle over configuration space degrees of freedom. Suppose that the zero energy state describing particle is proportional to a phase factor depending on electro-weak and color quantum numbers of the particle. This phase factor would be simply $exp[i\int Tr(gQA_\mu)(dx^\mu/ds)ds]$ assignable to the strand of the number theoretic braid: gQ is the diagonal charge matrix characterizing the particle and A_μ represents gauge potential: in the electro-weak case components of the induced spinor connection and the case of color interactions the space-time projection of Killing forms j_k^A of color isometries. Stationary phase approximation selects a preferred light-like 3-surface X_l^3 for given quantum numbers and boundary conditions assign to this preferred extremal of Kähler action defining the exponent of Kähler function so that also Δh depends on quantum numbers of the particle.

Second challenge is to understand how the mixing of neutral gauge bosons B_3 and B_0 relates to the group theoretic factor $cos^2(\theta_W)$. The condition that the Higgs expectation value for gauge boson B is proportional to $\Delta h(B)$ and that the coherent state of Higgs couples gauge bosons regarded as fermion anti-fermion pairs should explain the mixing.

1. If gauge bosons and Higgs correspond to wormhole contacts, the discussion reduces to one-fermion level. The value of Δh should be different for different charge states $F_{\pm 1/2}$ of elementary fermion (in the following I will drop from discussion delicacies due to the fact that both quarks and leptons and fermion families are involved). The values of λ of fermion and anti-fermion assignable to gauge boson are naturally identical

$$\Delta\lambda(F_{\pm 1/2} = \Delta\lambda(\overline{F}_{\pm 1/2}) \equiv x_{\pm 1/2} \ . \tag{3.3.1}$$

This implies

$$\begin{aligned} \Delta h(Z,W) &\equiv \Delta h(Z) - \Delta h(W) = m_Z^2 - m_W^2 = m_Z^2 sin^2(\theta) \ , \\ \Delta h(Z) &= 1/2\sum_{\pm}(\Delta\lambda(F_{\pm 1/2}) + \Delta\lambda(\overline{F}_{\mp 1/2})^2 = 2\sum_{\pm} x_{\pm 1/2}^2 \ , \\ \Delta h(W) &= 1/2\sum_{\pm}(\Delta\lambda(F_{\pm 1/2}) + \Delta\lambda(\overline{F}_{\pm 1/2})^2 = (x_{1/2} + x_{-1/2})^2 \ . \end{aligned} \tag{3.3.2}$$

This gives

$$\Delta h(Z,W) = (x_{1/2} - x_{-1/2})^2 \tag{3.3.3}$$

giving the condition

$$(x_{1/2} - x_{-1/2})^2 = (x_{1/2} + x_{-1/2})^2 sin^2(\theta_W) \ . \tag{3.3.4}$$

The interpretation is as breaking of electro-weak $SU(2)_L$ symmetry coded by the geometry of CP_2 in the structure of spinor connection so that the symmetry breaking is expected to take place. One can *define* the value of Weinberg angle from the formula

$$sin(\theta_W) \equiv \pm\frac{x_{1/2} - x_{-1/2}}{x_{1/2} + x_{-1/2}} \ . \tag{3.3.5}$$

2. This definition of Weinberg angle should be consistent with the identification of Weinberg angle coming from the couplings of Z^0 and photon to fermions. Also here the reduction of couplings to one-fermion level might help to understand the symmetry breaking. Z^0 and γ decompose as $Z_0 = cos(\theta_W)B_3 + sin(\theta_W)B_0$ and $\gamma = -sin(\theta_W)B_3 + cos(\theta_W)B_0$, where B_3 corresponds to the gauge potential in $SU(2)_L$ triplet and B_0 the gauge potential in $SU(2)_L$ singlet. Why this mixing should be induced by the splitting of the conformal weights? What induces the mixing of electro-weak triplet with singlet?

3. Could it be the coherent state of Higgs field which transforms left handed and right handed fermions to each other and hence also B_3 to B_0 and vice versa? If the Higgs expectation value associated with the coherent state is proportional to Δh, it would not be too surprising if the mixing between B_3 and B_0 caused by the coherent Higgs state were proportional to $(x_{1/2}-x_{-1/2})/(x_{1/2}+x_{-1/2})$. The reason would be that B_3 is antisymmetric with respect to the exchange of weak isospins whereas B_0 is symmetric. Therefore also the mixing amplitude should be antisymmetric with respect to the exchange of isospins and proportional to $(x_{1/2} - x_{-1/2})$. The presence of the numerator is needed to make the amplitude dimensionless. Under this assumption the two identifications of the Weinberg angle are equivalent.

4. It is important to notice that Weinberg angle is a quantity assignable operationally to the wormhole contacts at the light-like boundaries of $CD \times CP_2$ but not to the generalized light-like 3-surfaces Y_l^3 parallel X_l^3. This suggest that Weinberg angle is necessarily constant for given CD and its evolution reduces to discrete p-adic coupling constant evolution labeled by the scales of CDs coming as powers of 2.

This - admittedly oversimplified - picture obviously changes considerably what-causes-what's in the description of gauge boson massivation and the basic argument should be developed into a more precise form.

3.4 Number theoretic compactification and $M^8 - H$ duality

This section summarizes the basic vision about number theoretic compactification reducing the classical dynamics to number theory. In strong form $M^8 - H$ duality boils down to the assumption that space-time surfaces can be regarded either as surfaces of H or as surfaces of M^8 composed of hyper-quaternionic and co-hyper-quaternionic regions identifiable as regions of space-time possessing Minkowskian *resp.* Euclidian signature of the induced metric.

3.4.1 Basic idea behind $M^8 - M^4 \times CP_2$ duality

The hopes of giving $M^4 \times CP_2$ hyper-octonionic structure are meager. This circumstance forces to ask whether four-surfaces $X^4 \subset M^8$ could under some conditions define 4-surfaces in $M^4 \times CP_2$ indirectly so that the spontaneous compactification of super string models would correspond in TGD to two different manners to interpret the space-time surface. The following arguments suggest that this is indeed the case.

The hard mathematical fact behind number theoretical compactification is that the quaternionic sub-algebras of octonions with fixed complex structure (that is complex sub-space) are parameterized by CP_2 just as the complex planes of quaternion space are parameterized by $CP_1 = S^2$. Same applies to hyper-quaternionic sub-spaces of hyper-octonions. $SU(3)$ would thus have an interpretation as the isometry group of CP_2, as the automorphism sub-group of octonions, and as color group.

1. The space of complex structures of the octonion space is parameterized by S^6. The subgroup $SU(3)$ of the full automorphism group G_2 respects the a priori selected complex structure and thus leaves invariant one octonionic imaginary unit, call it e_1. Hyper-quaternions can be identified as $U(2)$ Lie-algebra but it is obvious that hyper-octonions do not allow an identification as $SU(3)$ Lie algebra. Rather, octonions decompose as $1\oplus1\oplus3\oplus\overline{3}$ to the irreducible representations of $SU(3)$.

2. Geometrically the choice of a preferred complex (quaternionic) structure means fixing of complex (quaternionic) sub-space of octonions. The fixing of a hyper-quaternionic structure of hyper-octonionic M^8 means a selection of a fixed hyper-quaternionic sub-space $M^4 \subset M^8$ implying

the decomposition $M^8 = M^4 \times E^4$. If M^8 is identified as the tangent space of $H = M^4 \times CP_2$, this decomposition results naturally. It is also possible to select a fixed hyper-complex structure, which means a further decomposition $M^4 = M^2 \times E^2$.

3. The basic result behind number theoretic compactification and $M^8 - H$ duality is that hyper-quaternionic sub-spaces $M^4 \subset M^8$ containing a fixed hyper-complex sub-space $M^2 \subset M^4$ or its light-like line $M_\pm$ are parameterized by CP_2. The choices of a fixed hyper-quaternionic basis $1, e_1, e_2, e_3$ with a fixed complex sub-space (choice of e_1) are labeled by $U(2) \subset SU(3)$. The choice of e_2 and e_3 amounts to fixing $e_2 \pm \sqrt{-1}e_3$, which selects the $U(2) = SU(2) \times U(1)$ subgroup of $SU(3)$. $U(1)$ leaves 1 invariant and induced a phase multiplication of e_1 and $e_2 \pm e_3$. $SU(2)$ induces rotations of the spinor having e_2 and e_3 components. Hence all possible completions of $1, e_1$ by adding e_2, e_3 doublet are labeled by $SU(3)/U(2) = CP_2$.

4. Space-time surface $X^4 \subset M^8$ is by definition hyper-quaternionic if the tangent spaces of X^4 are hyper-quaternionic planes. Co-hyper-quaternionictity means the same for normal spaces. The presence of fixed hyper-complex structure means at space-time level that the tangent space of X^4 contains fixed M^2 at each point. Under this assumption one can map the points $(m, e) \in M^8$ to points $(m, s) \in H$ by assigning to the point (m, e) of X^4 the point (m, s), where $s \in CP_2$ characterize $T(X^4)$ as hyper-quaternionic plane.

5. The choice of M^2 can be made also local in the sense that one has $T(X^4) \supset M^2(x) \subset M^4 \subset H$. It turns out that strong form of number theoretic compactification requires this kind of generalization. In this case one must be able to fix the convention how the point of CP_2 is assigned to a hyper-quaternionic plane so that it applies to all possible choices of $M^2 \subset M^4$. Since $SO(3)$ hyper-quaternionic rotation relates the hyper-quaternionic planes to each other, the natural assumption is hyper-quaternionic planes related by $SO(3)$ rotation correspond to the same point of CP_2. Under this assumption it is possible to map hyper-quaternionic surfaces of M^8 for which $M^2 \subset M^4$ depends on point of X^4 to H.

3.4.2 Minimal form of $M^8 - H$ duality

The basic problem in the construction of quantum TGD has been the identification of the preferred extremals of Kähler action playing a key role in the definition of the theory. The most elegant manner to do this is by fixing the 4-D tangent space $T(X^4(X^3_l))$ of $X^4(X^3_l)$ at each point of X^3_l so that the boundary value problem is well defined. What I called number theoretical compactification allows to achieve just this although I did not fully realize this in the original vision. The minimal picture is following.

1. The basic observations are following. Let M^8 be endowed with hyper-octonionic structure. For hyper-quaternionic space-time surfaces in M^8 tangent spaces are by definition hyper-quaternionic. If they contain a preferred plane $M^2 \subset M^4 \subset M^8$ in their tangent space, they can be mapped to 4-surfaces in $M^4 \times CP_2$. The reason is that the hyper-quaternionic planes containing preferred the hyper-complex plane M^2 of $M_\pm \subset M^2$ are parameterized by points of CP_2. The map is simply $(m, e) \to (m, s(m, e))$, where m is point of M^4, e is point of E^4, and $s(m, 2)$ is point of CP_2 representing the hyperquaternionic tangent plane. The inverse map assigns to each point (m, s) in $M^4 \times CP_2$ point m of M^4, undetermined point e of E^4 and 4-D plane. The requirement that the distribution of planes containing the preferred M^2 or $M_\pm$ corresponds to a distribution of planes for 4-D surface is expected to fix the points e. The physical interpretation of M^2 is in terms of plane of non-physical polarizations so that gauge conditions have purely number theoretical interpretation.

2. In principle, the condition that $T(X^4)$ contains M^2 can be replaced with a weaker condition that either of the two light-like vectors of M^2 is contained in it since already this condition assigns to $T(X^4)$ M^2 and the map $H \to M^8$ becomes possible. Only this weaker form applies in the case of massless extremals [D1] as will be found.

3. The original idea was that hyper-quaternionic 4-surfaces in M^8 containing $M^2 \subset M^4$ in their tangent space could correspond to preferred extremals of Kähler action. This condition does not seem to be consistent with what is known about the extremals of Kähler action. The

weaker form of the hypothesis is that hyper-quaternionicity holds only for 4-D tangent spaces of $X_l^3 \subset H = M^4 \times CP_2$ identified as wormhole throats or boundary components lifted to 3-surfaces in 8-D tangent space M^8 of H. The minimal hypothesis would be that only $T(X^4(X_l^3))$ at X_l^3 is associative that is hyper-quaternionic for fixed M^2. $X_l^3 \subset M^8$ and $T(X^4(X_l^3))$ at X_l^3 can be mapped to $X_l^3 \subset H$ if tangent space contains also $M_\pm \subset M^2$ or $M^2 \subset M^4 \subset M^8$ itself having interpretation as preferred hyper-complex plane. This condition is not satisfied by all surfaces X_l^3 as is clear from the fact that the inverse map involves local E^4 translation. The requirements that the distribution of hyper-quaternionic planes containing M^2 corresponds to a distribution of 4-D tangent planes should fix the E^4 translation to a high degree.

4. A natural requirement is that the image of $X_l^3 \subset H$ in M^8 is light-like. The condition that the determinant of induced metric vanishes gives an additional condition reducing the number of free parameters by one. This condition cannot be formulated as a condition on CP_2 coordinate characterizing the hyper-quaternionic tangent plane. Since M^4 projections are same for the two representations, this condition is satisfied if the contributions from CP_2 and E^4 and projections to the induced metric are identical: $s_{kl}\partial_\alpha s^k \partial_\beta s^l = e_{kl}\partial_\alpha e^k \partial_\beta e^l$. This condition means that only a subset of light-like surfaces of M^8 are realized physically. One might argue that this is as it must be since the volume of E^4 is infinite and that of CP_2 finite: only an infinitesimal portion of all possible light-like 3-surfaces in M^8 can can have H counterparts. The conclusion would be that number theoretical compactification is 4-D isometry between $X^4 \subset H$ and $X^4 \subset M^8$ at X_l^3. This unproven conjecture is unavoidable.

5. $M^2 \subset T(X^4(X_l^3))$ condition fixes $T(X^4(X_l^3))$ in the generic case by extending the tangent space of X_l^3, and the construction of configuration space spinor structure fixes boundary conditions completely by additional conditions necessary when X_l^3 corresponds to a light-like 3 surfaces defining wormhole throat at which the signature of induced metric changes. What is especially beautiful that only the data in $T(X^4(X_l^3))$ at X_l^3 is needed to calculate the vacuum functional of the theory as Dirac determinant: the only remaining conjecture (strictly speaking un-necessary but realistic looking) is that this determinant gives exponent of Kähler action for the preferred extremal and there are excellent hopes for this by the structure of the basic construction.

The basic criticism relates to the condition that light-like 3-surfaces are mapped to light-like 3-surfaces guaranteed by the condition that $M^8 - H$ duality is isometry at X_l^3.

3.4.3 Strong form of $M^8 - H$ duality

The proposed picture is the minimal one. One can of course ask whether the original much stronger conjecture that the preferred extrema of Kähler action correspond to hyper-quaternionic surfaces could make sense in some form. One can also wonder whether one could allow the choice of the plane M^2 of non-physical polarization to be local so that one would have $M^2(x) \subset M^4 \subset M^4 \times E^4$, where M^4 is fixed hyper-quaternionic sub-space of M^8 and identifiable as M^4 factor of H.

1. If M^2 is same for all points of X_l^3, the inverse map $X_l^3 \subset H \to X_l^3 \subset M^8$ is fixed apart from possible non-uniquencess related to the local translation in E^4 from the condition that hyper-quaternionic planes represent light-like tangent 4-planes of light-like 3-surfaces. The question is whether not only X_l^3 but entire four-surface $X^4(X_l^3)$ could be mapped to the tangent space of M^8. By selecting suitably the local E^4 translation one might hope of achieving the achieving this. The conjecture would be that the preferred extrema of Kähler action are those for which the distribution integrates to a distribution of tangent planes.

2. There is however a problem. What is known about extremals of Kähler action is not consistent with the assumption that fixed M^2 of $M_\pm \subset M^2$is contained in the tangent space of X^4. This suggests that one should relax the condition that $M^2 \subset M^4 \subset M^8$ is a fixed hyper-complex plane associated with the tangent space or normal space X^4 and allow M^2 to vary from point to point so that one would have $M^2 = M^2(x)$. In $M^8 \to H$ direction the justification comes from the observation (to be discussed below) that it is possible to uniquely fix the convention assigning CP_2 point to a hyper-quaternionic plane containing varying hyper-complex plane $M^2(x) \subset M^4$.

   Number theoretic compactification fixes naturally $M^4 \subset M^8$ so that it applies to any $M^2(x) \subset M^4$. Under this condition the selection is parameterized by an element of $SO(3)/SO(2) = S^2$.

Note that M^4 projection of X^4 would be at least 2-dimensional in hyper-quaternionic case. In co-hyper-quaternionic case E^4 projection would be at least 2-D. $SO(2)$ would act as a number theoretic gauge symmetry and the $SO(3)$ valued chiral field would approach to constant at X_l^3 invariant under global $SO(2)$ in the case that one keeps the assumption that M^2 is fixed ad X_l^3.

3. This picture requires a generalization of the map assigning to hyper-quaternionic plane a point of CP_2 so that this map is defined for all possible choices of $M^2 \subset M^4$. Since the $SO(3)$ rotation of the hyper-quaternionic unit defining M^2 rotates different choices parameterized by S^2 to each other, a natural assumption is that the hyper-quaternionic planes related by $SO(3)$ rotation correspond to the same point of CP_2. Denoting by M^2 the standard representative of M^2, this means that for the map $M^8 \to H$ one must perform $SO(3)$ rotation of hyper-quaternionic plane taking $M^2(x)$ to M^2 and map the rotated tangent plane to CP_2 point. In $M^8 \to H$ case one must first map the point of CP_2 to hyper-quaternionic plane and rotate this plane by a rotation taking $M^2(x)$ to M^2.

4. In this framework local M^2 can vary also at the surfaces X_l^3, which considerably relaxes the boundary conditions at wormhole throats and light-like boundaries and allows much more general variety of light-like 3-surfaces since the basic requirement is that M^4 projection is at least 1-dimensional. The physical interpretation would be that a local choice of the plane of non-physical polarizations is possible everywhere in $X^4(X_l^3)$. This does not seem to be in any obvious conflict with physical intuition.

These observation provide support for the conjecture that (classical) $S^2 = SO(3)/SO(2)$ conformal field theory might be relevant for (classical) TGD.

1. General coordinate invariance suggests that the theory should allow a formulation using any light-like 3-surface X^3 inside $X^4(X_l^3)$ besides X_l^3 identified as union of wormhole throats and boundary components. For these surfaces the element $g(x) \in SO(3)$ would vary also at partonic 2-surfaces X^2 defined as intersections of $\delta CD \times CP_2$ and X^3 (here CD denotes causal diamond defined as intersection of future and past directed light-cones). Hence one could have $S^2 = SO(3)/SO(2)$ conformal field theory at X^2 (regarded as quantum fluctuating so that also $g(x)$ varies) generalizing to WZW model for light-like surfaces X^3.

2. The presence of E^4 factor would extend this theory to a classical $E^4 \times S^2$ WZW model bringing in mind string model with 6-D Euclidian target space extended to a model of light-like 3-surfaces. A further extension to X^4 would be needed to integrate the WZW models associated with 3-surfaces to a full 4-D description. General Coordinate Invariance however suggests that X_l^3 description is enough for practical purposes.

3. The choices of $M^2(x)$ in the interior of X_l^3 is dictated by dynamics and the first optimistic conjecture is that a classical solution of $SO(3)/SO(2)$ Wess-Zumino-Witten model obtained by coupling $SO(3)$ valued field to a covariantly constant $SO(2)$ gauge potential characterizes the choice of $M^2(x)$ in the interior of $M^8 \supset X^4(X_l^3) \subset H$ and thus also partially the structure of the preferred extremal. Second optimistic conjecture is that the Kähler action involving also E^4 degrees of freedom allows to assign light-like 3-surface to light-like 3-surface.

4. The best that one can hope is that $M^8 - H$ duality could allow to transform the extremely non-linear classical dynamics of TGD to a generalization of WZW-type model. The basic problem is to understand how to characterize the dynamics of CP_2 projection at each point.

In H picture there are two basic types of vacuum extremals: CP_2 type extremals representing elementary particles and vacuum extremals having CP_2 projection which is at most 2-dimensional Lagrange manifold and representing say hadron. Vacuum extremals can appear only as limiting cases of preferred extremals which are non-vacuum extremals. Since vacuum extremals have so decisive role in TGD, it is natural to requires that this notion makes sense also in M^8 picture. In particular, the notion of vacuum extremal makes sense in M^8.

This requires that Kähler form exist in M^8. E^4 indeed allows full S^2 of covariantly constant Kähler forms representing quaternionic imaginary units so that one can identify Kähler form and construct Kähler action. The obvious conjecture is that hyper-quaternionic space-time surface is extremal of this Kähler action and that the values of Kähler actions in M^8 and H are identical. The elegant manner to achieve this, as well as the mapping of vacuum extremals to vacuum extremals and the mapping of light-like 3-surfaces to light-like 3-surfaces is to assume that $M^8 - H$ duality is Kähler isometry so that induced Kähler forms are identical.

This picture contains many speculative elements and some words of warning are in order.

1. Light-likeness conjecture would boil down to the hypothesis that $M^8 - H$ correspondence is Kähler isometry so that the metric and Kähler form of X^4 induced from M^8 and H would be identical. This would guarantee also that Kähler actions for the preferred extremal are identical. This conjecture is beautiful but strong.

2. The slicing of $X^4(X^3_l)$ by light-like 3-surfaces is very strong condition on the classical dynamics of Kähler action and does not make sense for pieces of CP_2 type vacuum extremals.

Minkowskian-Euclidian $\leftrightarrow$ associative–co-associative

The 8-dimensionality of M^8 allows to consider both associativity (hyper-quaternionicity) of the tangent space and associativity of the normal space- let us call this co-assosiativity of tangent space- as alternative options. Both options are needed as has been already found. Since space-time surface decomposes into regions whose induced metric possesses either Minkowskian or Euclidian signature, there is a strong temptation to propose that Minkowskian regions correspond to associative and Euclidian regions to co-associative regions so that space-time itself would provide both the description and its dual.

The proposed interpretation of conjectured associative-co-associative duality relates in an interesting manner to p-adic length scale hypothesis selecting the primes $p \simeq 2^k$, k positive integer as preferred p-adic length scales. $L_p \propto \sqrt{p}$ corresponds to the p-adic length scale defining the size of the space-time sheet at which elementary particle represented as CP_2 type extremal is topologically condensed and is of order Compton length. $L_k \propto \sqrt{k}$ represents the p-adic length scale of the wormhole contacts associated with the CP_2 type extremal and CP_2 size is the natural length unit now. Obviously the quantitative formulation for associative-co-associative duality would be in terms $p \rightarrow k$ duality.

Are the known extremals of Kähler action consistent with the strong form of $M^8 - H$ duality

It is interesting to check whether the known extremals of Kähler action [D1] are consistent with strong form of $M^8 - H$ duality assuming that M^2 or its light-like ray is contained in $T(X^4)$ or normal space.

1. CP_2 type vacuum extremals correspond cannot be hyper-quaternionic surfaces but co-hyper-quaternionicity is natural for them. In the same manner canonically imbedded M^4 can be only hyper-quaternionic.

2. String like objects are associative since tangent space obviously contains $M^2(x)$. Objects of form $M^1 \times X^3 \subset M^4 \times CP_2$ do not have M^2 either in their tangent space or normal space in H. So that the map from $H \rightarrow M^8$ is not well defined. There are no known extremals of Kähler action of this type. The replacement of M^1 random light-like curve however gives vacuum extremal with vanishing volume, which need not mean physical triviality since fundamental objects of the theory are light-like 3-surfaces.

3. For canonically imbedded CP_2 the assignment of $M^2(x)$ to normal space is possible but the choice of $M^2(x) \subset N(CP_2)$ is completely arbitrary. For a generic CP_2 type vacuum extremals M^4 projection is a random light-like curve in $M^4 = M^1 \times E^3$ and $M^2(x)$ can be defined uniquely by the normal vector $n \in E^3$ for the local plane defined by the tangent vector dx^μ/dt and acceleration vector d^2x^μ/dt^2 assignable to the orbit.

4. Consider next massless extremals. Let us fix the coordinates of X^4 as $(t,z,x,y) = (m^0,m^2,m^1,m^2)$. For simplest massless extremals CP_2 coordinates are arbitrary functions of variables $u = k\cdot m = t-z$ and $v = \epsilon\cdot m = x$, where $k = (1,1,0,0)$ is light-like vector of M^4 and $\epsilon = (0,0,1,0)$ a polarization vector orthogonal to it. Obviously, the extremals defines a decomposition $M^4 = M^2 \times E^2$.

Tangent space is spanned by the four H-vectors $\nabla_\alpha h^k$ with M^4 part given by $\nabla_\alpha m^k = \delta^k_\alpha$ and CP_2 part by $\nabla_\alpha s^k = \partial_u s^k k_\alpha + \partial_v s^k \epsilon_\alpha$.

The normal space cannot contain M^4 vectors since the M^4 projection of the extremal is M^4. To realize hyper-quaternionic representation one should be able to from these vector two vectors of M^2, which means linear combinations of tangent vectors for which CP_2 part vanishes. The vector $\partial_t h^k - \partial_z h^k$ has vanishing CP_2 part and corresponds to M^4 vector $(1,-1,0,0)$ fix assigns to each point the plane M^2. To obtain M^2 one would need $(1,1,0,0)$ too but this is not possible. The vector $\partial_y h^k$ is M^4 vector orthogonal to ϵ but M^2 would require also $(1,0,0,0)$. The proposed generalization of massless extremals allows the light-like line $M_\pm$ to depend on point of M^4 [D1], and leads to the introduction of Hamilton-Jacobi coordinates involving a local decomposition of M^4 to $M^2(x)$ and its orthogonal complement with light-like coordinate lines having interpretation as curved light rays. $M^2(x) \subset T(X^4)$ assumption fails fails also for vacuum extremals of form $X^1 \times X^3 \subset M^4 \times CP_2$, where X^1 is light-like random curve. In the latter case, vacuum property follows from the vanishing of the determinant of the induced metric.

5. The deformations of string like objects to magnetic flux quanta are basic conjectural extremals of Kähler action and the proposed picture supports this conjecture. In hyper-quaternionic case the assumption that local 4-D tangent plane of X^3 contains $M^2(x)$ but that $T(X^3)$ does not contain it, is very strong. It states that $T(X^4)$ at each point can be regarded as a product $M^2(x) \times T^2$, $T^2 \subset T(CP_2)$, so that hyper-quaternionic X^4 would be a collection of Cartesian products of infinitesimal 2-D planes $M^2(x) \subset M^4$ and $T^2(x) \subset CP_2$. The extremals in question could be seen as local variants of string like objects $X^2 \times Y^2 \subset M^4 \times CP_2$, where X^2 is minimal surface and Y^2 holomorphic surface of CP_2. One can say that X^2 is replaced by a collection of infinitesimal pieces of $M^2(x)$ and Y^2 with similar pieces of homologically non-trivial geodesic sphere $S^2(x)$ of CP_2, and the Cartesian products of these pieces are glued together to form a continuous surface defining an extremal of Kähler action. Field equations would pose conditions on how $M^2(x)$ and $S^2(x)$ can depend on x. This description applies to magnetic flux quanta, which are the most important must-be extremals of Kähler action.

Geometric interpretation of strong $M^8 - H$ duality

In the proposed framework $M^8 - H$ duality would have a purely geometric meaning and there would nothing magical in it.

1. $X^4(X^3_l) \subset H$ could be seen a curve representing the orbit of a light-like 3-surface defining a 4-D surface. The question is how to determine the notion of tangent vector for the orbit of X^3_l. Intuitively tangent vector is a one-dimensional arrow tangential to the curve at point X^3_l. The identification of the hyper-quaternionic surface $X^4(X^3_l) \subset M^8$ as tangent vector conforms with this intuition.

2. One could argue that M^8 representation of space-time surface is kind of chart of the real space-time surface obtained by replacing real curve by its tangent line. If so, one cannot avoid the question under which conditions this kind of chart is faithful. An alternative interpretation is that a representation making possible to realize number theoretical universality is in question.

3. An interesting question is whether $X^4(X^3_l)$ as orbit of light-like 3-surface is analogous to a geodesic line -possibly light-like- so that its tangent vector would be parallel translated in the sense that $X^4(X^3)$ for any light-like surface at the orbit is same as $X^4(X^3_l)$. This would give justification for the possibility to interpret space-time surfaces as a geodesic of configuration space: this is one of the first -and practically forgotten- speculations inspired by the construction of configuration space geometry. The light-likeness of the geodesic could correspond at the level of X^4 the possibility to decompose the tangent space to a direct sum of two light-like spaces and 2-D transversal space producing the foliation of X^4 to light-like 3-surfaces X^3_l along light-like curves.

4. $M^8 - H$ duality would assign to X^3_l classical orbit and its tangent vector at X^3_l as a generalization of Bohr orbit. This picture differs from the wave particle duality of wave mechanics stating that

once the position of particle is known its momentum is completely unknown. The outcome is however the same: for X_l^3 corresponding to wormhole throats and light-like boundaries of X^4, canonical momentum densities in the normal direction vanish identically by conservation laws and one can say that the the analog of (q,p) phase space as the space carrying wave functions is replaced with the analog of subspace consisting of points $(q,0)$. The dual description in M^8 would not be analogous to wave functions in momentum space space but to those in the space of unique tangents of curves at their initial points.

The Kähler and spinor structures of M^8

If one introduces M^8 as dual of H, one cannot avoid the idea that hyper-quaternionic surfaces obtained as images of the preferred extremals of Kähler action in H are also extremals of M^8 Kähler action with same value of Kähler action. As found, this leads to the conclusion that the$M^8 - H$ duality is Kähler isometry. Coupling of spinors to Kähler potential is the next step and this in turn leads to the introduction of spinor structure so that quantum TGD in H should have full M^8 dual.

There are strong physical constraints on M^8 dual and they could kill the hypothesis. The basic constraint to the spinor structure of M^8 is that it reproduces basic facts about electro-weak interactions. This includes neutral electro-weak couplings to quarks and leptons identified as different H-chiralities and parity breaking.

1. By the flatness of the metric of E^4 its spinor connection is trivial. E^4 however allows full S^2 of covariantly constant Kähler forms so that one can accommodate free independent Abelian gauge fields assuming that the independent gauge fields are orthogonal to each other when interpreted as realizations of quaternionic imaginary units.

2. One should be able to distinguish between quarks and leptons also in M^8, which suggests that one introduce spinor structure and Kähler structure in E^4. The Kähler structure of E^4 is unique apart form $SO(3)$ rotation since all three quaternionic imaginary units and the unit vectors formed from them allow a representation as an antisymmetric tensor. Hence one must select one preferred Kähler structure, that is fix a point of S^2 representing the selected imaginary unit. It is natural to assume different couplings of the Kähler gauge potential to spinor chiralities representing quarks and leptons: these couplings can be assumed to be same as in case of H.

3. Electro-weak gauge potential has vectorial and axial parts. Em part is vectorial involving coupling to Kähler form and Z^0 contains both axial and vector parts. The free Kähler forms could thus allow to produce M^8 counterparts of these gauge potentials possessing same couplings as their H counterparts. This picture would produce parity breaking in M^8 picture correctly.

4. Only the charged parts of classical electro-weak gauge fields would be absent. This would conform with the standard thinking that charged classical fields are not important. The predicted classical W fields is one of the basic distinctions between TGD and standard model and in this framework. A further prediction is that this distinction becomes visible only in situations, where H picture is necessary. This is the case at high energies, where the description of quarks in terms of $SU(3)$ color is convenient whereas $SO(4)$ QCD would require large number of E^4 partial waves. At low energies large number of $SU(3)$ color partial waves are needed and the convenient description would be in terms of $SO(4)$ QCD. Proton spin crisis might relate to this.

5. Also super-symmetries of quantum TGD crucial for the construction of configuration space geometry force this picture. In the absence of coupling to Kähler gauge potential all constant spinor fields and their conjugates would generate super-symmetries so that M^8 would allow $N = 8$ super-symmetry. The introduction of the coupling to Kähler gauge potential in turn means that all covariantly constant spinor fields are lost. Only the representation of all three neutral parts of electro-weak gauge potentials in terms of three independent Kähler gauge potentials allows right-handed neutrino as the only super-symmetry generator as in the case of H.

6. The $SO(3)$ element characterizing $M^2(x)$ is fixed apart from a local $SO(2)$ transformation, which suggests an additional $U(1)$ gauge field associated with $SO(2)$ gauge invariance and representable as Kähler form corresponding to a quaternionic unit of E^4. A possible identification of this gauge field would be as a part of electro-weak gauge field.

M^8 dual of configuration space geometry and spinor structure?

If one introduces M^8 spinor structure and preferred extremals of M^8 Kähler action, one cannot avoid the question whether it is possible or useful to formulate the notion of configuration space geometry and spinor structure for light-like 3-surfaces in M^8 using the exponent of Kähler action as vacuum functional.

1. The isometries of the configuration space in M^8 and H formulations would correspond to symplectic transformation of $\delta M^4_\pm \times E^4$ and $\delta M^4_\pm \times CP_2$ and the Hamiltonians involved would belong to the representations of $SO(4)$ and $SU(3)$ with 2-dimensional Cartan sub-algebras. In H picture color group would be the familiar $SU(3)$ but in M^8 picture it would be $SO(4)$. Color confinement in both $SU(3)$ and $SO(4)$ sense could allow these two pictures without any inconsistency.

2. For $M^4 \times CP_2$ the two spin states of covariantly constant right handed neutrino and antineutrino spinors generate super-symmetries. This super-symmetry plays an important role in the proposed construction of configuration space geometry. As found, this symmetry would be present also in M^8 formulation so that the construction of M^8 geometry should reduce more or less to the replacement of CP_2 Hamiltonians in representations of $SU(3)$ with E^4 Hamiltonians in representations of $SO(4)$. These Hamiltonians can be taken to be proportional to functions of E^4 radius which is $SO(4)$ invariant and these functions bring in additional degree of freedom.

3. The construction of Dirac determinant identified as a vacuum functional can be done also in M^8 picture and the conjecture is that the result is same as in the case of H. In this framework the construction is much simpler due to the flatness of E^4. In particular, the generalized eigen modes of $D_K(X^2)$ identified as zero modes of 4-D Dirac operator D_K restricted to the X^3_l correspond to a situation in which one has fermion in induced Maxwell field mimicking the neutral part of electro-weak gauge field in H as far as couplings are considered. Induced Kähler field would be same as in H. Eigen modes are localized to regions inside which the Kähler magnetic field is non-vanishing and apart from the fact that the metric is the effective metric defined in terms of canonical momentum densities via the formula $\hat{\Gamma}^\alpha = \partial L_K/\partial h^k_\alpha \Gamma_k$ for effective gamma matrices. This in fact, forces the localization of modes implying that their number is finite so that Dirac determinant is a product over finite number eigenvalues. It is clear that M^8 picture could dramatically simplify the construction of configuration space geometry.

4. The eigenvalue spectra of the transversal parts of D_K operators in M^8 and H should identical. This motivates the question whether it is possible to achieve a complete correspondence between H and M^8 pictures also at the level of spinor fields at X^3 by performing a gauge transformation eliminating the classical W gauge boson field altogether at X^3_l and whether this allows to transform the modified Dirac equation in H to that in M^8 when restricted to X^3_l. That something like this might be achieved is supported by the fact that in Coulombic gauge the component of gauge potential in the light-like direction vanishes so that the situation is effectively 2-dimensional and holonomy group is Abelian.

Why $M^8 - H$ duality is useful?

Skeptic could of course argue that $M^8 - H$ duality produces only an inflation of unproven conjectures. There are however strong reasons for $M^8 - H$ duality: both theoretical and physical.

1. The map of $X^3_l \subset H \rightarrow X^3_l \subset M^8$ and corresponding map of space-time surfaces would allow to realize number theoretical universality. $M^8 = M^4 \times E^4$ allows linear coordinates as natural coordinates in which one can say what it means that the point of imbedding space is rational/algebraic. The point of $X^4 \subset H$ is algebraic if it is mapped to an algebraic point of M^8 in number theoretic compactification. This of course restricts the symmetry groups to their rational/algebraic variants but this does not have practical meaning. Number theoretical compactication could in fact be motivated by the number theoretical universality.

2. $M^8 - H$ duality could provide much simpler description of preferred extremals of Kähler action since the Kähler form in E^4 has constant components. If the spinor connection in E^4 is combination of the three Kähler forms mimicking neutral part of electro-weak gauge potential, the

eigenvalue spectrum for the modified Dirac operator would correspond to that for a fermion in $U(1)$ magnetic field defined by an Abelian magnetic field whereas in $M^4 \times CP_2$ picture $U(2)_{ew}$ magnetic fields would be present.

3. $M^8 - H$ duality provides insights to low energy hadron physics. M^8 description might work when H-description fails. For instance, perturbative QCD which corresponds to H-description fails at low energies whereas M^8 description might become perturbative description at this limit. Strong $SO(4) = SU(2)_L \times SU(2)_R$ invariance is the basic symmetry of the phenomenological low energy hadron models based on conserved vector current hypothesis (CVC) and partially conserved axial current hypothesis (PCAC). Strong $SO(4) = SU(2)_L \times SU(2)_R$ relates closely also to electro-weak gauge group $SU(2)_L \times U(1)$ and this connection is not well understood in QCD description. $M^8 - H$ duality could provide this connection. Strong $SO(4)$ symmetry would emerge as a low energy dual of the color symmetry. Orbital $SO(4)$ would correspond to strong $SU(2)_L \times SU(2)_R$ and by flatness of E^4 spin like $SO(4)$ would correspond to electro-weak group $SU(2)_L \times U(1)_R \subset SO(4)$. Note that the inclusion of coupling to Kähler gauge potential is necessary to achieve respectable spinor structure in CP_2. One could say that the orbital angular momentum in $SO(4)$ corresponds to strong isospin and spin part of angular momentum to the weak isospin.

3.4.4 The notion of number theoretical braid

The notion of number theoretic braid is essential for the view about quantum TGD as almost topological quantum field theory. It also realization discretization as a space-time correlate for the finite measurement resolution. Number theoretical universality leads to this notion also and requires that the points in the intersection of the number theoretic braid with partonic 2-surface correspond to rational or at most algebraic points of H in preferred coordinates fixed by symmetry considerations. The challenge has been to find a unique identification of the number theoretic braid. Number theoretic vision indeed makes this possible.

The core element of number theoretic vision is that the laws of physics could be reduced to associativity conditions. One realization for associativity conditions is the level of M^8 endowed with hyper-octonionic structure as a condition that the points sets possible as arguments of N-point function in X^4 are associative and thus belong to hyper-quaternionic subspace $M^4 \subset M^8$. This decomposition must be consistent with the $M^4 \times E^4$ decomposition implied by $M^4 \times CP_2$ decomposition of H. What comes first in mind is that partonic 2-surfaces X^2 belong to $\delta M^4_\pm \subset M^8$ defining the ends of the causal diamond and are thus associative. This boundary condition however freezes E^4 degrees of freedom completely so that M^8 configuration space geometry trivializes.

Are the points of number theoretic braid commutative?

One can also consider the commutativity condition by requiring that arguments belong to a preferred commutative hyper-complex sub-space M^2 of M^8 which can be regarded as a curve in complex plane. Fixing preferred real and imaginary units means a choice of M^2 interpreted as a partial choice of quantization axes at the level of M^8. One must distinguish this choice from the hyper-quaternionicity of space-time surfaces and from the condition that each tangent space of X^4 contains $M^2(x) \subset M^4$ in its tangent space or normal space. Commutativity condition indeed implies the notion of number theoretic braid and fixes it uniquely once a global selection of $M^2 \subset M^8$ is made. There is also an alternative identification of number theoretic braid based on the assumption that braids are light-like curves with tangent vector in $M^2(x)$.

1. The strong form of commutativity condition would require that the arguments of the n-point function at partonic 2-surface belong to the intersection $X^2 \cap M_\pm$. This however allows quite too few points since an intersection of 2-D and 1-D objects in 7-D space would be in question. Associativity condition would reduce cure the problem but would trivialize configuration space geometry.

2. The weaker condition that only $\delta M^4_\pm$ projections for the points of X^2 commute is however sensible since the intersection of 1-D and 2-D surfaces of 3-D space results. This condition is also invariant under number theoretical duality. In the generic case this gives a discrete set

of points as intersection of light-like radial geodesic and the projection $P_{\delta M^4_\pm}(X^2)$. This set is naturally identifiable in terms of points in the intersection of number theoretic braids with $\delta CD \times E^4$. One should show that this set of points consists of rational or at most algebraic points. Here the possibility to choose X^2 to some degree could be essential. Any radial light ray from the tip of light-cone allows commutativity and one can consider the possibility of integrating over n-point functions with arguments at light ray to obtain maximal information.

3. For the pre-images of light-like 3-surfaces commutativity of the points in $\delta M^4_\pm$ projection would allow the projections to be one-dimensional curves of M^2 having thus interpretation as braid strands. M^2 would play exactly the same role as the plane into which braid strands are projected in the construction of braid invariants. Therefore the plane of non-physical polarizations in gauge theories corresponds to the plane to which braids and knots are projected in braid and knot theories. A further constraint is that the braid strand connects algebraic points of M^8 to algebraic points of M^8. It seems that this can be guaranteed only by posing some additional conditions to the light-like 3-surfaces themselves which is of course possible since they are in the role of fundamental dynamical objects.

Are number theoretic braids light-like curves with tangent in $M^2(x)$?

There are reasons why the identification of the number theoretic braid strand as a curve having hyper-complex light-like tangent looks more attractive.

1. An alternative identification of the number theoretic braid would give up commutativity condition for M^4 projection and assume braid strand to be as a light-like curve having light-like tangent belonging to the local hyper-complex tangent sub-space $M^2(x)$ at point x. This definition would apply both in $X^3 \subset \delta M^4_\pm \times CP_2$ and in X^3_l. Also now one would have a continuous distribution of number theoretic braids, with one braid assignable to each light-like curve with tangent $\delta M^4_+ \supset M_+(x) \subset M^2(x)$. In this case each light-like curve at δM^4_+ with tangent in $M_+(x)$ would define a number theoretic braid so that the only difference would be the replacement of light-like ray with a more general light-like curve.

2. The preferred plane $M^2(x)$ can be interpreted as the local plane of non-physical polarizations so that the interpretation as a number theoretic analog of gauge conditions posed in both quantum field theories and string models is possible. In TGD framework this would mean that super-conformal degrees of freedom are restricted to the orthogonal complement of $M^2(x)$ and $M^2(x)$ does not contribute to the configuration space metric. In Hamilton-Jacobi coordinates the pairs of light-like curves associated with coordinate lines can be interpreted as curved light rays. Hence the partonic planes $M^2(x_i)$ associated with the points of the number theoretic braid could be also regarded as carriers four-momenta of fermions associated with the braid strands so that the standard gauge conditions $\epsilon \cdot p = 0$ for polarization vector and four-momentum would be realized geometrically. The possibility of M^2 to depend on point of X^3_l would be essential to have non-collinear momenta and for a classical description of interactions between braid strands.

3. One could also define analogs of string world sheets as sub-manifolds of $P_{M^4_+}(X^4)$ having $M^2(x) \subset M^4$ as their tangent space or being assignable to their tangent containing $M_+(x)$ in the case that the distribution defined by the planes $M^2(x)$ exists and is integrable. It must be emphasized that in the case of massless extremals one can assign only $M_+(x) \subset M^4$ to $T(X^4(x))$ so that only a foliation of X^4 by light-like curves in M^4 is possible. For $P_{M^4_+}(X^4)$ however a foliation by 2-D stringy surfaces is obtained. Integrability of this distribution and thus the duality with stringy description has been suggested to be a basic feature of the preferred extremals and is equivalent with the existence of Hamilton-Jacobi coordinates for a large class of extremals of Kähler action [D1].

4. The possibility of dual descriptions based on integrable distribution of planes $M^2(x)$ allowing identification as 2-dimensional stringy sub-manifolds of $X^4(X^3)$ and the flexibility provided by the hyper-complex conformal invariance raise the hopes of achieving the lifting of super-symplectic algebra SS and super Kac-Moody algebra SKM to H. At the light-cone boundary the light-like radial coordinate could be lifted to a hyper-complex coordinate defining coordinate

for M^2. At X_l^3 one could fix the light-like coordinate varying along the braid strands and it can can be lifted to a light-like hyper-complex coordinate in M^4 by requiring that the tangent to the coordinate curve is light-like line of $M^2(x)$ at point x. The total four-momenta and color quantum numbers assignable to SS and SKM degrees of freedom are naturally identical since they can be identified as the four-momentum of the partonic 2-surface $X^2 \subset X^3 \cap \delta M^4_\pm \times CP_2$. Equivalence Principle would emerge as an identity.

Are also CP_2 duals of number theoretic braids possible?

This picture is probably not enough. From the beginning the idea that also the CP_2 projections of points of X^2 define number theoretic braids has been present. The dual role of the braids defined by M^2 and CP_2 projections of X^2 is suggested both by the construction of the symplectic fusion algebras [C4] and by the model of anyons [F12]. M^2 and the geodesic sphere $S^2_i \subset CP_2$, where one has either $i = I$ or $i = II$, where $i = I/II$ corresponds to homologically trivial/non-trivial geodesic sphere, are in a key role in the geometric realization of the hierarchy of Planck constants in terms of the book like structure of the generalized imbedding space. The fact that S^2_I corresponds to vacuum extremals would suggest that only the intersection $S^2_{II} \cap P_{CP_2}(X^2)$ can define CP_2 counterpart of the number theoretic braid. M^4 braid could be the proper description in the associative case (Minkowskian signature of induced metric) and CP_2 braid in the co-associative case (Euclidian signature of induced metric). The duality of these descriptions would be reflected also by the fact that the physical Planck constant is given by $\hbar = r\hbar_0$, $r = \hbar(M^4)/\hbar(CP_2)$, so that only the ratio of the two Planck constants matters in commutation relations.

What about symplectic contribution to number theoretic braids?

Also the symplectically invariant degrees of freedom must be treated and this leads to the notion of symplectic QFT. The explicit construction of symplectic fusion rules has been discussed in [C4]. These rules make sense only as a discretized version. Discreteness can be understood also as a manifestation of finite measurement resolution: at this time it is associated with the impossibility to know the induced Kähler form at each point of partonic 2-surface. What one can measure is the Kähler flux associated with a triangle and the density of triangulation determines the measurement accuracy. The discrete set of points associated with the symplectic algebra characterizes the measurement resolution and there is an infinite hierarchy of symplectic fusion algebras corresponding to gradually increasing measurement resolution in classical sense.

An interesting question is whether the symplectic triangulation could be used to represent a hierarchy of cutoffs of super conformal algebras by introducing additional fermionic oscillators at the points of the triangulation. The M^4 coordinates at the points of symplectic triangulation of S^2_i, $i = I, II$ projection and CP_2 coordinates at the points of symplectic triangulation of S^2 could define discrete version of quantized conformal fields. The functional integral over symplectic group would mean integral over symplectic triangulations. Note that M^2 number theoretic braid is trivial as symplectic triangulation since the points are along light-like geodesic of $\delta M^4_\pm$.

In the original variant of symplectic triangulation [C4] the exact form of triangulation was left free. It would be however nice if symplectic triangulation could be fixed purely physically by the properties of the induced Kähler form since also the number of fermionic oscillator modes and number theoretical braids is fixed by the dynamics of Kähler action.

1. A symplectically invariant manner to fix the nodes of the triangulation could be in terms of extrema of the symplectic invariant $\epsilon^{\alpha\beta}J_{\alpha\beta}$. The maxima of the magnitude of Kähler magnetic field are indeed natural observables. What is nice that the nodes are completely fixed by dynamics and the contribition to number theoretic braid would involve no ad hoc elements.

2. It is not clear whether the precise specification of the edges of the triangulation is needed or has any physical meaning. One might consider the possibility of of extremizing the fluxes but it turns out impossible to formulate this in terms of a local variational principle. The situation is analogous to finding an extremum of function in a situation when the extremum happens to be at the end of the interval so that the vanishing of derivative cannot be taken as criterion. In the recent situation one can expect that the extrema correspond to "triangles" for which symplectic area vanishes or to regions inside which $\epsilon^{\alpha\beta}J_{\alpha\beta}$ has a fixed sign.

Also the symplectic contribution to all three types of number theoretic braids could be present and would differ from the above described contribution in that the points of the braid are not critical with respect to phase transitions changing Planck constant.

What makes braids number theoretic?

Are braids always number theoretic or are they number theoretic only under special conditions which might be said to characterize number theoretic criticality. To answer these questions one must define precisely what one means with number theoretic universality, which has been one of the basic guide lines in the construction of quantum TGD. There are two forms of the principle.

1. The strong form of number theoretical universality states that physics for any system should effectively reduce to a physics in algebraic extension of rational numbers at the level of M-matrix so that an interpretation in both real and p-adic sense (allowing a suitable algebraic extension of p-adics) is possible. One can however worry whether this principle only means that physics is algebraic so that there would be no need to talk about real and p-adic physics at the level of M-matrix elements. It is not possible to get rid of real and p-adic numbers at the level of classical physics since calculus is a prerequisite for the basic variational principles used to formulate the theory. For this option the possibility of completion is what poses conditions on M-matrix.

2. The weak form of principle requires only that both real and p-adic variants of physics make sense and that the intersection of these physics consist of physics associated with various algebraic extensions of rational numbers. In this rational physics would be like rational numbers allowing infinite number of algebraic extensions and real numbers and p-adic number fields as its completions. Real and p-adic physics would be completions of rational physics. In this framework criticality with respect to phase transitions changing number field becomes a viable concept. This form of principle allows also purely p-adic phenomena such as p-adic pseudo non-determinism assigned to imagination and cognition. Genuinely p-adic physics does not however allow definition of notions like conserved quantities since the notion of definite integral is lacking and only the purely local form of real physics allows p-adic counterpart.

Experience has taught that it is better to avoid too strong statements and perhaps the weak form of the principle is enough. It is however clear that number theoretical criticality could provide important insights to quantum TGD: p-adic thermodynamics is excellent example of this. In consciousness theory the transitions transforming intentions to actions and actions to cognitions would be key applications and number theoretic criticality would be almost defining feature of living matter. Needless to say, zero energy ontology is absolutely essential: otherwise this kind of transitions would not make sense.

Number theoretical criticality (or number theoretical universality in strong sense) requires that M-matrix elements are algebraic numbers. This is achieved naturally if the definition of M-matrix elements involves only the data associated with the number theoretic braid with the property that the coordinates for the points of imbedding space in question are algebraic numbers and that possible other data are also algebraic. This point has been discussed in more detail in [C2].

3.5 General vision about real and p-adic coupling constant evolution

The unification of super-symplectic and Super Kac-Moody symmetries allows new view about p-adic aspects of the theory forcing a considerable modification and refinement of the almost decade old first picture about color coupling constant evolution.

Perhaps the most important questions about coupling constant evolution relate to the basic hypothesis about preferred role of primes $p \simeq 2^k$, k an integer. Why integer values of k are favored, why prime values are even more preferred, and why Mersenne primes $M_n = 2^n - 1$ and Gaussian Mersennes seem to be at the top of the hierarchy?

Second bundle of questions relates to the color coupling constant evolution. Do Mersenne primes really define a hierarchy of fixed points of color coupling constant evolution for a hierarchy of asymptotically non-free QCD type theories both in quark and lepton sector of the theory? How the transitions $M_n \rightarrow M_{n(next)}$ occur? What are the space-time correlates for the coupling constant evolution and for

for these transitions and how space-time description relates to the usual description in terms of parton loops? How the condition that p-adic coupling constant evolution reflects the real coupling constant evolution can be satisfied and how strong conditions it poses on the coupling constant evolution?

3.5.1 A general view about coupling constant evolution

Zero energy ontology

In zero energy ontology one replaces positive energy states with zero energy states with positive and negative energy parts of the state at the boundaries of future and past direct light-cones forming a causal diamond. All conserved quantum numbers of the positive and negative energy states are of opposite sign so that these states can be created from vacuum. "Any physical state is creatable from vacuum" becomes thus a basic principle of quantum TGD and together with the notion of quantum jump resolves several philosophical problems (What was the initial state of universe?, What are the values of conserved quantities for Universe, Is theory building completely useless if only single solution of field equations is realized?).

At the level of elementary particle physics positive and negative energy parts of zero energy state are interpreted as initial and final states of a particle reaction so that quantum states become physical events. Equivalence Principle would hold true in the sense that the classical gravitational four-momentum of the vacuum extremal whose small deformations appear as the argument of configuration space spinor field is equal to the positive energy of the positive energy part of the zero energy quantum state. Equivalence Principle is expected to hold true for elementary particles and their composites but not for the quantum states defined around non-vacuum extremals.

Does the finiteness of measurement resolution dictate the laws of physics?

The hypothesis that the mere finiteness of measurement resolution could determine the laws of quantum physics [C2] completely belongs to the category of not at all obvious first principles. The basic observation is that the Clifford algebra spanned by the gamma matrices of the "world of classical worlds" represents a von Neumann algebra [16] known as hyperfinite factor of type II_1 (HFF) [A9, C6, C2]. HFF [17, 23] is an algebraic fractal having infinite hierarchy of included subalgebras isomorphic to the algebra itself [18]. The structure of HFF is closely related to several notions of modern theoretical physics such as integrable statistical physical systems [25], anyons [20], quantum groups and conformal field theories[17, 19], and knots and topological quantum field theories [26, 22].

Zero energy ontology is second key element. In zero energy ontology these inclusions allow an interpretation in terms of a finite measurement resolution: in the standard positive energy ontology this interpretation is not possible. Inclusion hierarchy defines in a natural manner the notion of coupling constant evolution and p-adic length scale hypothesis follows as a prediction. In this framework the extremely heavy machinery of renormalized quantum field theory involving the elimination of infinities is replaced by a precisely defined mathematical framework. More concretely, the included algebra creates states which are equivalent in the measurement resolution used. Zero energy states are associated with causal diamond formed by a pair of future and past directed light-cones having positive and negative energy parts of state at their boundaries. Zero energy state can be modified in a time scale shorter than the time scale of the zero energy state itself.

On can imagine two kinds of measurement resolutions. The element of the included algebra can leave the quantum numbers of the positive and negative energy parts of the state invariant, which means that the action of subalgebra leaves M-matrix invariant. The action of the included algebra can also modify the quantum numbers of the positive and negative energy parts of the state such that the zero energy property is respected. In this case the Hermitian operators subalgebra must commute with M-matrix.

The temporal distance between the tips of light-cones corresponds to the secondary p-adic time scale $T_{p,2} = \sqrt{p}T_p$ by a simple argument based on the observation that light-like randomness of light-like 3-surface is analogous to Brownian motion. This gives the relationship $T_p = L_p^2/Rc$, where R is CP_2 size. The action of the included algebra corresponds to an addition of zero energy parts to either positive or negative energy part of the state and is like addition of quantum fluctuation below the time scale of the measurement resolution. The natural hierarchy of time scales is obtained as $T_n = 2^{-n}T$ since these insertions must belong to either upper or lower half of the causal diamond. This implies that preferred p-adic primes are near powers of 2. For electron the time scale in question is .1 seconds defining the fundamental biorhythm of 10 Hz.

M-matrix representing a generalization of S-matrix and expressible as a product of a positive square root of the density matrix and unitary S-matrix would define the dynamics of quantum theory [C2]. The notion of thermodynamical state would cease to be a theoretical fiction and in a well-defined sense quantum theory could be regarded as a square root of thermodynamics. M-matrix is identifiable in terms of Connes tensor product [23] and therefore exists and is almost unique. Connes tensor product implies that the Hermitian elements of the included algebra commute with M-matrix and hence act like infinitesimal symmetries. A connection with integrable quantum field theories is suggestive. The remaining challenge is the calculation of M-matrix and the needed machinery might already exist.

The tension is present also now. The connection with visions should come from the discretization in terms of number theoretic braids providing space-time correlate for the finite measurement resolution and making p-adicization in terms of number theoretic braids possible. Number theoretic braids give a connection with the construction of configuration space geometry in terms of Dirac determinant and with TGD as almost TQFT and with conformal field theory approach. The mathematics for the inclusions of hyper-finite factors of type II_1 is also closely related to that for conformal field theories including quantum groups relating closely to Connes tensor product and non-commutativity.

How do p-adic coupling constant evolution and p-adic length scale hypothesis emerge?

Zero energy ontology in which zero energy states have as imbedding space correlates causal diamonds for which the distance between the tips of future and past directed light-cones are power of 2 multiples of fundamental time scale $T_n = 2^n T_0$) implies in a natural manner coupling constant evolution. A weaker condition would be $T_p = pT_0$, p prime, and would assign all p-adic time scales to the size scale hierarchy of CDs.

Could the coupling constant evolution in powers of 2 implying time scale hierarchy $T_n = 2^n T_0$ (or $T_p = pT_0$) induce p-adic coupling constant evolution and explain why p-adic length scales correspond to $L_p \propto \sqrt{p}R$, $p \simeq 2^k$, R CP_2 length scale? This looks attractive but there is a problem. p-Adic length scales come as powers of $\sqrt{2}$ rather than 2 and the strongly favored values of k are primes and thus odd so that $n = k/2$ would be half odd integer. This problem can be solved.

1. The observation that the distance traveled by a Brownian particle during time t satisfies $r^2 = Dt$ suggests a solution to the problem. p-Adic thermodynamics applies because the partonic 3-surfaces X^2 are as 2-D dynamical systems random apart from light-likeness of their orbit. For CP_2 type vacuum extremals the situation reduces to that for a one-dimensional random light-like curve in M^4. The orbits of Brownian particle would now correspond to light-like geodesics γ_3 at X^3. The projection of γ_3 to a time=constant section $X^2 \subset X^3$ would define the 2-D path γ_2 of the Brownian particle. The M^4 distance r between the end points of γ_2 would be given $r^2 = Dt$. The favored values of t would correspond to $T_n = 2^n T_0$ (the full light-like geodesic). p-Adic length scales would result as $L^2(k) = DT(k) = D2^k T_0$ for $D = R^2/T_0$. Since only CP_2 scale is available as a fundamental scale, one would have $T_0 = R$ and $D = R$ and $L^2(k) = T(k)R$.

2. p-Adic primes near powers of 2 would be in preferred position. p-Adic time scale would not relate to the p-adic length scale via $T_p = L_p/c$ as assumed implicitly earlier but via $T_p = L_p^2/R_0 = \sqrt{p}L_p$, which corresponds to secondary p-adic length scale. For instance, in the case of electron with $p = M_{127}$ one would have $T_{127} = .1$ second which defines a fundamental biological rhythm. Neutrinos with mass around .1 eV would correspond to $L(169) \simeq 5$ μm (size of a small cell) and $T(169) \simeq 1. \times 10^4$ years. A deep connection between elementary particle physics and biology becomes highly suggestive.

3. In the proposed picture the p-adic prime $p \simeq 2^k$ would characterize the thermodynamics of the random motion of light-like geodesics of X^3 so that p-adic prime p would indeed be an inherent property of X^3. For $T_p = pT_0$ the above argument is not enough for p-adic length scale hypothesis and p-adic length scale hypothesis might be seen as an outcome of a process analogous to natural selection. Resonance like effect favoring octaves of a fundamental frequency might be in question. In this case, p would a property of CD and all light-like 3-surfaces inside it and also that corresponding sector of configuration space.

3.5.2 Both symplectic and conformal field theories are needed in TGD framework

Before one can say anything quantitative about coupling constant evolution, one must have a formulation for its TGD counterpart and thus also a more detailed formulation for how to calculate M-matrix elements. There is also the question about infinities. By very general arguments infinities of quantum field theories are predicted to cancel in TGD Universe - basically by the non-locality of Kähler function as a functional of 3-surface and by the general properties of the vacuum functional identified as the exponent of Kähler function. The precise mechanism leading to the cancellation of infinities of local quantum field theories has remained unspecified. Only the realization that the symplectic invariance of quantum TGD provides a mechanism regulating the short distance behavior of N-point functions changed the situation in this respect. This also leads to concrete view about the generalized Feynman diagrams giving M-matrix elements and rather close resemblance with ordinary Feynman diagrammatics.

Symplectic invariance

Symplectic (or canonical as I have called them) symmetries of $\delta M^4_+ \times CP_2$ (light-cone boundary briefly) act as isometries of the "world of classical worlds". One can see these symmetries as analogs of Kac-Moody type symmetries with symplectic transformations of $S^2 \times CP_2$, where S^2 is $r_M = constant$ sphere of lightcone boundary, made local with respect to the light-like radial coordinate r_M taking the role of complex coordinate. Thus finite-dimensional Lie group G is replaced with infinite-dimensional group of symplectic transformations. This inspires the question whether a symplectic analog of conformal field theory at $\delta M^4_+ \times CP_2$ could be relevant for the construction of n-point functions in quantum TGD and what general properties these n-point functions would have. This section appears already in the previous chapter about symmetries of quantum TGD [C1] but because the results of the section provide the first concrete construction recipe of M-matrix in zero energy ontology, it is included also in this chapter.

Symplectic QFT at sphere

Actually the notion of symplectic QFT emerged as I tried to understand the properties of cosmic microwave background which comes from the sphere of last scattering which corresponds roughly to the age of 5×10^5 years [D8]. In this situation vacuum extremals of Kähler action around almost unique critical Robertson-Walker cosmology imbeddable in $M^4 \times S^2$, where there is homologically trivial geodesic sphere of CP_2. Vacuum extremal property is satisfied for any space-time surface which is surface in $M^4 \times Y^2$, Y^2 a Lagrangian sub-manifold of CP_2 with vanishing induced Kähler form. Symplectic transformations of CP_2 and general coordinate transformations of M^4 are dynamical symmetries of the vacuum extremals so that the idea of symplectic QFT emerges natural. Therefore I shall consider first symplectic QFT at the sphere S^2 of last scattering with temperature fluctution $\Delta T/T$ proportional to the fluctuation of the metric component g_{aa} in Robertson-Walker coordinates.

1. In quantum TGD the symplectic transformation of the light-cone boundary would induce action in the "world of classical worlds" (light-like 3-surfaces). In the recent situation it is convenient to regard perturbations of CP_2 coordinates as fields at the sphere of last scattering (call it S^2) so that symplectic transformations of CP_2 would act in the field space whereas those of S^2 would act in the coordinate space just like conformal transformations. The deformation of the metric would be a symplectic field in S^2. The symplectic dimension would be induced by the tensor properties of R-W metric in R-W coordinates: every S^2 coordinate index would correspond to one unit of symplectic dimension. The symplectic invariance in CP_2 degrees of freedom is guaranteed if the integration measure over the vacuum deformations is symplectic invariant. This symmetry does not play any role in the sequel.

2. For a symplectic scalar field $n \geq 3$-point functions with a vanishing anomalous dimension would be functions of the symplectic invariants defined by the areas of geodesic polygons defined by subsets of the arguments as points of S^2. Since n-polygon can be constructed from 3-polygons these invariants can be expressed as sums of the areas of 3-polygons expressible in terms of symplectic form. n-point functions would be constant if arguments are along geodesic circle

since the areas of all sub-polygons would vanish in this case. The decomposition of n-polygon to 3-polygons brings in mind the decomposition of the n-point function of conformal field theory to products of 2-point functions by using the fusion algebra of conformal fields (very symbolically $\Phi_k\Phi_l = c_{kl}^m\Phi_m$). This intuition seems to be correct.

3. Fusion rules stating the associativity of the products of fields at different points should generalize. In the recent case it is natural to assume a non-local form of fusion rules given in the case of symplectic scalars by the equation

$$\Phi_k(s_1)\Phi_l(s_2) = \int c_{kl}^m f(A(s_1,s_2,s_3))\Phi_m(s)d\mu_s \quad . \tag{3.5.1}$$

Here the coefficients c_{kl}^m are constants and $A(s_1,s_2,s_3)$ is the area of the geodesic triangle of S^2 defined by the sympletic measure and integration is over S^2 with symplectically invariant measure $d\mu_s$ defined by symplectic form of S^2. Fusion rules pose powerful conditions on n-point functions and one can hope that the coefficients are fixed completely.

4. The application of fusion rules gives at the last step an expectation value of 1-point function of the product of the fields involves unit operator term $\int c_{kl}f(A(s_1,s_2,s))Idd\mu_s$ so that one has

$$\langle\Phi_k(s_1)\Phi_l(s_2)\rangle = \int c_{kl}f(A(s_1,s_2,s))d\mu_s \quad . \tag{3.5.2}$$

Hence 2-point function is average of a 3-point function over the third argument. The absence of non-trivial symplectic invariants for 1-point function means that $n=1$- an are constant, most naturally vanishing, unless some kind of spontaneous symmetry breaking occurs. Since the function $f(A(s_1,s_2,s_3))$ is arbitrary, 2-point correlation function can have both signs. 2-point correlation function is invariant under rotations and reflections.

Symplectic QFT with spontaneous breaking of rotational and reflection symmetries

CMB data suggest breaking of rotational and reflection symmetries of S^2. A possible mechanism of spontaneous symmetry breaking is based on the observation that in TGD framework the hierarchy of Planck constants assigns to each sector of the generalized imbedding space a preferred quantization axes. The selection of the quantization axis is coded also to the geometry of "world of classical worlds", and to the quantum fluctuations of the metric in particular. Clearly, symplectic QFT with spontaneous symmetry breaking would provide the sought-for really deep reason for the quantization of Planck constant in the proposed manner.

1. The coding of angular momentum quantization axis to the generalized imbedding space geometry allows to select South and North poles as preferred points of S^2. To the three arguments s_1,s_2,s_3 of the 3-point function one can assign two squares with the added point being either North or South pole. The difference

$$\Delta A(s_1,s_2,s_3) \quad \equiv \quad A(s_1,s_2,s_3,N) - A(s_1,s_2,s_3,S) \tag{3.5.3}$$

of the corresponding areas defines a simple symplectic invariant breaking the reflection symmetry with respect to the equatorial plane. Note that ΔA vanishes if arguments lie along a geodesic line or if any two arguments co-incide. Quite generally, symplectic QFT differs from conformal QFT in that correlation functions do not possess singularities.

2. The reduction to 2-point correlation function gives a consistency conditions on the 3-point functions

$$\begin{aligned} \langle(\Phi_k(s_1)\Phi_l(s_2))\Phi_m(s_3)\rangle &= c^r_{kl}\int f(\Delta A(s_1,s_2,s))\langle\Phi_r(s)\Phi_m(s_3)\rangle d\mu_s \\ &= \quad (3.5.4) \end{aligned}$$

$$c^r_{kl}c_{rm}\int f(\Delta A(s_1,s_2,s))f(\Delta A(s,s_3,t))d\mu_s d\mu_t \ . \quad (3.5.5)$$

   Associativity requires that this expression equals to $\langle\Phi_k(s_1)(\Phi_l(s_2)\Phi_m(s_3))\rangle$ and this gives additional conditions. Associativity conditions apply to $f(\Delta A)$ and could fix it highly uniquely.

3. 2-point correlation function would be given by

$$\langle\Phi_k(s_1)\Phi_l(s_2)\rangle = c_{kl}\int f(\Delta A(s_1,s_2,s))d\mu_s \quad (3.5.6)$$

4. There is a clear difference between $n>3$ and $n=3$ cases: for $n>3$ also non-convex polygons are possible: this means that the interior angle associated with some vertices of the polygon is larger than π. $n=4$ theory is certainly well-defined, but one can argue that so are also $n>4$ theories and skeptic would argue that this leads to an inflation of theories. TGD however allows only finite number of preferred points and fusion rules could eliminate the hierarchy of theories.

5. To sum up, the general predictions are following. Quite generally, for $f(0)=0$ n-point correlation functions vanish if any two arguments co-incide which conforms with the spectrum of temperature fluctuations. It also implies that symplectic QFT is free of the usual singularities. For symmetry breaking scenario 3-point functions and thus also 2-point functions vanish also if s_1 and s_2 are at equator. All these are testable predictions using ensemble of CMB spectra.

Generalization to quantum TGD

Since number theoretic braids are the basic objects of quantum TGD, one can hope that the n-point functions assignable to them could code the properties of ground states and that one could separate from n-point functions the parts which correspond to the symplectic degrees of freedom acting as symmetries of vacuum extremals and isometries of the 'world of classical worlds'.

1. This approach indeed seems to generalize also to quantum TGD proper and the n-point functions associated with partonic 2-surfaces can be decomposed in such a manner that one obtains coefficients which are symplectic invariants associated with both S^2 and CP_2 Kähler form.

2. Fusion rules imply that the gauge fluxes of respective Kähler forms over geodesic triangles associated with the S^2 and CP_2 projections of the arguments of 3-point function serve basic building blocks of the correlation functions. The North and South poles of S^2 and three poles of CP_2 can be used to construct symmetry breaking n-point functions as symplectic invariants. Non-trivial 1-point functions vanish also now.

3. The important implication is that n-point functions vanish when some of the arguments co-incide. This might play a crucial role in taming of the singularities: the basic general prediction of TGD is that standard infinities of local field theories should be absent and this mechanism might realize this expectation.

Next some more technical but elementary first guesses about what might be involved.

1. It is natural to introduce the moduli space for n-tuples of points of the symplectic manifold as the space of symplectic equivalence classes of n-tuples. In the case of sphere S^2 convex n-polygon allows $n+1$ 3-sub-polygons and the areas of these provide symplectically invariant coordinates for the moduli space of symplectic equivalence classes of n-polygons (2^n-D space of polygons is reduced to $n+1$-D space). For non-convex polygons the number of 3-sub-polygons is reduced so that they seem to correspond to lower-dimensional sub-space. In the case of CP_2 n-polygon allows besides the areas of 3-polygons also 4-volumes of 5-polygons as fundamental symplectic invariants. The number of independent 5-polygons for n-polygon can be obtained by using induction: once the numbers $N(k,n)$ of independent $k \leq n$-simplices are known for n-simplex, the numbers of $k \leq n+1$-simplices for $n+1$-polygon are obtained by adding one vertex so that by little visual gymnastics the numbers $N(k,n+1)$ are given by $N(k,n+1) = N(k-1,n)+N(k,n)$. In the case of CP_2 the allowance of 3 analogs $\{N,S,T\}$ of North and South poles of S^2 means that besides the areas of polygons (s_1,s_2,s_3), (s_1,s_2,s_3,X), (s_1,s_2,s_3,X,Y), and (s_1,s_2,s_3,N,S,T) also the 4-volumes of 5-polygons (s_1,s_2,s_3,X,Y), and of 6-polygon (s_1,s_2,s_3,N,S,T), $X,Y \in \{N,S,T\}$ can appear as additional arguments in the definition of 3-point function.

2. What one really means with symplectic tensor is not clear since the naive first guess for the n-point function of tensor fields is not manifestly general coordinate invariant. For instance, in the model of CMB, the components of the metric deformation involving S^2 indices would be symplectic tensors. Tensorial n-point functions could be reduced to those for scalars obtained as inner products of tensors with Killing vector fields of $SO(3)$ at S^2. Again a preferred choice of quantization axis would be introduced and special points would correspond to the singularities of the Killing vector fields.

   The decomposition of Hamiltonians of the "world of classical worlds" expressible in terms of Hamiltonians of $S^2 \times CP_2$ to irreps of $SO(3)$ and $SU(3)$ could define the notion of symplectic tensor as the analog of spherical harmonic at the level of configuration space. Spin and gluon color would have natural interpretation as symplectic spin and color. The infinitesimal action of various Hamiltonians on n-point functions defined by Hamiltonians and their super counterparts is well-defined and group theoretical arguments allow to deduce general form of n-point functions in terms of symplectic invariants.

3. The need to unify p-adic and real physics by requiring them to be completions of rational physics, and the notion of finite measurement resolution suggest that discretization of also fusion algebra is necessary. The set of points appearing as arguments of n-point functions could be finite in a given resolution so that the p-adically troublesome integrals in the formulas for the fusion rules would be replaced with sums. Perhaps rational/algebraic variants of $S^2 \times CP_2 = SO(3)/SO(2) \times SU(3)/U(2)$ obtained by replacing these groups with their rational/algebraic variants are involved. Tedrahedra, octahedra, and dodecahedra suggest themselves as simplest candidates for these discretized spaces. Also the symplectic moduli space would be discretized to contain only n-tuples for which the symplectic invariants are numbers in the allowed algebraic extension of rationals. This would provide an abstract looking but actually very concrete operational approach to the discretization involving only areas of n-tuples as internal coordinates of symplectic equivalence classes of n-tuples. The best that one could achieve would be a formulation involving nothing below measurement resolution.

4. This picture based on elementary geometry might make sense also in the case of conformal symmetries. The angles associated with the vertices of the S^2 projection of n-polygon could define conformal invariants appearing in n-point functions and the algebraization of the corresponding phases would be an operational manner to introduce the space-time correlates for the roots of unity introduced at quantum level. In CP_2 degrees of freedom the projections of n-tuples to the homologically trivial geodesic sphere S^2 associated with the particular sector of CH would allow to define similar conformal invariants. This framework gives dimensionless areas (unit sphere is considered). p-Adic length scale hypothesis and hierarchy of Planck constants would bring in the fundamental units of length and time in terms of CP_2 length.

The recent view about M-matrix described in [C2] is something almost unique determined by Connes tensor product providing a formal realization for the statement that complex rays of state space are replaced with $\mathcal{N}$ rays where $\mathcal{N}$ defines the hyper-finite sub-factor of type II_1 defining the measurement resolution. M-matrix defines time-like entanglement coefficients between positive and negative energy parts of the zero energy state and need not be unitary. It is identified as square root of density matrix with real expressible as product of of real and positive square root and unitary S-matrix. This S-matrix is what is measured in laboratory. There is also a general vision about how vertices are realized: they correspond to light-like partonic 3-surfaces obtained by gluing incoming and outgoing partonic 3-surfaces along their ends together just like lines of Feynman diagrams. Note that in string models string world sheets are non-singular as 2-manifolds whereas 1-dimensional vertices are singular as 1-manifolds. These ingredients we should be able to fuse together. So we try once again!

1. *Iteration* starting from vertices and propagators is the basic approach in the construction of n-point function in standard QFT. This approach does not work in quantum TGD. Symplectic and conformal field theories suggest that *recursion* replaces iteration in the construction. One starts from an n-point function and reduces it step by step to a vacuum expectation value of a 2-point function using fusion rules. Associativity becomes the fundamental dynamical principle in this process. Associativity in the sense of classical number fields has already shown its power and led to a hyper-octoninic formulation of quantum TGD promising a unification of various visions about quantum TGD [E2].

2. Let us start from the representation of a zero energy state in terms of a causal diamond defined by future and past directed light-cones. Zero energy state corresponds to a quantum superposition of light-like partonic 3-surfaces each of them representing possible particle reaction. These 3-surfaces are very much like generalized Feynman diagrams with lines replaced by light-like 3-surfaces coming from the upper and lower light-cone boundaries and glued together along their ends at smooth 2-dimensional surfaces defining the generalized vertices.

3. It must be emphasized that the generalization of ordinary Feynman diagrammatics arises and conformal and symplectic QFTs appear only in the calculation of single generalized Feynman diagram. Therefore one could still worry about loop corrections. The fact that no integration over loop momenta is involved and there is always finite cutoff due to discretization together with recursive instead of iterative approach gives however good hopes that everything works.

4. One can actually simplify things by identifying generalized Feynman diagrams as maxima of Kähler function with functional integration carried over perturbations around it. Thus one would have conformal field theory in both fermionic and configuration space degrees of freedom. The light-like time coordinate along light-like 3-surface is analogous to the complex coordinate of conformal field theories restricted to some curve. If it is possible continue the light-like time coordinate to a hyper-complex coordinate in the interior of 4-D space-time sheet, the correspondence with conformal field theories becomes rather concrete. Same applies to the light-like radial coordinates associated with the light-cone boundaries. At light-cone boundaries one can apply fusion rules of a symplectic QFT to the remaining coordinates. Conformal fusion rules are applied only to point pairs which are at different ends of the partonic surface and there are no conformal singularities since arguments of n-point functions do not co-incide. By applying the conformal and symplectic fusion rules one can eventually reduce the n-point function defined by the various fermionic and bosonic operators appearing at the ends of the generalized Feynman diagram to something calculable.

5. Finite measurement resolution defining the Connes tensor product is realized by the discretization applied to the choice of the arguments of n-point functions so that discretion is not only a space-time correlate of finite resolution but actually defines it. No explicit realization of the measurement resolution algebra $\mathcal{N}$ seems to be needed. Everything should boil down to the fusion rules and integration measure over different 3-surfaces defined by exponent of Kähler function and by imaginary exponent of Chern-Simons action. The continuation of the configuration space Clifford algebra for 3-surfaces with cm degrees of freedom fixed to a hyper-octonionic variant of gamma matrix field of super-string models defined in M^8 (hyper-octonionic space) and $M^8 \leftrightarrow M^4 \times CP_2$ duality leads to a unique choice of the points, which can contribute to n-point functions as intersection of M^4 subspace of M^8 with the counterparts of partonic 2-surfaces at the boundaries of light-cones of M^8. Therefore there are hopes that the resulting theory is

highly unique. Symplectic fusion algebra reduces to a finite algebra for each space-time surface if this picture is correct.

6. Consider next some of the details of how the light-like 3-surface codes for the fusion rules associated with it. The intermediate partonic 2- surfaces must be involved since otherwise the construction would carry no information about the properties of the light-like 3-surface, and one would not obtain perturbation series in terms of the relevant coupling constants. The natural assumption is that partonic 2-surfaces belong to future/past directed light-cone boundary depending on whether they are on lower/upper half of the causal diamond. Hyper-octonionic conformal field approach fixes the n_{int} points at intermediate partonic two-sphere for a given light-like 3-surface representing generalized Feynman diagram, and this means that the contribution is just N-point function with $N = n_{out} + n_{int} + n_{in}$ calculable by the basic fusion rules. Coupling constant strengths would emerge through the fusion coefficients, and at least in the case of gauge interactions they must be proportional to Kähler coupling strength since n-point functions are obtained by averaging over small deformations with vacuum functional given by the exponent of Kähler function. The first guess is that one can identify the spheres $S^2 \subset \delta M^4_\pm$ associated with initial, final and, and intermediate states so that symplectic n-points functions could be calculated using single sphere.

These findings raise the hope that quantum TGD is indeed a solvable theory. The coupling constant evolution is based on the same mechanism as in QFT and symplectic invariance replaces ad hoc UV cutoff with a genuine dynamical regulation mechanism. Causal diamond itself defines the physical IR cutoff. p-Adic and real coupling constant evolutions reflect the underlying evolution in powers of two for the temporal distance between the tips of the light-cones of the causal diamond and the association of macroscopic time scale as secondary p-adic time scale to elementary particles (.1 seconds for electron) serves as a first test for the picture. Even if one is not willing to swallow any bit of TGD, the classification of the symplectic QFTs remains a fascinating mathematical challenge in itself. A further challenge is the fusion of conformal QFT and symplectic QFT in the construction of n-point functions. One might hope that conformal and symplectic fusion rules could be treated independently.

More detailed view about the construction of M-matrix elements

After three decades there are excellent hopes of building an explicit recipe for constructing M-matrix elements but the devil is in the details.

1. Elimination of infinities and coupling constant evolution

The elimination of infinities would follow from the symplectic QFT part of the theory. The symplectic contribution to n-point functions vanishes when two arguments co-incide. The UV cancellation mechanism has nothing to do with the finite measurement resolution which corresponds to the size of the causal diamonds inside which the space-time sheets representing radiative corrections are. There is also IR cutoff due to the presence of largest causal diamond.

On can decompose the radiative corrections two two types. First kind of corrections appear both at the level of positive/and negative energy parts of zero energy states. Second kind of corrections appear at the level of interactions between them. This decomposition is standard in quantum field theories and corresponds to the renormalization constants of fields *resp.* renormalization of coupling constants. The corrections due to the increase of measurement resolution in time comes as very specific corrections to positive and negative energy states involving gluing of smaller causal diamonds to the upper and lower boundaries of causal diamonds along any radial light-like ray. The radiative corresponds to the interactions correspond to the addition of smaller causal diamonds in the interior of the larger causal diamond. Scales for the corrections come as scalings in powers of 2 rather than as continuous scaling of measurement resolution.

2. Conformal symmetries

The basic questions are the following ones. How hyper-octonionic/-quaternionic/-complex super-conformal symmetry relates to the super-symplectic conformal symmetry at the imbedding space level and the super Kac-Moody symmetry associated with the light-like 3-surfaces? How do the dual $HO = M^8$ and $H = M^4 \times CP_2$ descriptions (number theoretic compactifcation) relate?

Concerning the understanding of these issues, the earlier construction of physical states poses strong constraints [C1].

1. The state construction utilizes both super-symplectic and super Kac-Moody algebras. Super-symplectic algebra has negative conformal weights and creates tachyonic ground states from which Super Kac-Moody algebra generates states with non-negative conformal weight determining the mass squared value of the state. The commutator of these two algebras annihilates the physical states. This requires that both super conformal algebras must allow continuation to hyper-octonionic algebras, which are independent.

2. The light-like radial coordinate at $\delta M^4_\pm$ can be continued to a hyper-complex coordinate in $M^2_\pm$ defined the preferred commutative plane of non-physical polarizations, and also to a hyper-quaternionic coordinate in $M^4_\pm$. Hence it would seem that super-symplectic algebra can be continued to an algebra in $M^2_\pm$ or perhaps in the entire $M^4_\pm$. This would allow to continue also the operators G, L and other super-symplectic operators to operators in hyper-quaternionic $M^4_\pm$ needed in stringy perturbation theory.

3. Also the super KM algebra associated with the light-like 3-surfaces should be continueable to hyper-quaternionic $M^4_\pm$. Here $HO - H$ duality comes in rescue. It requires that the preferred hyper-complex plane M^2 is contained in the tangent plane of the space-time sheet at each point, in particular at light-like 3-surfaces. We already know that this allows to assign a unique space-time surface to a given collection of light-like 3-surfaces as hyper-quaternionic 4-surface of HO hypothesized to correspond to (an obviously preferred) extremal of Kähler action. An equally important implication is that the light-like coordinate of X^3 can be continued to hyper-complex coordinate M^2 coordinate and thus also to hyperquaternionic M^4 coordinate.

4. The four-momentum appears in super generators G_n and L_n. It seems that the formal Fourier transform of four-momentum components to gradient operators to $M^4_\pm$ is needed and defines these operators as particular elements of the CH Clifford algebra elements extended to fields in imbedding space.

3. What about stringy perturbation theory?

The analog of stringy perturbation theory does not seems only a highly attractive but also an unavoidable outcome since a generalization of massless fermionic propagator is needed. The inverse for the sum of super Kac-Moody and super-symplectic super-Virasoro generators G (L) extended to an operator acting on the difference of the M^4 coordinates of the end points of the propagator line connecting two partonic 2-surfaces should appear as fermionic (bosonic) propagator in stringy perturbation theory. Virasoro conditions imply that only G_0 and L_0 appear as propagators. Momentum eigenstates are not strictly speaking possible since since discretization is present due to the finite measurement resolution. One can however represent these states using Fourier transform as a superposition of momentum eigenstates so that standard formalism can be applied.

Symplectic QFT gives an additional multiplicative contribution to n-point functions and there would be also braiding S-matrices involved with the propagator lines in the case that partonic 2-surface carriers more than 1 point. This leaves still modular degrees of freedom of the partonic 2-surfaces describable in terms of elementary particle vacuum functionals and the proper treatment of these degrees of freedom remains a challenge.

4. What about non-hermiticity of the CH super-generators carrying fermion number?

TGD represents also a rather special challenge, which actually represents the fundamental difference between quantum TGD and super string models. The assignment of fermion number to CH gamma matrices and thus also to the super-generator G is unavoidable. Also M^4 and H gamma matrices carry fermion number. This has been a long-standing interpretational problem in quantum TGD and I have been even ready to give up the interpretation of four-momentum operator appearing in G_n and L_n as actual four-momenta. The manner to get rid of this problem would be the assumption of Majorana property but this would force to give up the interpretation of different imbedding space chiralities in terms of conserved lepton and quark numbers and would also lead to super-string theory with critical dimension 10 or 11. A further problem is how to obtain amplitudes which respect fermion number conservation using string perturbation theory if $1/G = G^\dagger/L_0$ carries fermion number.

The recent picture does not leave many choices so that I was forced to face the truth and see how everything falls down to this single nasty detail! It became as a total surprise that gamma matrices carrying fermion number do not cause any difficulties in zero energy ontology and make sense even in the ordinary Feynman diagrammatics.

1. Non-hermiticity of G means that the center of mass terms CH gamma matrices must be distinguished from their Hermitian conjugates. In particular, one has $\gamma_0 \neq \gamma_0^{dagger}$. One can interpret the fermion number carrying M^4 gamma matrices of the complexified quaternion space.

2. One might think that $M^4 \times CP_2$ gamma matrices carrying fermion number is a catastrophe but this is not the case in massless theory. Massless momentum eigen states can be created by the operator $p^k\gamma_k^\dagger$ from a vacuum annihilated by gamma matrices and satisfying massless Dirac equation. The conserved fermion number defined by the integral of $\overline{\Psi}\gamma^0\Psi$ over 3-space gives just its standard value. A further experimentation shows that Feynman diagrams with non-hermitian gamma matrices give just the standard results since fermionic propagator and boson-emission vertices give compensating fermion numbers.

3. If the theory would contain massive fermions or a coupling to a scalar Higgs, a catastrophe would result. Hence ordinary Higgs mechanism is not possible in this framework. Of course, also the quantization of fermions is totally different. In TGD fermion mass is not a scalar in H. Part of it is given by CP_2 Dirac operator, part by p-adic thermodynamics for L_0, and part by Higgs field which behaves like vector field in CP_2 degrees of freedom, so that the catastrophe is avoided.

4. In zero energy ontology zero energy states are characterized by M-matrix elements constructed by applying the combination of stringy and symplectic Feynman rules and fermionic propagator is replaced with its super-conformal generalization reducing to an ordinary fermionic propagator for massless states. The norm of a single fermion state is given by a propagator connecting positive energy state and its conjugate with the propagator G_0/L_0 and the standard value of the norm is obtained by using Dirac equation and the fact that Dirac operator appears also in G_0.

5. The hermiticity of super-generators G would require Majorana property and one would end up with superstring theory with critical dimension $D = 10$ or $D = 11$ for the imbedding space. Hence the new interpretation of gamma matrices, proposed already years ago, has very profound consequences and convincingly demonstrates that TGD approach is indeed internally consistent.

In this framework coupling constant evolution would have interpretation in terms of addition of intermediate zero energy states corresponding to the generalized Feynman diagrams obtained by the insertion of causal diamonds with a new shorter time scale $T = T_{prev}/2$ to the previous Feynman diagram. p-Adic length scale hypothesis follows naturally. A very close correspondence with ordinary Feynman diagrammatics arises and and ordinary vision about coupling constant evolutions arises. The absence of infinities follows from the symplectic invariance which is genuinely new element. p-Adic and real coupling constant evolutions can be seen as completions of coupling constant evolutions for physics based on rationals and their algebraic extensions.

3.5.3 Coupling constant evolution in Quantum TGD

The following gives a concise summary of the recent views about p-adic coupling constant evolution.

The most recent view about coupling constant evolution

Zero energy ontology, the construction of M-matrix as time like entanglement coefficients defining Connes tensor product characterizing finite measurement resolution in terms of inclusion of hyper-finite factors of type II_1, the realization that symplectic invariance of N-point functions provides a detailed mechanism eliminating UV divergences, and the understanding of the relationship between super-symplectic and super Kac-Moody symmetries: these are the pieces of the puzzle whose combination makes possible a rather concrete vision about coupling constant evolution in TGD Universe and one can even speak about rudimentary form of generalized Feynman rules.

Equivalence Principle and evolution of gravitational constant

Before saying anything about evolution of gravitational constant one must understand whether it is a fundamental constant or prediction of quantum TGD. Also one should understand whether Equivalence Principle holds true and if so, in what sense. Also the identification of gravitational and inertial masses seems to be necessary.

1. The coset construction for super-symplectic and super Kac-Moody algebras implies Equivalence Principle in the sense that four-momenta assignable to the Super Virasoro generators of the two algebras are identical. The challenge is to understand this result in more concrete terms.

2. The progress made in the understanding of number theoretical compactification led to a dramatic progress in the construction of configuration space geometry and spinor structure in terms of the modified Dirac operator associated with light-like 3-surfaces appearing in the slicing of the preferred extremal $X^(X_l^3)$ of Kähler action to light-like 3-surfaces Y_l^3 "parallel" to X_l^3. Even more the M^4 projection is predicted to have a slicing into 2-dimensional stringy worldsheets having $M^2(x) \subset M^4$ as a tangent space at point x.

3. By dimensional reduction one can assign to any stringy slice Y^2 a stringy action obtained by integrating Kähler action over the transversal degrees of freedom labeling the copies of Y^2. One can assign length scale evolution to the string tension $T(x)$, which in principle can depend on the point of the string world sheet and thus evolves. $T(x)$ is not identifiable as inverse of gravitational constant but by general arguments proportional to $1/L_p^2$, where L_p is p-adic length scale.

4. Gravitational constant can be understood as a product of L_p^2 with the exponential of the Kähler action for the two pieces of CP_2 type vacuum extremals representing wormhole contacts assignable to graviton connected by the string world sheets. The volume of the typical CP_2 type extremal associated with the graviton increases with L_p so that the exponential factor decreases reducing the growth due to the increase of L_p. Hence G could be RG invariant in p-adic coupling constant evolution. It does not make sense to formulate evolution of gravitational constant at space-time level and gravitational constant characterizes given CD.

5. Gravitational mass is assigned to the stringy world sheet and should be identical with the inertial mass identified as Noether charge assignable to the preferred extremal. By construction there are good hopes that for a proper choice of G gravitational and inertial masses are identical.

The RG invariance of gauge couplings inside causal diamond

Quantum classical correspondence suggests that the notion of p-adic coupling constant evolution should have space-time correlate. Zero energy ontology suggests that this counterpart is realized in terms of CDs in the sense that coupling constant evolution has formulation at space-time level inside CD of given size scale and that RG invariance holds true for this evolution. Number theoretic compactification forces to conclude that space-time surfaces has slicing into light-like 3-surfaces Y_l^3: this prediction is consistent with that is known about the extremals. General Coordinate Invariance requires that basic theory can be formulated by replacing the light-like 3-surface X_l^3 associated with wormhole throats with any surface Y_l^3 appearing in the associated slicing.

The natural identification for the renormalization group parameter is as the light-like coordinate labeling different light-like slices. The light-likeness of the RG parameter suggests RG invariance. Quantum classical correspondence requires that the classical gauge fluxes to X_l^3 selected by stationary phase approximation correspond to the expectation values of gQ_g, where g is coupling constant and Q_g the expectation (eigen) value of corresponding charge matrix in the state in question. If the gauge currents are light-like and in direction of Y_l^3 as they are for known extremals under proper selection of X_l^3, RG invariance follows because Abelian gauge fluxes are conserved due to the absence of the component of vacuum current in the direction of slicing.

In principle TGD predicts the values of all coupling constants including also the value of Kähler coupling strength which follows from the identification of Kähler action of the preferred extremal $X^4(X_l^3)$ of Kähler action as Dirac determinant associated with modified Dirac action. Hence Kähler coupling strength could have several values. Quantum criticality in the strongest form however motivates the hypothesis that g_K^2 is invariant under p-adic coupling constant evolution and evolution under evolution associated with the hierarchy of Planck constants.

Quantitative predictions for the values of coupling constants

The latest progress in the understanding of p-adic coupling constant evolution comes from a formula for Kähler coupling strength α_K in terms of Dirac determinant assignable to the modified Dirac operator associated with Kähler action.

The formula for α_K fixes its number theoretic anatomy and also that of other coupling strengths. The assumption that simple rationals (p-adicization) are involved can be combined with the input from p-adic mass calculations and with an old conjecture for the formula of gravitational constant allowing to express it in terms of CP_2 length scale and Kähler action of topologically condensed CP_2 type vacuum extremal. The prediction is that α_K is renormalization group invariant and equals to the value of fine structure constant at electron length scale characterized by M_{127}. Newton's constant is proportional to p-adic length scale squared and ordinary gravitons correspond to M_{127}. The number theoretic anatomy of R^2/G allows to consider two options. For the first one only M_{127} gravitons are possible number theoretically. For the second option gravitons corresponding to $p \simeq 2^k$ are possible.

A relationship between electromagnetic and color coupling constant evolutions based on the formula $1/\alpha_{em} + 1/\alpha_s = 1/\alpha_K$ is suggested by the induced gauge field concept, and would mean that the otherwise hard-to-calculate evolution of color coupling strength is fixed completely. The predicted value of α_s at intermediate boson length scale is correct.

p-Adic length scale evolution of gauge couplings

Understanding the dependence of gauge couplings constants on p-adic prime is one of the basic challenges of quantum TGD. The problem has been poorly understood even at the conceptual level to say nothing about concrete calculations. The generalization of the motion of S-matrix to that of M-matrix changed however the situation. M-matrix is always defined with respect to measurement resolution characterized in terms of an inclusion of von Neumann algebra. Coupling constant evolution reduces to a discrete evolution involving only octaves of $T(k) = 2^k T_0$ of the fundamental time scale $T_0 = R$, where R CP_2 scale. p-Adic length scale $L(k)$ is related to $T(k)$ by $L^2(k) = T(k)T_0$. p-Adic length scale hypothesis $p \simeq 2^k$, k integer, is automatic prediction of the theory. There is also a close connection with the description of coupling constant evolution in terms of radiative corrections.

If RG invariance at given space-time sheet holds true, the question arises whether it is possible to understand p-adic coupling constant evolution at space-time level and why certain p-adic primes are favored.

1. Simple considerations lead to the idea that M^4 scalings of the intersections of 3-surfaces defined by the intersections of space-time surfaces with light-cone boundary induce transformations of space-time surface identifiable as RG transformations. If sufficiently small they leave gauge charges invariant: this seems to be the case for known extremals which form scaling invariant families. When the scaling corresponds to a ratio p_2/p_1, $p_2 > p_1$, bifurcation would become possible replacing p_1-adic effective topology with p_2-adic one.

2. Stability considerations determine whether p_2-adic topology is actually realized and could explain why primes near powers of 2 are favored. The renormalization of coupling constant would be dictated by the requirement that Q_i/g_i^2 remains invariant.

3.6 Does the evolution of gravitational coupling make sense at space-time level?

Coset construction for super-symplectic and super Kac-Moody algebras discussed in [B4, F2, C1] allows to generalize Equivalence Principle and understand it at quantum level. This is however not quite enough: a precise understanding of Equivalence Principle is required also at the classical level. In the following the notion of gravitational mass and its equivalence with inertial mass is discussed first. The strategy is to deduce connection with string model type description rather than trying to show that General Relativity emerges from TGD. This connection emerges trough dimensional reduction of the dynamics defined by Kähler action to stringy dynamics. If one believes that string model description implies General Relativity in long scales, the situation is settled. The determination of gravitational mass as flux does not apply generally so that one cannot identify GM as a gravitational flux assignable to a wormhole throat. Hence one cannot formulate the evolution of G at space-time level as evolution of gravitational fluxes and it seems that only p-adic coupling constant evolution makes sense for G.

3.6.1 Is stringy action principle coded by the geometry of preferred extremals?

It seems very difficult to deduce Equivalence Principle as an identity of gravitational and inertial masses identified as Noether charges associated with corresponding action principles. Since string model is an excellent theory of quantum gravitation, one can consider a less direct approach in which one tries to deduce a connection between classical TGD and string model and hope that the bridge from string model to General Relativity is easier to build. Number theoretical compactification gives good hopes that this kind of connection exists.

1. Number theoretic compactification implies that the preferred extremals of Kähler action have the property that one can assign to each point of M^4 projection $P_{M^4}(X^4(X_l^3))$ of the preferred extremal $M^2(x)$ identified as the plane of non-physical polarizations and also as the plane in which local massless four-momentum lies.

2. If the distribution of the planes $M^2(x)$ is integrable, one can slice $P_{M^4}(X^4(X_l^3))$ to string world-sheets. The intersection of string world sheets with $X^3 \subset \delta M^4_\pm \times CP_2$ corresponds to a light-like curve having tangent in local tangent space $M^2(x)$ at light-cone boundary. This is the first candidate for the definition of number theoretic braid. Second definition assumes M^2 to be fixed at δCD: in this case the slicing is parameterized by the sphere S^2 defined by the light rays of $\delta M^4_\pm$.

3. One can assign to the string world sheet -call it Y^2 - the standard area action

$$S_G(Y^2) = \int_{Y^2} T\sqrt{g_2}d^2y \ , \tag{3.6.1}$$

   where g_2 is either the induced metric or only its M^4 part. The latter option looks more natural since M^4 projection is considered. T is string tension.

4. The naivest guess would be $T = 1/\hbar G$ apart from some numerical constant but one must be very cautious here since $T = 1/L_p^2$ apart from a numerical constant is also a good candidate if one accepts the basic argument identifying G in terms of p-adic length L_p and Kähler action for two pieces of CP_2 type vacuum extremals representing propagating graviton. The formula reads $G = L_p^2 exp(-2aS_K(CP_2))$, $a \leq 1$. The interaction strength which would be L_p^2 without the presence of CP_2 type vacuum extremals is reduced by the exponential factor coming from the exponent of Kähler function of configuration space.

5. One would have string model in either $CD \times CP_2$ or $CD \subset M^4$ with the constraint that stringy world sheet belongs to $X^4(X_l^3)$. For the extremals of $S_G(Y^2)$ gravitational four-momentum defined as Noether charge is conserved. The extremal property of string world sheet need not however be consistent with the preferred extremal property. This constraint might bring in coupling of gravitons to matter. The natural guess is that graviton corresponds to a string connecting wormhole contacts. The strings could also represent formation of gravitational bound states when they connect wormhole contacts separated by a large distance. The energy of the string is roughly $E \sim \hbar TL$ and for $T = 1/\hbar G$ gives $E \sim L/G$. Macroscopic strings are not allowed except as models of black holes. The identification $T \sim 1/L_p^2$ gives $E \sim \hbar L/L_p^2$, which does not favor long strings for large values of $\hbar$. The identification $G_p = L_p^2/\hbar_0$ gives $T = 1/\hbar G_p$

and $E \sim \hbar_0 L/L_p^2$, which makes sense and allows strings with length not much longer than p-adic length scale. Quantization - that is the presence of configuration space degrees of freedom- would bring in massless gravitons as deformations of string whereas strings would carry the gravitational mass.

6. The exponent $exp(iS_G)$ can appear as a phase factor in the definition of quantum states for preferred extremals. S_G is not however enough. One can assign also to the points of number theoretic braid action describing the interaction of a point like current Qdx^μ/ds with induced gauge potentials A_μ. The corresponding contribution to the action is

$$S_{braid} = \int_{braid} iTr(Q\frac{dx^\mu}{ds}A_\mu)dx \quad . \tag{3.6.2}$$

In stationary phase approximation subject to the additional constraint that a preferred extremal of Kähler action is in question one obtains the desired correlation between the geometry of preferred extremal and the quantum numbers of elementary particle. This interaction term carries information only about the charges of elementary particle. It is quite possible that the interaction term is more complex: for instance, it could contain spin dependent terms (Stern-Gerlach experiment).

7. The constraint coming from preferred extremal property of Kähler action can be expressed in terms of Lagrange multipliers

$$S_c = \int_{Y^2} \lambda^k D_\alpha(\frac{\partial L_K}{\partial_\alpha h^k})\sqrt{g_2}d^2y \quad . \tag{3.6.3}$$

8. The action exponential reads as

$$exp(iS_G + S_{braid} + S_c) \quad . \tag{3.6.4}$$

The resulting field equations couple stringy M^4 degrees of freedom to the second variation of Kähler action with respect to M^4 coordinates and involve third derivatives of M^4 coordinates at the right hand side. If the second variation of Kähler action with respect to M^4 coordinates vanishes, free string results. This is trivially the case if a vacuum extremal of Kähler action is in question.

9. An interesting question is whether the preferred extremal property boils down to the condition that the second variation of Kähler action with respect to M^4 coordinates vanishes so that gravitonic string is free. The physical interpretation would be in terms of quantum criticality which is the basic conjecture about the dynamics of quantum TGD. This is clear from the fact that in 1-D system criticality means that the potential $V(x) = ax + bx^2 + ..$ has $b = 0$. In field theory criticality corresponds to the vanishing of the term $m^2\phi^2/2$ so that massless situation corresponds to massless theory and criticality and long range correlations.

3.6.2 What does the equality of gravitational and inertial masses mean?

Consider next the question in what form Equivalence Principle could be realized in this framework.

1. Coset construction inspires the conjecture that gravitational and inertial four-momenta are identical. Also some milder form of it would make sense. What is clear is that the construction of preferred extremal involving the distribution of $M^2(x)$ implies that conserved four-momentum associated with Kähler action can be expressed formally as stringy four-momentum. The integral of the conserved inertial momentum current over X^3 indeed reduces to an integral over the curve

defining string as one integrates over other two degrees of freedom. It would not be surprising if a stringy expression for four-momentum would result but with string tension depending on the point of string and possibly also on the component of four-momentum. If the dependence of string tension on the point of string and on the choice of the stringy world sheet is slow, the interpretation could be in terms of coupling constant evolution associated with the stringy coordinates. An alternative interpretation is that string tension corresponds to a scalar field. A quite reasonable option is that for given X_l^3 T defines a scalar field and that the observed T corresponds to the average value of T over deformations of X_l^3.

2. The minimum option is that Kähler mass is equal to the sum gravitational masses assignable to strings connecting points of wormhole throat or two different wormhole throats. This hypothesis makes sense even for wormhole contacts having size of order Planck length.

3. The condition that gravitational mass equals to the inertial mass (rest energy) assigned to Kähler action is the most obvious condition that one can imagine. The breaking of Poincare invariance to Lorentz invariance with respect to the tip of CD supports this form of Equivalence Principle. This would predict the value of the ratio of the parameter R^2T and p-adic length scale hypothesis would allow only discrete values for this parameter. $p \simeq 2^k$ following from the quantization of the temporal distance $T(n)$ between the tips of CD as $T(n) = 2^nT_0$ would suggest string tension $T_n = 2^nR^2$ apart from a numerical factor. $G_p \propto 2^nR^2/\hbar_0$ would emerge as a prediction of the theory. G could be seen as a prediction or RG invariant input parameter fixed by quantum criticality. The arguments related to p-adic coupling constant evolution suggest $R^2/\hbar_0 G = 3 \times 2^{23}$ [A9].

4. The scalar field property of string tension should be consistent with the vacuum degeneracy of Kähler action. For instance, for the vacuum extremals of Kähler action stringy action is non-vanishing. The simplest possibility is that one includes the integral of the scalar $J^{\mu\nu}J_{\mu\nu}$ over the degrees transversal to M^2 to the stringy action so that string tension vanishes for vacuum extremals. This would be nothing but dimensional reduction of 4-D theory to a 2-D theory using the slicing of $X^4(X_l^3)$ to partonic 2-surfaces and stringy word sheets. For cosmic strings Kähler action reduces to stringy action with string tension $T \propto 1/g_K^2R^2$ apart from a numerical constant. If one wants consistency with $T \propto 1/L_p^2$, one must have $T \propto 1/g_K^2 2^nR^2$ for the cosmic strings deformed to Kähler magnetic flux tubes. This looks rather plausible if the thickness of deformed string in M^4 degrees of freedom is given by p-adic length scale.

Should one introduce induced spinor fields at string world sheets?

In the previous section it was found that TGD should allow also dimensionally reduced descriptions in terms of either string world sheets or partonic 2-surfaces. This raises the question whether it makes sense to introduce induced spinor fields at string world sheets. This is indeed the case. The modified Dirac action would in this case correspond to the Dirac operator for the dimensionally reduced Kähler action. The effective minimal surface property of Y^2 would guarantee the conservation of the super current. The realization of the effective 3-dimensionality in turn means that the stringy coordinate u corresponds to a gauge degree of freedom or to the condition $D_u\Psi = 0$. There would no spinor waves propagating along this direction of string and only the deformations of string represented by symplectic and Kac-Moody algebras present also in the dynamics of Kähler action responsible for the p-adic thermodynamics would be present. Besides this there would be the fermionic excitations associated with the ends of the string and correspond to the eigenmodes of $D_K(X^2)$ or equivalently with $D_K(Y^1)$ so that the Dirac determinant would be the same as obtained for D_K. For the description in terms of partonic 2-surfaces the Dirac operator would be just $D_K(X^2)$ and also now the equivalence with the 4-D description follows trivially.

3.6.3 What is the connection with General Relativity?

The connection with the stringy description makes it easier to believe that General Relativity gives a reasonable approximate description of gravitational interactions in long length scales also in TGD framework. The vacuum degeneracy of Kähler action is in key role here. The topological condensation of CP_2 type vacuum extremals representing fermions and pieces of CP_2 type extremals (wormhole contacts) identified as gauge bosons deforms the vacuum extremals to non-vacuum extremals, and the resulting density of inertial momentum equals to the density of gravitational momentum in stringy sense. If stringy gravitational energy momentum density is proportional to $1/L_p^2$ and if G relates to L_p^2 in the proposed manner, the natural hypothesis is that Einstein tensor provides a good approximation for the density of gravitational four-momentum as non-conserved Noether currents for the curvature scalar action associated with the induced metric. In zero energy ontology the non-conservation of the density of gravitational momentum does not lead to a contradiction with the conservation of inertial four-momentum since inertial four-momentum is defined only for CD in given scale so that conservation laws hold also only in this scale and in finite measurement resolution.

3.6.4 What does one mean with the evolution of gravitational constant?

From above it is clear that although it is possible to speak about the evolution of string tension $T(x)$ for string space-time sheets inside given CD, it does not makes sense to speak about evolution of G inside CDs because the relationship between T and G is not so simple as one might naively expect. One can of course consider the possibility that $T(x)$ is RG invariant and thus constant for the preferred extremals of Kähler action. This could hold module finite measurement resolution for M^4 coordinates defined by the size of the sub-CDs of a given CD. Hence string model description would be exact under quantum criticality assumption in the sense that the second variation of Kähler action with respect to M^4 coordinates vanishes.

As found, gravitational constant can be understood as a product of L_p^2 with the exponential of Kähler action for the two pieces of CP_2 type vacuum extremals representing wormhole contacts assignable to graviton connected by string world sheet. The volume of the typical CP_2 type extremals associated with the graviton increases with L_p so that the exponential factor decreases reducing the growth due to the increase of L_p. Hence G could be RG invariant in p-adic coupling constant evolution: this requires that volume depends on logarithmically on L_p. This point will be discussed in more detail later.

3.7 RG invariance of gauge couplings inside CD

The first question is whether the RG evolution of all gauge couplings could have interpretation as a flow at space-time level and what the flow in question could be. Second question is how the p-adic coupling constant evolution suggesting that coupling constants are piece constant functions of length scale is realized at space-time level. The obvious guess would be that RG invariance holds true for given CD. This would conform with the fact that partonic wormhole throats associated with the light-like boundaries of CDs can be regarded as carriers of quantum numbers in zero energy ontology.

3.7.1 Are all gauge couplings RG invariants within given CD?

No extremals for which the gauge currents would have non-vanishing ordinary divergence are known at this moment (gauge currents are light-like always). Therefore one cannot exclude the possibility that all gauge coupling constants are renormalization group invariants within given CD , so that the hypothesis that RG evolution reduces to a discrete p-adic coupling constant evolution would be correct.

This requires that also Weinberg angle, being determined by the ratio of $SU(2)$ and $U(1)$ couplings, is constant inside a given space-time sheet. Its value in this case is determined most naturally by the requirement that the net vacuum em charge of the space-time sheet vanishes.

A further hypothesis is Kähler coupling strength is invariant also under p-adic coupling constant evolution. Kähler coupling strength is in principle prediction of the theory if Dirac determinant gives Kähler action so that this hypothesis can in principle be checked.

3.7.2 Slicing of space-time surface by light-like 3-surfaces

The basic question concerns the identification of the geometric parameter identifiable as the space-time counterpart of the scale associated with RG evolution. Number theoretical compactification gives clues concerning the identification of this kind of parameter.

1. Number theoretic compactification implies that the preferred extremals of Kähler action have the property that one can assign to each point of M^4 projection $P_{M^4}(X^4(X^3_l))$ of the preferred extremal $M^2(x)$ identified as the plane of non-physical polarizations and also as the plane in which local massless four-momentum lies.

2. If the distribution of the planes $M^2(x)$ is integrable, one can slice $P_{M^4}(X^4(X^3_l))$ to string world-sheets. The intersection of string world sheets with $X^3 \subset \delta M^4_\pm \times CP_2$ corresponds to a light-like curve having tangent in local tangent space $M^2(x)$ at light-cone boundary. This is the first candidate for the definition of number theoretic braid. Second definition assumes M^2 to be fixed at δCD: in this case the slicing is parameterized by the sphere S^2 defined by the light rays of $\delta M^4_\pm$.

3. Another slicing is based on the use of light-like 3-surfaces for which second light-like coordinate associated with M^2 - call it u - is constant for a given slice. By general coordinate invariance it should be a matter of taste whether deduced the predictions of the theory using any of these light-like 3-surfaces. In particular the value of Kähler function remains invariant. The conditions guaranteing under what conditions this is true are discussed in [C1, B4]

The natural identification of the RG group parameter would be as the light-like coordinate u of M^4. This parameter corresponds roughly to radial motion away from wormhole throat and in this sense scaling. Light-likeness however means that M^4 length along this coordinate line is zero so that the length of RG parameter does not increase during RG evolution. Hence RG invariance looks natural.

3.7.3 Coupling constant evolution as evolution of classical gauge fluxes

Wormhole throats are in special role in the evolution as fixed points which is obvious from the fact that the determinant of induced metric approaches to zero. At the wormhole throats one must pose the conditions $g_{ui} = 0$ and $J_{ui} = 0$ in order to guarantee that the normal components of conserved currents vanish. This guarantees standard conservation laws for space-like 3-surfaces and is also required by zero energy ontology. The condition J_{ui} does not imply that the flux of Kähler electric field associated with 2-surface at wormhole throat vanishes. The point is that J^{uv} diverges whereas $\sqrt{g_4}$ vanishes at this limit and the limiting value of the flux defined by $J^{ub}\sqrt{g_4}$ can be finite and should be so unless there is Kähler charge density associated with vacuum, or more precisely, $j^u = D_i J^{ui}$ is non-vanishing. j^v can be non-vanishing and would mean that there are light-like currents along the light-like 3-surfaces Y^3_l associated with the slicing. This of course conforms with the idea that any light-like 3-surface can be regarded as a carrier of quantum numbers. The only known extremals of Kähler action for which gauge currents are non-vanishing are indeed those for which they are light-like. If $j^v = 0$ holds for Kähler current it holds true for all gauge currents and it would not be surprising that the gauge fluxes vanish.

Consider first electro-weak coupling constant evolution.

1. It is natural to restrict the coupling constant evolution to the neutral part F_{nc} of the electro-weak gauge field consisting of γ and Z^0, whose expressions in terms of Kähler form and R_{03} component of spinor curvature are given by

$$\begin{aligned} F_{nc} &= \gamma Q_{em} + Z^0(I^3_L - sin^2\theta_W Q_{em}) \ , \\ \gamma &= 3J - sin^2\theta_W R_{03} \ , \\ Z^0 &= 2R_{03} \ . \end{aligned} \tag{3.7.1}$$

   These expressions are discussed in more detail in Appendix.

2. One must find a gauge field which is Abelian in order that the notion of gauge flux is well-defined. If one restricts the consideration to right-handed parts Z^0 and γ this is achieved since W has only left handed part. The fluxes are determined by γ and Z^0 and the charge matrices multiplied with $(1-\gamma_5)$ and I^3_L is dropped from the charge matrix of Z^0.

3. Quantum classical correspondence suggests a quantization of classical gauge charged. This can be understood as resulting from the presence of phase factors of form $exp(i(dx^{mu}/dv)Tr(QA_{\mu})$ associated with braid strands at X_l^3. In stationary phase approximation an extremal with classical charges equal to those associated with positive (negative) energy part of zero energy state is selected. This extremal should have the property that classical gauge flux equals to the appropriate diagonal element of charge matrix multiplied by the corresponding coupling constant. This boils down to the conditions

$$\begin{aligned} e\langle Q_{em}\rangle &= \int \gamma da = (3J - sin^2(\theta_W)R_{03})da \ , \\ -g_Z sin^2(\theta_W)\langle Q_{em}\rangle &= \int Z_0 da = 2\int R_{03}da \ . \end{aligned} \tag{3.7.2}$$

The most natural possibility is that the diagonal charge matrix element is between positive and negative energy parts of the zero energy state associated with CD. A stronger form of quantum classical correspondence would require that similar equations hold true also for the fluxes of W bosons. The expectation values would be vanishing in charge eigen states so that also the classical fluxes should vanish.

4. Since the fluxes of J and R_{03} remain constant by the previous assumption e and g_Z are RG invariants if $sin^2(\theta_W)$ is RG invariant. There is no natural manner for $sin^2(\theta)$ to evolve since it is determined in terms of quantities associated with the throats associated with gauge boson wormhole contact.

The RG evolution of α_s inside CD can be discussed along similar lines.

1. Color gauge field is given by $G^A = kH^AJ_{\alpha\beta}$, where k is numerical constant and H^A is a Hamiltonian of color isometry. Color gauge field has Abelian holonomy, which suggests that one can reduce the situation to Abelian one by performing a local gauge rotation rotating the color gauge field to a fixed direction. This is however somewhat tricky point since strictly local color rotations are not symmetries of Kähler action. The naive guess would be

$$g_s\langle T^A\rangle = k\int H^AJda \ , \tag{3.7.3}$$

Also no expectation would be naturally between positive and negative energy parts of zero energy state. Only the fluxes associated with I_3 and Y_A would be non-vanishing so that additional conditions of color fluxes would be obtained.

2. The formula

$$\frac{1}{\alpha_{em}} + \frac{1}{\alpha_s} = \frac{1}{\alpha_K}$$

proposed in previous section would fix the p-adic evolution of color coupling and imply the RG invariance of α_s within given CD.

3.7.4 Questions related to the physical interpretation

This picture raises several interesting questions related to the physical interpretation.

1. What is the TGD counterpart of Higgs=0 phase? The dimension of CP_2 projection is is analogous to temperature and one can argue that massivation is analogous to a loss of correlations due to the increase of D bringing in additional degrees of freedom. Massless extremals having $D = 2$ all induced gauge fields are massless so that they are excellent candidates for Higgs=0 phase. Indeed, the construction of S-matrix leads to the interpretation that MEs allow massless particle exchanges with arbitrary long range but the very fact that the scattering is limited to massless momentum exchanges it is difficult to detect. Note that this scattering is not possible in two-particle system. Does the result mean that already $D = 3$ space-time sheets correspond to a massive phase?

2. Why electro-weak length scale corresponding to Mersenne prime M_{89} is preferred [F3]? Are there also other length scales in which electro-weak massivation occurs and thus scaled copies of electro-weak bosons? These questions reduce to the questions about the stability of the proposed bifurcations.

3. The basic problem of TGD based model of condensed matter is to explain why classical long range gauge fields do not give rise to large parity breaking effects in atomic length scale but do so in cell length length scale at least in the case of living matter (bio-catalysis). The proposal has been that particles feed electro-weak and em gauge fluxes to different space-time sheets. Could it be that blocks of bio-matter with size larger than cell the space-time sheets at which em and weak charges are feeded can be in Higgs=0 phase whereas for smaller blocks screening occurs already at quark and lepton level.

   This would be consistent with the fact that the dimension D of CP_2 projection tends to decrease with the size of the space-time sheet: the larger the space-time sheet, the nearer it is to a vacuum extremal. Robertson-Walker cosmologies are exact vacuum extremals carrying however non-vanishing gravitational 4-momentum densities. By previous argument W and Z masses are identical in this kind of phase if the vanishing of vacuum em field is used to fix p. The weakening of correlations caused by classical non-determinism might imply massivation.

4. Do long ranged non-screened vacuum Z^0 and W gauge fields have some quantum counterparts as quantum-classical correspondence would suggest? Does dark matter identified as a phase with large value of $\hbar$ [J6] correspond to a phase in which electro-weak symmetry breaking is absent in the bosonic sector?

   This phase would differ from the ordinary one in that the weak charges of dark counterparts of leptons and quarks are not screened in electro-weak length scale but that their masses are very nearly the same as in Higgs=0 phase since the dominant contribution to the masses of elementary fermions is not given by a coupling to Higgs type particle but determined by p-adic thermodynamics [F2, F3]. According to the TGD based model of condensed matter developed in [F9], em charges would be feeded to space-time sheets of order atomic size in this phase.

   Does bio-matter involve this kind of phase at larger space-time sheets as chirality selection suggests [F9]? Does this phase of condensed matter emerge only above length scale defined by the cell size or cell membrane thickness?

   The possibility to assign separate spectrum of values of M^4 and CP_2 Planck constants means also spectrum of scale factors of metric for both M^4 and CP_2 with scaling of covariant metric given by the square of integer n characterizing the quantum phase. If gravitational Planck constant can be identified as CP_2 Planck constant, gigantic values of CP_2 radius are possible in the sectors of the imbedding space corresponding to the dark matter.

   Even if one does not accept this identification, the conclusion would seem to be that CP_2 radius can be very large in these phases. Obviously the ranges of weak and color interactions in this kind of phases would be macroscopic and even astrophysical. Second implication would be the presence of precise quantal lattice like structure involving strict quantum correlations in macroscopic length scales. The unavoidable question is whether the extremely tiny size of CP_2 could be scaled up to a macroscopic length scale even at the level of living matter and whether even the science fictive notion of hyper-space travel (which I have never liked!) might make sense after all.

5. An interesting question relates to the predicted presence of long ranged classical color gauge fields in all length scales suggesting a hierarchy of QCD type physics if quantum classical correspondence is taken seriously. The possibility to define the color Hamiltonians apart from an additive constant in principle makes possible to have vanishing classical color isospin and hyper charges at a given space-time sheet without affecting the color transformation properties of Hamiltonians. It is however far from clear whether this trick is enough. A more natural approach is to take seriously the prediction of infinite p-adic hierarchy of QCD type physics and look what the implications are.

3.8 Quantitative predictions for the values of coupling constants

This focus of attention in this section is in quantitative for the p-adic evolution of couplings constants obtained by combining information coming from p-adic mass calculations with number theoretic constraints and general formula for gravitational constant inspired by simple physical picture.

3.8.1 A revised view about coupling constant evolution

The development of the ideas related to number theoretic aspects has been rather tortuous and based on guess work since basic theory has been lacking.

1. The original hypothesis was that Kähler coupling strength is invariant under p-adic coupling constant evolution. Later I gave up this hypothesis and replaced it with the invariance of gravitational coupling since otherwise the prediction would have been that gravitational coupling strength is proportional to p-adic length scale squared. Second first guess was that Kähler coupling strength equals to the value of fine structure constant at electron length scale corresponding to Mersenne prime M_{127}. Later I replaced fine structure constant with electro-weak U(1) coupling strength at this length scale. The recent discussion returns back to the roots in both aspects.

2. The recent discussion relies on the progress made in the understanding of quantum TGD at partonic level [B4]. What comes out is an explicit formula for Kähler couplings strength in terms of Dirac determinant involving only a finite number of eigenvalues of the modified Dirac operator. This formula dictates the number theoretical anatomy of g_K^2 and also of other coupling constants: the most general option is that α_K is a root of rational. The requirement that the rationals involved are simple combined with simple experimental inputs leads to very powerful predictions for the coupling parameters.

3. A further simplification is due to the discreteness of p-adic coupling constant evolution allowing to consider only length scales coming as powers of $\sqrt{2}$. This kind of discretization is necessary also number theoretically since logarithms can be replaced with 2-adic logarithms for powers of 2 giving integers. This raises the question whether $p \simeq 2^k$ should be replaced with 2^k in all formulas as the recent view about quantum TGD suggests.

4. The prediction is that Kähler coupling strength α_K is invariant under p-adic coupling constant evolution and from the constraint coming from electron and top quark masses very near to fine structure constant so that the identification as fine structure constant is natural. Gravitational constant is predicted to be proportional to p-adic length scale squared and corresponds to the largest Mersenne prime (M_{127}), which does not correspond to a completely super-astronomical p-adic length scale. For the parameter R^2/G p-adicization program allows to consider two options: either this constant is of form e^q or 2^q: in both cases q is rational number. $R^2/G = exp(q)$ allows only M_{127} gravitons if number theory is taken completely seriously. $R^2/G = 2^q$ allows all p-adic length scales for gravitons and thus both strong and weak variants of ordinary gravitation.

5. A relationship between electromagnetic and color coupling constant evolutions based on the formula $1/\alpha_{em} + 1/\alpha_s = 1/\alpha_K$ is suggested by the induced gauge field concept, and would mean that the otherwise hard-to-calculate evolution of color coupling strength is fixed completely. The predicted value of α_s at intermediate boson length scale is correct.

It seems fair to conclude that the attempts to understand the implications of p-adicization for coupling constant evolution have begun to bear fruits.

General formula for the Kähler coupling strength

The identification of exponent of Kähler function as Dirac determinant leads to a formula relating Kähler action for the preferred extremal to the Dirac determinant. The eigenvalues are proportional to $1/\alpha_K$ since the matrices $\hat{\Gamma}^\alpha$ have this proportionality. This gives the formula

$$exp(\frac{S_{K,R}(X^4(X^3))}{2g_K^2}) = \prod_i \lambda_i = \frac{\prod_i \lambda_{0,i}}{(g_K)^{2N}} \ . \tag{3.8.1}$$

Here $\lambda_{0,i}$ by definition corresponds to $g_K^2 = 4\pi\alpha_K = 1$. $S_{K,R} = \int J^*J$ is the reduced Kähler action.

For $S_{K,R} = 0$, which might correspond to so called massless extremals [D1] one obtains the formula

$$g_K^2 = (\prod_i \lambda_{0,i})^{1/N} \ . \tag{3.8.2}$$

Thus for $S_{K,R} = 0$ extremals one has an explicit formula for g_K^2 having interpretation as the geometric mean of the eigenvalues $\lambda_{0,i}$. Several values of α_K are in principle possible.

p-Adicization suggests that $\lambda_{0,i}$ are rational or at most algebraic numbers. This would mean that g_K^2 is N:th root of this kind of number. $S_{K,R}$ in turn would be

$$S_{K,R} = 2g_K^2 log(\frac{\prod_i \lambda_{0,i}}{g_K^{2N}}) \ . \tag{3.8.3}$$

so that the reduced Kähler action $S_{K,R}$ would be expressible as a product N:th root of rational, and logarithm of rational. This result would provide a general answer to the question about number theoretical anatomy of Kähler coupling strength and S_K.

For CP_2 type vacuum extremal one would have $S_{K,R} = \frac{\pi^2}{2}$ in apparent conflict with the above result. The conflict is of course only apparent since topological condensation of CP_2 type vacuum extremal generates a hole in CP_2 having light-like wormhole throat as boundary so that the value of the action is modified.

Identifications of Kähler coupling strength and gravitational coupling strength

To construct an expression for gravitational constant one can use the following ingredients.

1. The exponent $exp(S_K(CP_2))$ defining vacuum functional and thus the value of Kähler function in terms of the Kähler action $S_K(CP_2)$ of CP_2 type extremal representing elementary particle expressible as

$$S_K(CP_2) = \frac{S_{K,R}(CP_2)}{8\pi\alpha_K} = \frac{\pi}{8\alpha_K} \ . \tag{3.8.4}$$

Since CP_2 type extremals suffer topological condensation, one expects that the action is modified:

$$S_K(CP_2) \rightarrow a \times S_K(CP_2) \ . \tag{3.8.5}$$

$a < 1$ conforms with the idea that a piece of CP_2 type extremal defining a wormhole contact is in question. One must however keep mind open in this respect.

2. The p-adic length scale L_p assignable to the space-time sheet along which gravitational interactions are mediated. Since Mersenne primes seem to characterized elementary bosons and since the Mersenne prime $M_{127} = 2^{127} - 1$ defining electron length scale is the largest non-super-astronomical length scale it is natural to guess that M_{127} characterizes these space-time sheets.

1. The formula for the gravitational constant

A long standing basic conjecture has been that gravitational constant satisfies the following formula

$$\begin{aligned} \hbar G &\equiv r\hbar_0 G = L_p^2 \times exp(-2aS_K(CP_2)) \ , \\ L_p &= \sqrt{p}R \ . \end{aligned} \tag{3.8.6}$$

Here R is CP_2 radius defined by the length $2\pi R$ of the geodesic circle. What was noticed before is that this relationship allows even constant value of G if a has appropriate dependence on p.

This formula seems to be correct but the argument leading to it was based on two erratic assumptions compensating each other.

1. I assumed that modulus squared for vacuum functional is in question: hence the factor $2a$ in the exponent. The interpretation of zero energy state as a generalized Feynman diagram requires the use of vacuum functional so that the replacement $2a \rightarrow a$ is necessary.
2. Second wrong assumption was that graviton corresponds to CP_2 type vacuum extremal- that is wormhole contact in the recent picture. This does allow graviton to have spin 2. Rather, two wormhole contacts represented by CP_2 vacuum extremals and connected by fluxes associated with various charges at their throats are needed so that graviton is string like object. This saves the factor $2a$ in the exponent.

The highly non-trivial implication to be discussed later is that ordinary coupling constant strengths should be proportional to $exp(-aS_K(CP_2))$.

The basic constraint to the coupling constant evolution comes for the invariance of g_K^2 in p-adic coupling constant evolution:

$$\begin{aligned} g_K^2 &= \frac{a(p,r)\pi^2}{log(pK)} \ , \\ K &= \frac{R^2}{\hbar G(p)} = \frac{1}{r}\frac{R^2}{\hbar_0 G(p)} \equiv \frac{K_0(p)}{r} \ . \end{aligned} \tag{3.8.7}$$

2. How to guarantee that g_K^2 is RG invariant and N:th root of rational?

Suppose that g_K^2 is N:th root of rational number and invariant under p-adic coupling constant evolution.

1. The most general manner to guarantee the expressibility of g_K^2 as N:th root of rational is guaranteed for both options by the condition

$$a(p,r) = \frac{g_K^2}{\pi^2} log(\frac{pK_0}{r}) \ . \tag{3.8.8}$$

That a would depend logarithmically on p and $r = \hbar/\hbar_0$ looks rather natural. Even the invariance of G under p-adic coupling constant evolution can be considered.

2. The condition

$$\frac{r}{p} < K_0(p) \ . \tag{3.8.9}$$

must hold true to guarantee the condition $a > 0$. Since the value of gravitational Planck constant is very large, also the value of corresponding p-adic prime must very large to guarantee this condition. The condition $a < 1$ is guaranteed by the condition

$$\frac{r}{p} > exp(-\frac{\pi^2}{g_K^2}) \times K_0(p) \ . \tag{3.8.10}$$

The condition implies that for very large values of p the value of Planck constant must be larger than $\hbar_0$.

3. The two conditions are summarized by the formula

$$K_0(p) \times exp(-\frac{\pi^2}{g_K^2}) < \frac{r}{p} < K_0(p) \tag{3.8.11}$$

characterizing the allowed interval for r/p. If G does not depend on p, the minimum value for r/p is constant. The factor $exp(-\frac{\pi^2}{g_K^2})$ equals to 1.8×10^{-47} for $\alpha_K = \alpha_{em}$ so that $r > 1$ is required for $p \geq 4.2 \times 10^{-40}$. $M_{127} \sim 10^{38}$ is near the upper bound for p allowing $r = 1$. The constraint on r would be roughly $r \geq 2^{k-131}$ and $p \simeq 2^{131}$ is the first p-adic prime for which $\hbar > 1$ is necessarily. The corresponding p-adic length scale is .1 Angstroms.

This conclusion need not apply to elementary particles such as neutrinos but only to the space-time sheets mediating gravitational interaction so that in the minimal scenario it would be gravitons which must become dark above this scale. This would bring a new aspect to vision about the role of gravitation in quantum biology and consciousness.

The upper bound for r behaves roughly as $r < 2.3 \times 10^7 p$. This condition becomes relevant for gravitational Planck constant GM_1M_2/v_0 having gigantic values. For Earth-Sun system and for $v_0 = 2^{-11}$ the condition gives the rough estimate $p > 6 \times 10^{63}$. The corresponding p-adic length scale would be of around $L(215) \sim 40$ meters.

4. p-Adic mass calculations predict the mass of electron as $m_e^2 = (5+Y_e)2^{-127}/R^2$ where $Y_e \in [0,1)$ parameterizes the not completely known second order contribution. Top quark mass favors a small value of Y_e (the original experimental estimates for m_t were above the range allowed by TGD but the recent estimates are consistent with small value Y_e [F4]). The range $[0,1)$ for Y_e restricts $K_0 = R^2/\hbar_0 G$ to the range $[2.3683, 2.5262] \times 10^7$.

5. The best value for the inverse of the fine structure constant is $1/\alpha_{em} = 137.035999070(98)$ and would correspond to $1/g_K^2 = 10.9050$ and to the range $(0.9757, 0.9763)$ for a for $\hbar = \hbar_0$ and $p = M_{127}$. Hence one can seriously consider the possibility that $\alpha_K = \alpha_{em}(M_{127}$ holds true. As a matter fact, this was the original hypothesis but was replaced later with the hypothesis that α_K corresponds to electro-weak $U(1)$ coupling strength in this length scale. The fact that M_{127} defines the largest Mersenne prime, which does not correspond to super-astrophysical length scale might relate to this co-incidence.

To sum up, the recent view about coupling constant evolution differs strongly from previous much more speculative scenarios. It implies that g_K^2 is root of rational number, possibly even rational, and can be assumed to be equal to e^2. Also $R^2/\hbar G$ could be rational. The new element is that G need not be proportional to p and can be even invariant under coupling constant evolution since the the parameter a can depend on both p and r. An unexpected constraint relating p and r for space-time sheets mediating gravitation emerges.

Are the color and electromagnetic coupling constant evolutions related?

Classical theory should be also able to say something non-trivial about color coupling strength α_s too at the general level. The basic observations are following.

1. Both classical color YM action and electro-weak U(1) action reduce to Kähler action.
2. Classical color holonomy is Abelian which is consistent also with the fact that the only signature of color that induced spinor fields carry is anomalous color hyper charge identifiable as an electro-weak hyper charge.

Suppose that α_K is a strict RG invariant. One can consider two options.

1. The original idea was that the sum of classical color action and electro-weak U(1) action is RG invariant and thus equals to its asymptotic value obtained for $\alpha_{U(1)} = \alpha_s = 2\alpha_K$. Asymptotically the couplings would approach to a fixed point defined by $2\alpha_K$ rather than to zero as in asymptotically free gauge theories.

   Thus one would have

$$\frac{1}{\alpha_{U(1)}} + \frac{1}{\alpha_s} = \frac{1}{\alpha_K} \quad . \tag{3.8.12}$$

   The relationship between $U(1)$ and em coupling strengths is

$$\begin{aligned} \alpha_{U(1)} &= \frac{\alpha_{em}}{cos^2(\theta_W)} \simeq \frac{1}{104.1867} \quad , \\ sin^2(\theta_W)_{|10\ MeV} &\simeq 0.2397(13) \quad , \\ \alpha_{em}(M_{127}) &= 0.00729735253327 \quad . \end{aligned} \tag{3.8.13}$$

   Here Weinberg angle corresponds to 10 MeV energy is reasonably near to the value at electron mass scale. The value $sin^2(\theta_W) = 0.2397(13)$ corresponding to 10 MeV mass scale [21] is used. Note however that the previous argument implying $\alpha_K = \alpha_{em}(M_{127})$ excludes $\alpha = \alpha_{U(1)}(M_{127})$ option.

2. Second option is obtained by replacing $U(1)$ with electromagnetic gauge $U(1)_{em}$.

$$\frac{1}{\alpha_{em}} + \frac{1}{\alpha_s} = \frac{1}{\alpha_K} . \tag{3.8.14}$$

   Possible justifications for this assumption are following. The notion of induced gauge field makes it possible to characterize the dynamics of classical electro-weak gauge fields using only the Kähler part of electro-weak action, and the induced Kähler form appears only in the electromagnetic part of the induced classical gauge field. A further justification is that em and color interactions correspond to unbroken gauge symmetries.

The following arguments are consistent with this conclusion.

1. In TGD framework coupling constant is discrete and comes as powers of $\sqrt{2}$ corresponding to p-adic primes $p \simeq 2^k$. Number theoretic considerations suggest that coupling constants g_i^2 are algebraic or perhaps even rational numbers, and that the logarithm of mass scale appearing as argument of the renormalized coupling constant is replaced with 2-based logarithm of the p-adic length scale so that one would have $g_i^2 = g_i^2(k)$. g_K^2 is predicted to be N:th root of rational but could also reduce to a rational. This would allow rational values for other coupling strengths too. This is possible if $sin(\theta_W)$ and $cos(\theta_W)$ are rational numbers which would mean that Weinberg angle corresponds to a Pythagorean triangle as proposed already earlier. This would mean the formulas $sin(\theta_W) = (r^2 - s^2)/(r^2 + s^2)$ and $cos(\theta_W) = 2rs(r^2 + s^2)$.

2. A very strong prediction is that the beta functions for color and $U(1)$ degrees of freedom are apart from sign identical and the increase of $U(1)$ coupling compensates the decrease of the color coupling. This allows to predict the hard-to-calculate evolution of QCD coupling constant strength completely.

3. $\alpha(M_{127}) = \alpha_K$ implies that M_{127} defines the confinement length scale in which the sign of α_s becomes negative. TGD predicts that also M_{127} copy of QCD should exist and that M_{127} quarks should play a key role in nuclear physics [F8, F9]. Hence one can argue that color coupling strength indeed diverges at M_{127} (the largest not completely super-astrophysical Mersenne prime) so that one would have $\alpha_K = \alpha(M_{127})$. Therefore the precise knowledge of $\alpha(M_{127})$ in principle fixes the value of parameter $K = R^2/G$ and thus also the second order contribution to the mass of electron.

4. $\alpha_s(M_{89})$ is predicted to be $1/\alpha_s(M_{89}) = 1/\alpha_K - 1/\alpha(M_{89})$. $sin^2(\theta_W) = .23120$, $\alpha_{em}(M_{89}) \simeq 1/127$, and $\alpha_{U(1)} = \alpha_{em}/cos^2(\theta_W)$ give $1/\alpha_{U(1)}(M_{89}) = 97.6374$. $\alpha = \alpha_{em}$ option gives $1/\alpha_s(M_{89}) \simeq 10$, which is consistent with experimental facts. $\alpha = \alpha_{U(1)}$ option gives $\alpha_s(M_{89}) = 0.1572$, which is larger than QCD value. Hence $\alpha = \alpha_{em}$ option is favored.

To sum up, the proposed formula would dictate the evolution of α_s from the evolution of the electro-weak parameters without any need for perturbative computations. Although the formula of proposed kind is encouraged by the strong constraints between classical gauge fields in TGD framework, it should be deduced in a rigorous manner from the basic assumptions of TGD before it can be taken seriously.

Can one deduce formulae for gauge couplings?

The improved physical picture behind gravitational constant allows also to consider a general formula for gauge couplings.

1. The natural guess for the general formula would be as

$$g^2(p,r) = kg_K^2 \times exp[-a_g(p,r) \times S_K(CP_2)] \ . \tag{3.8.15}$$

   here k is a numerical constant.

2. The condition
   $g_K^2 = e^2(M_{127})$ fixes the value of k if it's value does not depend on the character of gauge interaction:

$$k = exp[a_{gr}(M_{127}, r=1) \times S_K(CP_2)] \ . \tag{3.8.16}$$

   Hence the general formula reads as

$$g^2(p,r) = g_K^2 \times exp[(-a_g(p,r) + a_{gr}(M_{127}), r=1)) \times S_K(CP_2)] \ . \tag{3.8.17}$$

   The value of $a(M_{127}, r=1)$ is near to its maximum value so that the exponential factor tends to increase the value of g^2 from e^2. The formula can reproduce α_s and various electro-weak couplings although it is quite possibile that Weinberg angle corresponds to a group theoretic factor not representable in terms of $a_g(p,r)$. The volume of the CP_2 type vacuum extremal would characterize gauge bosons. Analogous formula should apply also in the case of Higgs.

3. α_{em} in very long length scales would correspond to

$$e^2(p \rightarrow \infty, r=1) = e^2 \times exp[(-1+a(M_{127}), r=1)) \times S_K(CP_2)] = e^2 x \ , \tag{3.8.18}$$

where x is in the range $[0.6549, 0.6609]$.

Formula relating v_0 to α_K and $R^2/\hbar G$

The parameter $v_0 = 2^{-11}$ plays a key role in the formula for gravitational Planck constant and can be also seen as a fundamental constant in TGD framework. As a matter, factor v_0 has interpretation as velocity parameter and is dimensionless when $c = 1$ is used.

If v_0 is identified as the rotation velocity of distant stars in galactic plane, one can use the Newtonian model for the motion of mass in the gravitational field of long straight string giving $v_0 = \sqrt{TG}$. String tension T can be expressed in terms of Kähler coupling strength as

$$T = \frac{b}{2\alpha_K R^2} \ ,$$

where R is the radius of geodesic circle. The factor $b \leq 1$ would explain reduction of string tension in topological condensation caused by the fact that not entire geodesic sphere contributes to the action.

This gives

$$\begin{aligned} v_0 &= \frac{b}{2\sqrt{\alpha_K K}} \ , \\ \alpha_K(p) &= \frac{a\pi}{4log(pK)} \ , \\ K &= \frac{R^2}{\hbar G} \ . \end{aligned} \tag{3.8.19}$$

The condition that α_K has the desired value for $p = M_{127} = 2^{127}-1$ defining the p-adic length scale of electron fixes the value of b for given value of a. The value of b should be smaller than 1 corresponding to the reduction of string tension in topological condensation.

The condition 3.8.19 for $v_0 = 2^{-m}$, say $m = 11$, allows to deduce the value of a/b as

$$\frac{a}{b} = \frac{4 * log(pK)}{\pi} \frac{2^{2m-1}}{K} \ . \tag{3.8.20}$$

For both $K = e^q$ with $q = 17$ and $K = 2^q$ option with $q = 24 + 1/2$ $m = 10$ is the smallest integer giving $b < 1$. $K = e^q$ option gives $b = .3302$ $(.0826)$ and $K = 2^q$ option gives $b = .3362$ $(.0841)$ for $m = 10$ $(m = 11)$.

$m = 10$ corresponds to one third of the action of free cosmic string. $m = 11$ corresponds to much smaller action smaller by a factor rather near $1/12$. The interpretation would be that as m increases the action of the topologically condensed cosmic string decreases. This would correspond to a gradual transformation of the cosmic string to a magnetic flux tube.

To sum up, the resulting overall vision seems to be internally consistent and is consistent with generalized Feynman graphics, predicts exactly the spectrum of α_K, suggests the identification of the inverse of p-adic temperature with k, allows to understand the differences between fermionic and bosonic massivation. One might hope that the additional objections (to be found sooner or later!) could allow to develop a more detailed picture.

3.8.2 Why gravitation is so weak as compared to gauge interactions?

The weakness of gravitational interaction in contrast to other gauge interactions is definitely a fundamental test for the proposed picture. The heuristic argument allowing to understand the value of gravitational constant is based on the assumption that graviton exchange corresponds to the exchange of CP_2 type extremal for which vacuum functional implies huge reduction of the gravitational constant from the value $\sim L_p^2$ implied by dimensional considerations based on p-adic length scale hypothesis to a value $G = exp(-2S_K)L_p^2$ which for $p = M_{127}$ gives gravitational constant for $\alpha_K = \pi a/log(M_{127} \times K)$, where a is near unity and $K = 2\times3\times5....\times23$ is a choice motivated by number theoretical arguments. The value of K is fixed rather precisely from electron mass scale and the proposed scenario for coupling constant evolution fixes both α_K and K completely in terms of electron mass (using p-adic mass calculations) and electro-magnetic coupling at electron length scale $L_{M_{127}}$ by the formula $\alpha_K = \alpha_{em}$ [A9]. The interpretation would be that gravitational masses are measured using p-adic mass scale $M_p = \pi/L_p$ as a natural unit.

Why gravitational interaction is weak?

The first problem is that CP_2 type extremal cannot represent the lowest order contribution to the interaction since otherwise the normalization of the configuration space vacuum functional would give $exp[-2S_K(CP_2)]$ factor canceling the exponential in the propagator so that one would have $G = L_p^2$. The following observations allow to understand the solution of the problem.

1. As already found, the key feature of CP_2 type vacuum extremals distinguishing them from other 3-surfaces is their non-deterministic behavior allowing them to carry off mass shell four-momenta. Other 3-surfaces can give rise only to scattering involving exchange of on mass shell particles and for space-like momentum exchanges there is no contribution.

2. All possible light-like 3-surfaces must be allowed as propagator portions of surfaces X_V^3 but in absence of non-determinism they can give rise to massless exchanges which are typically non-allowed.

3. The contributions of CP_2 type vacuum extremals are suppressed by $exp[-2NS_K(CP_2)]$ factor in presence of N CP_2 type extremals with maximal action. CP_2 type extremals are vacuum extremals and interact with surrounding world only via the topological condensation generating 3-D CP_2 projection near the throat of the wormhole contact. This motivates the assumption that the sector of the configuration space containing N CP_2 type extremals has the approximate structure $CH(N) = CH(0)\times CP^N$, where $CH(0)$ corresponds to the situation without CP_2 type extremals and CP to the degrees of freedom associated with single CP_2 type extremal. With this assumption the functional integral gives a result of form $X \times exp(-2NS_K(CP_2)$ for N CP_2 type extremals. This factorization allows to forget all the complexities of the world of classical worlds which on the first sight seem to destroy all hopes about calculating something and the normalization factor is in lowest order equal to $X(0)$ whereas single CP_2 type extremal gives $exp[-2S_K(CP_2)]$ factor. This argument generalizes also to the case when CP_2 type extremals are allowed to have varying value of action (the distance travelled by the virtual particle can vary).

Massless extremals (MEs) define a natural candidate for the lowest order contribution since for them Kähler action vanishes. MEs describes a dispersion free on-mass shell propagation of massless modes of both induced gauge fields and metric. Hence they can describe only on mass shell massless exchanges of bosons and gravitons which typically vanishes for kinematical reasons except for collinear scattering in the case of massless particles so that CP_2 type extremals would give the leading contribution to the S-matrix element.

There are however exceptional situations in which exchange of ordinary CP_2 type extremals makes kinematically possible the emission of MEs as brehmstrahlung in turn giving rise to exchange of light-like momentum. Since MEs carry also classical gravitational fields, one can wonder whether this kind of exchanges could make possible strong on mass shell gravitation made kinematically possible by ordinary gauge boson exchanges inside interacting systems.

If one takes absolutely seriously the number theoretic argument based on $R^2/G = exp(q)$ ansatz then M_{127} is selected uniquely as the space-time sheet of gravitons and the predicted gravitational coupling strength is indeed weak.

What differentiates between gravitons and gauge bosons?

The simplest explanation for the difference between gauge bosons and gravitons is that for virtual gauge bosons the volume of CP_2 type extremals is reduced dramatically from its maximal value so that $exp(-2S_K)$ brings in only a small reduction factor. The reason would be that for virtual gauge bosons the length of a typical CP_2 type extremal is far from the value giving rise to the saturation of the Kähler action. For gravitational interactions in astrophysical length scales CP_2 type extremals must indeed be very long.

Gravitational interaction should become strong sufficiently below the saturation length scale with gravitational constant approaching its stringy value L_p^2. According to the argument discussed in [A9], this length scale corresponds to the Mersenne prime M_{127} characterizing gravitonic space-time sheets so that gravitation should become strong below electron's Compton length. This suggests a connection with stringy description of graviton. M_{127} quarks connected by the corresponding strings are indeed a basic element of TGD based model of nuclei [F8]. TGD suggests also the existence of lepto-hadrons as bound state of color excited leptons in length scale M_{127} [F7]. Also gravitons corresponding to smaller Mersenne primes are possible but corresponding forces are much weaker than ordinary gravitation. On the other hand, M_{127} is the largest Mersenne prime which does not give rise to super-astronomical p-adic length scale so that stronger gravitational forces are not be predicted in experimentally accessible length scales.

More generally, the saturation length scale should relate very closely to the p-adic length scale L_p characterizing the particle. The amount of zitterbewegung determines the amount dS_K/dl of Kähler action per unit length along the orbit of virtual particle. L_p would naturally define the length scale below which the particle moves in a good approximation along M^4 geodesic. The shorter this length scale is, the larger the value of dS_K/dl is.

If the Kähler action of CP_2 type extremal increases linearly with the distance (in a statistical sense at least), an exponential Yukawa screening results at distances much shorter than saturation length. Therefore CP_2 extremals would provide a fundamental description of particle massivation at space-time level. p-Adic thermodynamics would characterize what happens for a topologically condensed CP_2 type extremal carrying given quantum numbers at the resulting light-like CD. Besides p-adic length scale also the quantized value $T_p = 1/n$ of the p-adic temperature would be decisive. For weak bosons Mersenne prime M_{89} would define the saturation length scale. For photons the p-adic length scale defining the Yukawa screening should be rather long. An n-ary p-adic length scale $L_{M_{89}}(n) = p^{(n-1)/2}L_{M_{89}}$ would most naturally be in question so that the p-adic temperature associated with photon would be $T_p = 1/n$, $n > 1$ [F3]. In the case of gluons confinement length scale should be much shorter than the scale at which the Yukawa screening becomes visible. If also gluons correspond to $n > 1$ this is certainly the case.

All gauge interactions would give rise to ultra-weak long ranged interactions, which are extremely weak compared to the gravitational interaction: the ratio for the strengths of these interactions would be of order $\alpha Q_1Q_2m_e^2/M_1M_2$ and very small for particles whose masses are above electron mass. Note however that MEs give rise to arbitrarily unscreened long ranged weak and color interactions restricted to light-like momentum transfers and these interactions play a key role in the TGD based model of living matter [J6, M3]. This prediction is in principle testable.

3.9 Super-symplectic degrees of freedom

3.9.1 What could happen in the transition to non-perturbative QCD?

What happens mathematically in the transition to non-perturbative QCD has remained more or less a mystery. The number theoretical considerations of [E9] inspired the idea that Planck constant is dynamical and has a spectrum given as $\hbar(n) = n\hbar_0$, where n characterizes the quantum phase $q = exp(i2\pi/n)$ associated with Jones inclusion. The strange finding that the orbits of planets seem to obey Bohr quantization rules with a gigantic value of Planck constant inspired the hypothesis that the increase of Planck constant provides a unique mechanism allowing strongly interacting system to stay in perturbative phase [A9, D6]. The resulting model allows to understand dark matter as a macroscopic quantum phase in astrophysical length and time scales, and strongly suggest a connection with dark matter and biology.

The phase transition increasing Planck constant could provide a model for the transition to confining phase in QCD. When combined with the recent ideas about value spectrum of Kähler coupling strength one ends up with a rather explicit model about non-perturbative aspects of hadron physics already successfully applied in hadron mass calculations [F4]. Mersenne primes seem to define the p-adic length scales of gauge bosons and of hadronic space-time sheets. The quantization of Planck constant provides additional insight to p-adic length scales hypothesis and to the preferred role of Mersenne primes.

Super-symplectic gluons and non-perturbative aspects of hadron physics

According to the model of hadron masses [F4], in the case of light pseudoscalar mesons the contribution of quark masses to the mass squared of meson dominates whereas spin 1 mesons contain a large contribution identified as color interaction conformal weight (color magnetic spin-spin interaction conformal weight and color Coulombic conformal weight). This conformal weight cannot however correspond to the ordinary color interactions alone and is negative for pseudo-scalars and compensated by some unknown contribution in the case of pion in order to avoid tachyonic mass. Quite generally this realizes the idea about light pseudoscalar mesons as Goldstone bosons. Analogous mass formulas hold for baryons but in this case the additional contribution which dominates.

The unknown contribution can be assigned to the $k = 107$ hadronic space-time sheet and must correspond to the non-perturbative aspects of QCD and the failure of the quantum field theory approach at low energies. In TGD the failure of QFT picture corresponds to the presence of configuration space degrees of freedom ("world of classical worlds") in which super-symplectic algebra acts. The failure of the approximation assuming single fixed background space-time is in question.

The purely bosonic generators carry color and spin quantum numbers: spin has however the character of orbital angular momentum. The only electro-weak quantum numbers of super-generators are those of right-handed neutrino. If the super-generators degrees carry the quark spin at high energies, a solution of proton spin puzzle emerges.

The presence of these degrees of freedom means that there are two contributions to color interaction energies corresponding to the ordinary gluon exchanges and exchanges of super-symplectic gluons. It turns out the model assuming same topological mixing of super-symplectic bosons identical to that experienced by U type quarks leads to excellent understanding of hadron masses assuming that hadron spin correlates with the super-symplectic particle content of the hadronic space-time sheet.

According to the argument already discussed, at the hadronic $k = 107$ space electro-weak interactions would be absent and classical $U(1)$ action should vanish. This is guaranteed if $\alpha_{U(1)}$ diverges. This would give

$$\alpha_s = \alpha_K = \frac{1}{4} \quad .$$

This would give also a quantitative articulation for the statement that strong interactions are charge independent.

This α_s would correspond to the interaction via super-symplectic colored gluons and would lead to the failure of perturbation theory. By the general criterion stating that the failure of perturbation theory leads to a phase transition increasing the value of Planck constant one expects that the value of $\hbar$ increases [A9]. The value leaving the value of α_K invariant would be $\hbar \rightarrow 26\hbar$ and would mean that p-adic length scale L_{107} is replaced with length scale $26L_{107} = 46$ fm, the size of large nucleus so that also the basic length scale nuclear physics would be implicitly coded into the structure of hadrons.

Why Mersenne primes should label a fractal hierarchy of physics?

There are motivations for the working hypothesis stating that there is fractal hierarchy of copies of standard model physics, and that Mersenne primes label both hadronic space-time sheets and gauge bosons. The reason for this is not yet well understood and I have considered several speculative explanations.

1. *First picture*

The first thing to come in mind is that Mersenne primes correspond to fixed points of the discrete p-adic coupling constant evolution, most naturally to the maxima of the color coupling constant strength. This would mean that gluons are emitted with higher probability than in other p-adic length scales.

There is however an objection againt this idea. If one accepts the new vision about non-perturbative aspects of QCD, it would seem that super-symplectic bosons or the interaction between super-symplectic bosons and quarks for some reason favors Mersenne primes. However, if color coupling strength corresponds to $\alpha_K = \alpha_s = 1/4$ scaled down by the increase of the Planck constant, the evolution of super-symplectic color coupling strength does not seem to play any role. What becomes large should be a geometric "form factor", when the boson in the vertex corresponds to Mersenne prime rather than "bare" coupling.

The resolution of the problem could be that boson emission vertices $g(p_1, p_2, p_3)$ are functions of p-adic primes labeling the particles of the vertices so that actually three p-adic length scales are involved instead of single length scale as in the ordinary coupling constant evolution. Hence one can imagine that the interaction between particles corresponding to primes near powers of 2 and Mersenne primes is especially strong and analogous to a resonant interaction. The geometric resonance due to the fact that the length scales involved are related by a fractal scaling by a power of 2 would make the form factors $F(p_1 \simeq 2^{k_1}, p_2 \simeq 2^{k_2}, M_n)$ large. The selection of primes near powers of two and Mersenne bosons would be analogous to evolutionary selection of a population consisting of species able to interact strongly.

Since $k = 113$ quarks are possible for $k = 107$ hadron physics, it seems that quarks can have join along boundaries bonds directed to M_n space-times with $n < k$. This suggests that neighboring Mersenne primes compete for join along boundaries bonds of quarks. For instance, when the p-adic length scale characterizing quark of M_{107} hadron physics begins to approach M_{89} quarks tend to feed their gauge flux to M_{89} space-time sheet and M_{89} hadron physics takes over and color coupling strength begins to increase. This would be the space-time correlate for the loss of asymptotic freedom.

2. Second picture

Preferred values of Planck constants could play a key role in the selection of Mersenne primes. Ruler-and-compass hypothesis predicts that Planck constants, which correspond to ratios of ruler and compass integers proportional to a product of distinct Fermat primes (four of them are known) and any power of two are favored. As a special case one obtains ruler and compass integers. As a consequence, p-adic length scales have satellites obtained by multiplying them with ruler-and-compass integers, and entire fractal hierarchy of power-of-two multiples of a given p-adic length scale results.

Mersenne length scales would be special since their satellites would form a subset of satellites of shorter Mersenne length scales. The copies of standard model physics associated with Mersenne primes would define a kind of resonating subset of physics since corresponding wavelengths and frequencies would coincide. This would also explain why fermions labeled by primes near power of two couple strongly with Mersenne primes.

3.9.2 Super-symplectic bosons as a particular kind of dark matter

Super-symplectic bosons

TGD predicts also exotic bosons which are analogous to fermion in the sense that they correspond to single wormhole throat associated with CP_2 type vacuum extremal whereas ordinary gauge bosons corresponds to a pair of wormhole contacts assignable to wormhole contact connecting positive and negative energy space-time sheets. These bosons have super-conformal partners with quantum numbers of right handed neutrino and thus having no electro-weak couplings. The bosons are created by the purely bosonic part of super-symplectic algebra [B2, B3, B4], whose generators belong to the representations of the color group and 3-D rotation group but have vanishing electro-weak quantum numbers. Their spin is analogous to orbital angular momentum whereas the spin of ordinary gauge bosons reduces to fermionic spin. Recall that super-symplectic algebra is crucial for the construction of configuration space Kähler geometry. If one assumes that super-symplectic gluons suffer topological mixing identical with that suffered by say U type quarks, the conformal weights would be (5,6,58) for the three lowest generations. The application of super-symplectic bosons in TGD based model of hadron masses is discussed in [F4] and here only a brief summary is given.

As explained in [F4], the assignment of these bosons to hadronic space-time sheet is an attractive idea.

1. Quarks explain only a small fraction of the baryon mass and that there is an additional contribution which in a good approximation does not depend on baryon. This contribution should correspond to the non-perturbative aspects of QCD. A possible identification of this contribution is in terms of super-symplectic gluons. Baryonic space-time sheet with $k = 107$ would contain a many-particle state of super-symplectic gluons with net conformal weight of 16 units. This leads to a model of baryons masses in which masses are predicted with an accuracy better than 1 per cent.

2. Hadronic string model provides a phenomenological description of non-perturbative aspects of QCD and a connection with the hadronic string model indeed emerges. Hadronic string tension is predicted correctly from the additivity of mass squared for $J = 2$ bound states of super-symplectic quanta. If the topological mixing for super-symplectic bosons is equal to that for U type quarks then a 3-particle state formed by 2 super-symplectic quanta from the first generation and 1 quantum from the second generation would define baryonic ground state with 16 units of conformal weight. A very precise prediction for hadron masses results by assuming that the spin of hadron correlates with its super-symplectic particle content.

3. Also the baryonic spin puzzle caused by the fact that quarks give only a small contribution to the spin of baryons, could find a natural solution since these bosons could give to the spin of baryon an angular momentum like contribution having nothing to do with the angular momentum of quarks.

4. Super-symplectic bosons suggest a solution to several other anomalies related to hadron physics. The events observed for a couple of years ago in RHIC [31] suggest a creation of a black-hole like state in the collision of heavy nuclei and inspire the notion of color glass condensate of gluons, whose natural identification in TGD framework would be in terms of a fusion of hadronic space-time sheets containing super-symplectic matter materialized also from the collision energy. In the collision, valence quarks connected together by color bonds to form separate units would evaporate from their hadronic space-time sheets in the collision, and would define TGD counterpart of Pomeron, which experienced a reincarnation for few years ago [30]. The strange features of the events related to the collisions of high energy cosmic rays with hadrons of atmosphere (the particles in question are hadron like but the penetration length is anomalously long and the rate for the production of hadrons increases as one approaches surface of Earth) could be also understood in terms of the same general mechanism.

Topological evaporation, quark gluon plasma and Pomeron

Topological evaporation of elementary particles means nothing if CP_2 type vacuum extremal evaporates so that one must assume that it is quark space-time sheet or join along boundaries block of quark space-time sheets which evaporates. Second new element is the identification of valence quarks as dark matter in the sense of having large $\hbar$: $\hbar_s \simeq (n/v_0)\hbar$, $v_0 \simeq 2^{-11}$, $n = 1$ so that Compton length is scaled by the same factor. Quark gluon plasma would correspond to a phase with ordinary value $\hbar$ and possibly also sea partons can be regarded as this kind of phase. Color bonds between partons are possible also in this phase.

Concerning the evaporation there are two options.

1. The space-time sheets of sea partons are condensed at much larger space-time sheets defined by the space-time sheets of valence quarks connected by color bonds. Topological evaporation of the parton sea would correspond to the splitting of # contacts connecting sea partons space-time sheets to valence quark space-time sheets.

2. Sea partons condensed at a larger space-time sheet which in turn condenses at the space-time sheet of valence quarks. In this case topological evaporation occurs for the entire sea parton space-time sheet.

One can consider two possible scenarios for topological evaporation of quarks and gluons.

1. Color gauge charge is not identified as gauge flux and single secondarily condensed quark space-time sheet can suffer topological evaporation. In this case quark gluon plasma could be identified as vapor phase state for quarks and gluons.

2. Color gauge charge is identified as gauge flux and only join along boundaries blocks formed from quarks can evaporate. Join along boundaries contacts are naturally identified as color flux tubes between quarks. These tubes need not be static. Quark gluon plasma corresponds to condensed state in which the join along boundaries contacts between quark like 3-surfaces are broken. The evaporation of single quark is possible but as a consequence a compensating color charge develops on the interior of the outer boundary of the evaporated quark and the process probably can be interpreted as an emission of meson from hadron. The production of hadrons in hadron collision could be interpreted as a topological evaporation process for sea and valence quarks.

The problematic feature of scenario 1) is the understanding of color confinement In scenario 2) color confinement of the vapor phase particles is an automatic consequence of the assumption that color charge corresponds to gauge flux classically (gauge field is $H^A J_{\alpha\beta}$, H^A being the Hamiltonian of the color isometry. This does not however exclude the possibility that hadron might feed part of its color isospin or hypercharge gauge flux to surrounding condensate. The concept of anomalous hypercharge introduced in earlier work as proportional to electromagnetic charge indeed suggests this kind of possibility. It should be noticed that for the vacuum extremals of Kähler action induced Kähler field and thus also color fields vanish identically.

The alternatives a) and b) have an additional nice feature that they lead to elegant description for the mysterious concept of Pomeron originally introduced to describe hadronic diffractive scattering as the exchange of Pomeron Regge trajectory [44]. No hadrons belonging to Pomeron trajectory were however found and via the advent of QCD Pomeron was almost forgotten. Pomeron has recently experienced reincarnation [30, 46, 48]. In Hera [30] $e-p$ collisions, in which proton scatters essentially elastically whereas jets in the direction of incoming virtual photon emitted by electron are observed. These events can be understood by assuming that proton emits color singlet particle carrying a small fraction of proton's momentum. This particle in turn collides with the virtual photon (antiproton) whereas proton scatters essentially elastically.

The identification of the color singlet particle as Pomeron looks natural since Pomeron emission describes nicely the diffractive scattering of hadrons. Analogous hard diffractive scattering events in pX diffractive scattering with $X = \bar{p}$ [46] or $X = p$ [48] have also been observed. What happens is that proton scatters essentially elastically and the emitted Pomeron collides with X and suffers hard scattering so that large rapidity gap jets in the direction of X are observed. These results suggest that Pomeron is real and consists of ordinary partons.

The TGD identification of Pomeron is as sea partons in vapor phase. In TGD inspired phenomenology events involving Pomeron correspond to pX collisions, where incoming X collides with proton, when sea quarks have suffered coherent simultaneous (by color confinement) evaporation into vapor phase. System X sees only the sea left behind in the evaporation and scatters from it whereas dark valence quarks continue without noticing X and condense later to form quasi-elastically scattered proton. If X suffers hard scattering from the sea, the peculiar hard diffractive scattering events are observed. The fraction of these events is equal to the fraction f of time spent by sea quarks in vapor phase.

Dimensional arguments suggest a rough order of magnitude estimate for $f \sim \alpha_K \sim 1/137 \sim 10^{-2}$ for f. The fraction of the peculiar deep inelastic scattering events at Hera is about 5 percent, which suggest that f is about 6.8 times larger and of same order of magnitude as QCD α_s The time spent in condensate is by dimensional arguments of the order of the p-adic legth scale $L(M_{107})$, not far from proton Compton length. Time dilation effects at high collision energies guarantee that valence quarks indeed stay in vapor phase during the collision. The identification of Pomeron as sea explains also why Pomeron Regge trajectory does not correspond to actual on mass shell particles.

The existing detailed knowledge about the properties of sea structure functions provides a stringent test for the TGD based scenario. According to [46] Pomeron structure function seems to consist of soft ($(1-x)^5$), hard ($(1-x)$) and super-hard component (delta function like component at $x=1$). The peculiar super hard component finds explanation in TGD based picture. The structure function $q_P(x,z)$ of parton in Pomeron contains the longitudinal momentum fraction z of the Pomeron as a parameter and $q_P(x,z)$ is obtained by scaling from the sea structure function $q(x)$ for proton $q_P(x,z) = q(zx)$. The value of structure function at $x=1$ is non-vanishing: $q_P(x=1,z) = q(z)$ and this explains the necessity to introduce super hard delta function component in the fit of [46].

Simulating big bang in laboratory

An important steps in the development of ideas were stimulated by the findings made during period 2002-2005 in Relativist Heavy Ion Collider (RHIC) in Brookhaven compared with the finding of America and for full reason.

1. The first was finding of longitudinal Lorentz invariance at single particle level suggesting a collective behavior. This was around 2002.
2. The collective behavior which was later interpreted in terms of color glass condensate meaning the presence of a blob of liquid like phase decaying later to quark gluon plasma since it was found that the density of what was expected to be quark gluon plasma was about ten times higher than expected.
3. The last finding is that this object seems to absorb partons like black hole and behaves like evaporating black hole.

In my personal Theory Universe the history went as follows.

1. I proposed 2002 a model for Gold-Gold collision as a mini big bang identified as a scaled down variant of TGD inspired cosmology. This makes sense because in TGD based critical cosmology the initial state has vanishing mass per comoving volume instead of being infinite as in radiation dominated cosmology. Any phase transition involving a generation of a new space-time sheet might proceed in this universal manner.
2. Cosmic string soup in the primordial stage is replaced by a tangle of color flux tubes containing the color glass condensate. CGC is made macroscopic quantum phase by conformal confinement (the conformal weights of partons are complex and relate to zeros of zeta) and only the net conformal weight is real in this phase). Flux tubes correspond to flow lines of incompressible liquid flow and non-perturbative phase with a very large $\hbar$ is in question. Gravitational constant is replaced by strong gravitational constant defined by the relevant p-adic length scale squared since color flux tubes are analogs of hadronic strings. Presumably L_p, $p = M_107 = 2^107 - 1$, is the p-adic length scale since Mersenne prime M_{107} labels the space-time sheet at which partons feed their color gauge fluxes. Temperature during this phase could correspond to Hagedorn temperature for strings and is determined by string tension. Density would be maximal.
3. Next phase is critical phase in which the notion of space-time in ordinary sense makes sense and 3-space is flat since there is no length scale in critical system (so that curvature vanishes). During this critical phase phase a transition to quark gluon plasma occurs. The duration of this phase fixes all relevant parameters such as temperature (which is the analog of Hagedorn temperature corresponding since critical density is maximal density of gravitational mass in TGD Universe).
4. The next phase is radiation dominated quark gluon plasma phase and then follows hadronization to matter dominated phase provided cosmological picture still applies.

Since black hole formation and evaporation is very much like formation big crunch followed by big bang, the picture is more or less equivalent with the picture in which black hole like object consisting of string like objects (mass is determined by string length just as it is determined by the radius for black holes) is formed and then evaporates. Black hole temperature corresponds to Hagedorn temperature and to the duration of critical period of the mini cosmology.

Are ordinary black-holes replaced with super-symplectic black-holes in TGD Universe?

Some variants of super string model predict the production of small black-holes at LHC. I have never taken this idea seriously but in a well-defined sense TGD predicts black-holes associated with super-symplectic gravitons with strong gravitational constant defined by the hadronic string tension. The proposal is that super-symplectic black-holes have been already seen in Hera, RHIC, and the strange cosmic ray events.

Baryonic super-symplectic black-holes of the ordinary M_{107} hadron physics would have mass 934.2 MeV, very near to proton mass. The mass of their M_{89} counterparts would be 512 times higher, about 478 GeV if quark massses scale also by this factor. This need not be the case: if one has $k = 113 \rightarrow 103$ instead of 105 one has 434 GeV mass. "Ionization energy" for Pomeron, the structure formed by valence quarks connected by color bonds separating from the space-time sheet of super-symplectic black-hole in the production process, corresponds to the total quark mass and is about 170 MeV for ordinary proton and 87 GeV for M_{89} proton. This kind of picture about black-hole formation expected to occur in LHC differs from the stringy picture since a fusion of the hadronic mini black-holes to a larger black-hole is in question.

An interesting question is whether the ultrahigh energy cosmic rays having energies larger than the GZK cut-off of 5×10^{10} GeV are baryons, which have lost their valence quarks in a collision with hadron and therefore have no interactions with the microwave background so that they are able to propagate through long distances.

In neutron stars the hadronic space-time sheets could form a gigantic super-symplectic black-hole and ordinary black-holes would be naturally replaced with super-symplectic black-holes in TGD framework (only a small part of black-hole interior metric is representable as an induced metric). This obviously means a profound difference between TGD and string models.

1. Hawking-Bekenstein black-hole entropy would be replaced with its p-adic counterpart given by

$$S_p = (\frac{M}{m(CP_2)})^2 \times log(p) \ , \tag{3.9.1}$$

where $m(CP_2)$ is CP_2 mass, which is roughly 10^{-4} times Planck mass. M is the contribution of p-adic thermodynamics to the mass. This contribution is extremely small for gauge bosons but for fermions and super-symplectic particles it gives the entire mass.

2. If p-adic length scale hypothesis $p \simeq 2^k$ holds true, one obtains

$$S_p = klog(2) \times (\frac{M}{m(CP_2)})^2 , \tag{3.9.2}$$

$m(CP_2) = \hbar/R$, R the "radius" of CP_2, corresponds to the standard value of $\hbar_0$ for all values of $\hbar$.

3. Hawking-Bekenstein area law gives in the case of Schwartschild black-hole

$$S = \frac{A}{4G} \times \hbar = \pi G M^2 \times \hbar \ . \tag{3.9.3}$$

For the p-adic variant of the law Planck mass is replaced with CP_2 mass and $klog(2) \simeq log(p)$ appears as an additional factor. Area law is obtained in the case of elementary particles if k is prime and wormhole throats have M^4 radius given by p-adic length scale $L_k = \sqrt{k}R$ which is exponentially smaller than L_p. For macroscopic super-symplectic black-holes modified area law results if the radius of the large wormhole throat equals to Schwartschild radius. Schwartschild radius is indeed natural: in [D3] I have shown that a simple deformation of the Schwartschild exterior metric to a metric representing rotating star transforms Schwartschild horizon to a light-like 3-surface at which the signature of the induced metric is transformed from Minkowskian to Euclidian.

4. The formula for the gravitational Planck constant appearing in the Bohr quantization of planetary orbits and characterizing the gravitational field body mediating gravitational interaction between masses M and m [D6] reads as

$$\hbar_{gr} = \frac{GMm}{v_0}\hbar_0 \ .$$

$v_0 = 2^{-11}$ is the preferred value of v_0. One could argue that the value of gravitational Planck constant is such that the Compton length $\hbar_{gr}/M$ of the black-hole equals to its Schwartshild radius. This would give

$$\hbar_{gr} = \frac{GM^2}{v_0}\hbar_0 \ , \ v_0 = 1/2 \ . \tag{3.9.4}$$

The requirement that $\hbar_{gr}$ is a ratio of ruler-and-compass integers expressible as a product of distinct Fermat primes (only four of them are known) and power of 2 would quantize the mass spectrum of black hole [D6]. Even without this constraint M^2 is integer valued using p-adic mass squared unit and if p-adic length scale hypothesis holds true this unit is in an excellent approximation power of two.

5. The gravitational collapse of a star would correspond to a process in which the initial value of v_0 , say $v_0 = 2^{-11}$, increases in a stepwise manner to some value $v_0 \leq 1/2$. For a supernova with solar mass with radius of 9 km the final value of v_0 would be $v_0 = 1/6$. The star could have an onion like structure with largest values of v_0 at the core as suggested by the model of planetary system. Powers of two would be favored values of v_0. If the formula holds true also for Sun one obtains $1/v_0 = 3 \times 17 \times 2^{13}$ with 10 per cent error.

6. Black-hole evaporation could be seen as means for the super-symplectic black-hole to get rid of its electro-weak charges and fermion numbers (except right handed neutrino number) as the antiparticles of the emitted particles annihilate with the particles inside super-symplectic black-hole. This kind of minimally interacting state is a natural final state of star. Ideal super-symplectic black-hole would have only angular momentum and right handed neutrino number.

7. In TGD light-like partonic 3-surfaces are the fundamental objects and space-time interior defines only the classical correlates of quantum physics. The space-time sheet containing the highly entangled cosmic string might be separated from environment by a wormhole contact with size of black-hole horizon.

   This looks the most plausible option but one can of course ask whether the large partonic 3-surface defining the horizon of the black-hole actually contains all super-symplectic particles so that super-symplectic black-hole would be single gigantic super-symplectic parton. The interior of super-symplectic black-hole would be a space-like region of space-time, perhaps resulting as a large deformation of CP_2 type vacuum extremal. Black-hole sized wormhole contact would define a gauge boson like variant of the black-hole connecting two space-time sheets and getting its mass through Higgs mechanism. A good guess is that these states are extremely light.

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Part II

MANY-SHEETED COSMOLOGY, AND ASTROPHYSICS

Chapter 4

The Relationship Between TGD and GRT

4.1 Introduction

In this chapter the recent view about TGD as Poincare invariant theory of gravitation is discussed. It must be admitted that the development of the proper interpretation of the theory has been rather slow and involved rather weird twists motivated by conformist attitudes. Typically these attempts have brought into theory ad hoc identifications of say gravitational four-momentum although theory itself has from very beginning provided completely general formulas.

Perhaps the real problem has been that radically new views about ontology were necessary before it was possible to see what had been there all the time. Zero energy ontology states that all physical states have vanishing net quantum numbers. The hierarchy of dark matter identified as macroscopic quantum phases labeled by arbitrarily large values of Planck constant is second aspect of the new ontology.

4.1.1 Does Equivalence Principle hold true in TGD Universe?

The motivation for TGD as a Poincare invariant theory of gravitation was that the notion of four-momentum is poorly defined in curved space-time since corresponding Noether currents do not exist. There however seems to be a fundamental obstacle against the existence of a Poincare invariant theory of gravitation related to the notions of inertial and gravitational energy.

1. The conservation laws of inertial energy and momentum assigned to the fundamental action would be exact in this kind of a theory. Gravitational four-momentum can be assigned to the curvature scalar as Noether currents and is thus completely well-defined unlike in GRT. Equivalence Principle requires that inertial and gravitational four-momenta are identical. This is satisfied if curvature scalar defines the fundamental action principle crucial for the definition of quantum TGD. Curvature scalar as a fundamental action is however non-physical and had to be replaced with so called Kähler action.

2. One can question Equivalence Principle because the conservation of gravitational four-momentum seems to fail in cosmological scales.

3. For the extremals of Kähler action the Noether currents associated with curvature scalar are well-defined but non-conserved. Also for vacuum extremals satisfying Einstein's equations gravitational four-momentum fails to be conserved and non-conservation becomes large for small values of cosmic time. This looks fine but the problem is whether the possible failure of Equivalence Principle is so serious that it leads to conflict with experimental facts.

The failure of Equivalence Principle was something which I could not take seriously and I ended up with a long series of ad hoc constructs trying to save Equivalence Principle. Eventually I decided to take the possible failure seriously and to find out whether it has catastrophic consequences, and to look also for possible positive consequences by trying to relate the failure to the recent problems of cosmology, in particular the necessity to postulate somewhat mysterious dark energy characterized by cosmological constant.

My basic mistake looks now obvious. I tried to deduce the formulation of Equivalence Principle in the framework provided by General Relativity framework rather than in string model context. There were several steps in the enlightment process.

1. First came the conviction that coset representation for super-symplectic and super Kac-Moody algebras provides extremely general formulation of Equivalence Principle in which inertial and gravitational four-momenta are replaced with Super Virasoro generators of two algebras whose differences annihilate physical states. This idea came for years before becoming aware of its importance and I simply forgot it.

2. Next came the realization of the fundamental role of number theoretical compactification providing a number theoretical interpretation of $M^4 \times CP_2$ and thus also of standard model quantum numbers. This lead to the identification of the preferred extremals of Kähler action and to the formulation of quantum TGD in terms of second quantized induced spinors fields. One of conclusion was that dimensional reduction for preferred extremals of Kähler action- if they have the properties required by theoretic compactification- leads to string model with string tension which is however not proportional to the inverse of Newton's constant but to L_p^2, p-adic length scale squared and thus gigantic. The connection between gravitational constant and L_p^2 comes from an old argument that I discovered about two decades ago and which allowed to predict the value of Kähler coupling strength by using as input electron mass and p-adic mass calculations. In this framework the role of Planck length as a fundamental length scale is taken by CP_2 size so that Planck length scale loses its magic role as a length scale in which usual views about space-time geometry cease to hold true.

3. The next step was the realization that zero energy ontology allows to avoid the paradox implied in positive energy ontology by the fact that gravitational energy is not conserved but inertial energy identified as Noether charge is. Energy conservation is always in some length scale in zero energy ontology.

4. As a matter fact, there was still one step. I had to become fully aware that the identification of gravitational four-momentum in terms of Einstein tensor makes sense only in long length scales. This is of course trivial but for some reason I did not realize that this fact resolves the paradoxes associated with objects like cosmic strings.

To sum up, the understanding of Equivalence Principle in TGD context required quite many discoveries of mostly mathematical character: the understanding of the super-conformal symmetries of quantum TGD, the discovery of zero energy ontology, the identification of preferred extremals of Kähler action by requiring number theoretical compactification, and the discovery that dimensional reduction allows to formulate quantum in terms of slicing of space-time surface by stringy word sheets.

4.1.2 Zero energy ontology

In zero energy ontology one replaces positive energy states with zero energy states with positive and negative energy parts of the state at the boundaries of future and past direct light-cones forming a causal diamond. All conserved quantum numbers of the positive and negative energy states are of opposite sign so that these states can be created from vacuum. "Any physical state is creatable from vacuum" becomes thus a basic principle of quantum TGD and together with the notion of quantum jump resolves several philosophical problems (What was the initial state of universe?, What are the values of conserved quantities for Universe, Is theory building completely useless if only single solution of field equations is realized?).

At the level of elementary particle physics positive and negative energy parts of zero energy state are interpreted as initial and final states of a particle reaction so that quantum states become physical events. Equivalence Principle would hold true in the sense that the classical gravitational four-momentum of the vacuum extremal whose small deformations appear as the argument of configuration space spinor field is equal to the positive energy of the positive energy part of the zero energy quantum state.

Robertson-Walker cosmologies correspond to vacua with respect to inertial energy and in fact with respect to all quantum numbers. They are not vacua with respect to gravitational charges defined as Noether charges associated with the curvature scalar. Also more general imbeddings of Einstein's equations are typically vacuum extremals with respect to Noether charges assignable to Kähler action since otherwise one ends up with conflict between imbeddability and dynamics. This suggests that physical states have vanishing net quantum numbers quite generally. The construction of quantum theory [C1, D3] indeed leads naturally to zero energy ontology stating that everything is creatable from vacuum.

Zero energy states decompose into positive and negative energy parts having identification as initial and final states of particle reaction in time scales of perception longer than the geometro-temporal separation T of positive and negative energy parts of the state. If the time scale of perception is smaller than T, the usual positive energy ontology applies.

In zero energy ontology inertial four-momentum is a quantity depending on the temporal time scale T used and in time scales longer than T the contribution of zero energy states with parameter $T_1 < T$ to four-momentum vanishes. This scale dependence alone implies that it does not make sense to speak about conservation of inertial four-momentum in cosmological scales. Hence it would be in principle possible to identify inertial and gravitational four-momenta and achieve strong form of Equivalence Principle. It however seems that this is not the correct approach to follow.

The concept of negative potential energy is completely standard notion in physics. Perhaps so standard that physicists have begun to regard it as understood. The precise physical origin of the negative potential energy is however complete mystery, and one is forced to take the potential energy as a purely phenomenological concept deriving from quantum theory as an effective description.

In TGD framework topological field quantization leads to the hypothesis that quantum concepts should have geometric counterparts and also potential energy should have precise correlate at the level of description based on topological field quanta. This indeed seems to be the case. As already explained, TGD allows space-time sheets to have both positive and negative time orientations. This in turn implies that also the sign of energy can be also negative. This suggests that the generation of negative energy space-time sheets representing virtual gravitons together with energy conservation makes possible the generation of huge gravitationally induced kinetic energies and gravitational collapse. In this process inertial energy would be conserved since instead, of positive energy gravitons, the inertial energy would go to the energy of matter.

This picture has a direct correlate in quantum field theory where the exchange negative energy virtual bosons gives rise to the interaction potential. The gravitational red-shift of microwave background photons is the strongest support for the non-conservation of energy in General Relativity. In TGD it could have concrete explanation in terms of absorption of negative energy virtual gravitons by photons leading to gradual reduction of their energies. This explanation is consistent with the classical geometry based explanation of the red-shift based on the stretching of electromagnetic wave lengths. This explanation is also consistent with the intuition based on Feynman diagram description of gravitational acceleration in terms of graviton exchanges.

4.1.3 Dark matter hierarchy and hierarchy of Planck constants

The idea about hierarchy of Planck constants relying on generalization of the imbedding space was inspired both by empirical input (Bohr quantization of planetary orbits) and by the mathematics of hyper-finite factors of type II_1 combined with the quantum classical correspondence.

Quantum classical correspondence suggests that Jones inclusions [18] have space-time correlates [C6, A9]. There is a symplectic hierarchy of Jones inclusions labeled by finite subgroups of SU(2)[17] This leads to a generalization of the imbedding space obtained by gluing an infinite number of copies of H regarded as singular bundles over $H/G_a \times G_b$, where $G_a \times G_b$ is a subgroup of $SU(2) \times SU(2) \subset SL(2,C) \times SU(3)$. Gluing occurs along a factor for which the group is same. The generalized imbedding space has clearly a book like structure with pages of books intersecting along 4-D sub-manifold $M^2 \times S^2$, S^2 a geodesic sphere of CP_2 characterizing the choice of quantization axies. Entire configuration space is union over "books" corresponding to various choices of this sub-manifold.

The groups in question define in a natural manner the direction of quantization axes for for various isometry charges and this hierarchy seems to be an essential element of quantum measurement theory. Ordinary Planck constant, as opposed to Planck constants $\hbar_a = n_a\hbar_0$ and $\hbar_b = n_b\hbar_0$ appearing in the commutation relations of symmetry algebras assignable to M^4 and CP_2, is naturally quantized as $\hbar = (n_a/n_b)\hbar_0$, where n_i is the order of maximal cyclic subgroup of G_i. The hierarchy of Planck constants is interpreted in terms of dark matter hierarchy [A9]. What is also important is that $(n_a/n_b)^2$ appear as a scaling factor of M^4 metric so that Kähler action via its dependence on induced metric codes for radiative corrections coming in powers of ordinary Planck constant: therefore quantum criticality and vanishing of radiative corrections to functional integral over WCW does not mean vanishing of radiative corrections.

G_a would correspond directly to the observed symmetries of visible matter induced by the underlying dark matter [A9]. For instance, in living matter molecules with 5- and 6-cycles could directly reflect the fact that free electron pairs associated with these cycles correspond to $n_a = 5$ and $n_a = 6$ dark matter possibly responsible for anomalous conductivity of DNA [A9, J1] and recently reported strange properties of graphene [75]. Also the tedrahedral and icosahedral symmetries of water molecule clusters could have similar interpretation [53, F9].

A further fascinating possibility is that the observed indications for Bohr orbit quantization of planetary orbits [30] could have interpretation in terms of gigantic Planck constant for underlying dark matter [D6] so that macroscopic and -temporal quantum coherence would be possible in astrophysical length scales manifesting itself in many manners: say as preferred directions of quantization axis (perhaps related to the CMB anomaly) or as anomalously low dissipation rates.

Since the gravitational Planck constant is proportional to the product of the gravitational masses of interacting systems, it must be assigned to the field body of the two systems and characterizes the interaction between systems rather than systems themselves. This observation applies quite generally and each field body of the system (em, weak, color, gravitational) is characterized by its own Planck constant.

In the gravitational case the order of G_a is gigantic and at least GM_1m/v_0, $v_0 = 2^{-11}$ the favored value. The natural interpretation is as a discrete rotational symmetry of the gravitational field body of the system having both gravimagnetic and gravi-electric parts. The subgroups of G_a for which order is a divisor of the order of G_a define broken symmetries at the lower levels of dark matter hierarchy, in particular symmetries of visible matter.

The number theoretically simple ruler-and-compass integers having as factors only first powers of Fermat primes and power of 2 would define a physically preferred sub-hierarchy of quantum criticality for which subsequent levels would correspond to powers of 2: a connection with p-adic length scale hypothesis suggests itself. Ruler and compass hypothesis implies that besides p-adic length scales also their 3- and 5- multiples should be important. Note that in the structure of chromosomes p-adic length scale $L(151) \simeq 10$ characterizes beads-on-string structure of DNA whereas the length scale $3L(151)$ appears in the coiling of this structure.

4.1.4 The problem of cosmological constant

A further implication of dark matter hierarchy is that astrophysical systems correspond to stationary states analogous to atoms and do not participate to cosmic expansion in a continuous manner but via discrete quantum phase transitions in which gravitational Planck constant increases. By quantum criticality of these phase transitions critical cosmologies are excellent candidates for the modeling of these transitions. Imbeddable critical cosmologies are unique apart from a parameter determining their duration and represent accelerating cosmic expansion so that there is no need to introduce cosmological constant.

It indeed turns out possible to understand these critical phases in terms of quantum phase transition increasing the size of large modeled in terms of "big" cosmic strings with negative gravitational mass whose repulsive gravitation drives "galactic" cosmic strings with positive gravitational mass to the boundaries of the void. In this framework cosmological constant like parameter does not characterize the density of dark energy but that of dark matter identifiable as quantum phases with large Planck constant.

A further problem is that the naive estimate for the cosmological constant is predicted to be by a factor 10^{120} larger than its value deduced from the accelerated expansion of the Universe. In TGD framework the resolution of the problem comes naturally from the fact that large voids are quantum systems which follow the cosmic expansion only during the quantum critical phases.

p-Adic fractality predicting that cosmological constant is reduced by a power of 2 in phase transitions occurring at times $T(k) \propto 2^{k/2}$, which correspond to p-adic time scales. These phase transitions would naturally correspond to quantum phase transitions increasing the size of the large voids during which critical cosmology predicting accelerated expansion naturally applies. On the average $\Lambda(k)$ behaves as $1/a^2$, where a is the light-cone proper time. This predicts correctly the order of magnitude for observed value of Λ.

4.1.5 Topics of the chapter

The notion of many-sheeted space-time has been extensively discussed in the previous chapters [D2, D3] and is therefore left out from this chapter. The topics included in this chapter are following.

The first two sections are devoted to the general theoretical picture.

1. There is a discussion of General Coordinate Invariance, Equivalence Principle, and Machian Principle in TGD context with a special emphasis on the recent views about the relationship of inertial and gravitational masses, the zero energy ontology, and dark matter hierarchy.

2. The vacuum extremal imbeddings of Reissner-Nordström and Schwartschild metric are studied. The interpretational problems involved were responsible for much of the tension which eventually led to the recent understanding of Equivalence Principle in TGD framework.

The remaining sections are devoted to examples about applications.

1. A simple model for the final state of a star is proposed. The model indicates that Z^0 force, presumably created by dark matter, might have an important role in the dynamics of the compact objects. During year 2003, more than decade after the formulation of the model, the discovery of the connection between supernovas and gamma ray bursts [32] provided strong support for the predicted axial magnetic and Z^0 magnetic flux tube structures predicted by the model for the final state of a rotating star. Two years later the interpretation of the predicted long range weak forces as being caused by dark matter emerged.

   The recent progress in the understanding of hadronic mass calculations [F4] has led to the identification of so called super-symplectic bosons and their super-counterparts as basic building blocks of hadrons. This notion suggests also a microscopic description of neutron stars and black-holes in terms of highly entangled string like objects in Hagedorn temperature and in very precise sense analogous to gigantic hadrons.

2. In the remaining sections the role of cosmic strings in TGD Universe is summarized, Allais effect as a possible evidence for large $\hbar$ dark gravitons is discussed, and a TGD inspired model of gravimagnetism is studied. Last section is devoted to miscellaneous topics including the time dilation effect caused by the warping of space-time sheet in absence of matter.

4.2 Basic principles of General Relativity from TGD point of view

General Coordinate Invariance, Equivalence Principle, and Machian Principle are the basic principles underlying General Relativity. One can say that TGD shares all of these basic principles albeit in different form.

4.2.1 General Coordinate Invariance

General Coordinate Invariance plays in the formulation of quantum TGD even deeper role than in that of GRT. Since the fundamental objects are 3-D surfaces, the construction of the geometry of the configuration space of 3-surfaces (the world of classical worlds, WCW) requires that the definition of the geometry assigns to a given 3-surface X^3 a unique space-time surface $X^4(X^3)$. This space-time surface is completely analogous to Bohr orbit, which means a completely unexpected connection with quantum theory.

General Coordinate Invariance is a gauge symmetry and requires gauge fixing. The definition assigning $X^4(X^3)$ to given X^3 must be such that the outcome is same for all 4-diffeomorphs of X^3. This condition is highly non-trivial since $X^4(X^3) = X^4(Y^3)$ must hold true if X^3 and Y^3 are 4-diffeomorphs. One manner to satisfy this condition is by assuming quantum holography and weakened form of General Coordinate Invariance: there exists physically preferred 3-surfaces X^3 defining $X^4(X^3)$, and the 4-diffeomorphs Y^3 of X^3 at $X^4(X^3)$ provide classical holograms of X^3: $X^4(Y^3) = X^4(X^3)$ is trivially true. Zero energy ontology allows to realize this form of General Coordinate Invariance.

1. In zero energy ontology configuration space decomposes into a union of sub-configuration spaces associated with causal diamonds $CD \times CP_2$ (CD denotes the intersection of future and past directed light-cones of M^4), and the intersections of space-time surface with the light-light boundaries of $CD \times CP_2$ are excellent candidates for preferred space-like 3-surfaces X^3. The 3-surfaces at $\delta CD \times CP_2$ are indeed physically special since they carry the quantum numbers of positive and negative energy parts of the zero energy state.

2. Preferred 3-surfaces could be also identified as light-like 3-surfaces X_l^3 at which the Euclidian signature of the induced space-time metric changes to Minkowskian. Also light-like boundaries of X^4 can be considered. These 3-surfaces are assumed to carry elementary particle quantum numbers and their intersections with the space-like 3-surfaces X^3 are 2-dimensional partonic surfaces so that effective 2-dimensionality consistent with the conformal symmetries of X_l^3 results if the identifications of 3-surfaces are physically equivalent. Light-like 3-surfaces are identified as generalized Feynman diagrams and due to the presence of 2-D partonic 2-surfaces representing vertices fail to be 3-manifolds. Generalized Feynman diagrams could be also identified as Euclidian regions of space-time surface.

3. General Coordinate Invariance in minimal form requires that the slicing of $X^4(X_l^3)$ by light light 3-surfaces Y_l^3 "parallel" to X_l^3 predicted by number theoretic compactification gives rise to quantum holography in the sense that the data associated with any Y_l^3 allows an equivalent formulation of quantum TGD. This poses a strong condition on the spectra of the modified Dirac operator at Y_l^3 and thus to the preferred extremals of Kähler action since the configuration space Kähler functions defined by various choices of Y_l^3 can differ only by a sum of a holomorphic function and its conjugate [B4, C1].

4.2.2 Equivalence Principle

Coset construction for super-symplectic and super Kac-Moody algebras discussed in [B4, F2, C1] allows to generalize Equivalence Principle and understand it at quantum level. This is however not quite enough: a precise understanding of Equivalence Principle is required also at the classical level. In the following the notion of gravitational mass and its equivalence with inertial mass is discussed first. The strategy is to deduce connection with string model type description rather than trying to show that General Relativity emerges from TGD. This connection emerges trough dimensional reduction of the dynamics defined by Kähler action to stringy dynamics. If one believes that string model description implies General Relativity in long scales, the situation is settled. The determination of gravitational mass as flux does not apply generally so that one cannot identify GM as a gravitational flux assignable to a wormhole throat. Hence one cannot formulate the evolution of G at space-time level as evolution of gravitational fluxes and it seems that only p-adic coupling constant evolution makes sense for G.

Is stringy action principle coded by the geometry of preferred extremals?

It seems very difficult to deduce Equivalence Principle as an identity of gravitational and inertial masses identified as Noether charges associated with corresponding action principles. Since string model is an excellent theory of quantum gravitation, one can consider a less direct approach in which one tries to deduce a connection between classical TGD and string model and hope that the bridge from string model to General Relativity is easier to build. Number theoretical compactification gives good hopes that this kind of connection exists.

1. Number theoretic compactification implies that the preferred extremals of Kähler action have the property that one can assign to each point of M^4 projection $P_{M^4}(X^4(X_l^3))$ of the preferred extremal $M^2(x)$ identified as the plane of non-physical polarizations and also as the plane in which local massless four-momentum lies.

2. If the distribution of the planes $M^2(x)$ is integrable, one can slice $P_{M^4}(X^4(X^3_l))$ to string world-sheets. The intersection of string world sheets with $X^3 \subset \delta M^4_\pm \times CP_2$ corresponds to a light-like curve having tangent in local tangent space $M^2(x)$ at light-cone boundary. This is the first candidate for the definition of number theoretic braid. Second definition assumes M^2 to be fixed at δCD: in this case the slicing is parameterized by the sphere S^2 defined by the light rays of $\delta M^4_\pm$.

3. One can assign to the string world sheet -call it Y^2 - the standard area action

$$S_G(Y^2) = \int_{Y^2} T\sqrt{g_2}d^2y \ , \tag{4.2.1}$$

where g_2 is either the induced metric or only its M^4 part. The latter option looks more natural since M^4 projection is considered. T is string tension.

4. The naivest guess would be $T = 1/\hbar G$ apart from some numerical constant but one must be very cautious here since $T = 1/L_p^2$ apart from a numerical constant is also a good candidate if one accepts the basic argument identifying G in terms of p-adic length L_p and Kähler action for two pieces of CP_2 type vacuum extremals representing propagating graviton. The formula reads $G = L_p^2 exp(-2aS_K(CP_2))$, $a \leq 1$. The interaction strength which would be L_p^2 without the presence of CP_2 type vacuum extremals is reduced by the exponential factor coming from the exponent of Kähler function of configuration space.

5. One would have string model in either $CD \times CP_2$ or $CD \subset M^4$ with the constraint that stringy world sheet belongs to $X^4(X^3_l)$. For the extremals of $S_G(Y^2)$ gravitational four-momentum defined as Noether charge is conserved. The extremal property of string world sheet need not however be consistent with the preferred extremal property. This constraint might bring in coupling of gravitons to matter. The natural guess is that graviton corresponds to a string connecting wormhole contacts. The strings could also represent formation of gravitational bound states when they connect wormhole contacts separated by a large distance. The energy of the string is roughly $E \sim \hbar TL$ and for $T = 1/\hbar G$ gives $E \sim L/G$. Macroscopic strings are not allowed except as models of black holes. The identification $T \sim 1/L_p^2$ gives $E \sim \hbar L/L_p^2$, which does not favor long strings for large values of $\hbar$. The identification $G_p = L_p^2/\hbar_0$ gives $T = 1/\hbar G_p$ and $E \sim \hbar_0 L/L_p^2$, which makes sense and allows strings with length not much longer than p-adic length scale. Quantization - that is the presence of configuration space degrees of freedom- would bring in massless gravitons as deformations of string whereas strings would carry the gravitational mass.

6. The exponent $exp(iS_G)$ can appear as a phase factor in the definition of quantum states for preferred extremals. S_G is not however enough. One can assign also to the points of number theoretic braid action describing the interaction of a point like current Qdx^μ/ds with induced gauge potentials A_μ. The corresponding contribution to the action is

$$S_{braid} = \int_{braid} iTr(Q\frac{dx^\mu}{ds}A_\mu)dx \ . \tag{4.2.2}$$

In stationary phase approximation subject to the additional constraint that a preferred extremal of Kähler action is in question one obtains the desired correlation between the geometry of preferred extremal and the quantum numbers of elementary particle. This interaction term carries information only about the charges of elementary particle. It is quite possible that the interaction term is more complex: for instance, it could contain spin dependent terms (Stern-Gerlach experiment).

7. The constraint coming from preferred extremal property of Kähler action can be expressed in terms of Lagrange multipliers

$$S_c = \int_{Y^2} \lambda^k D_\alpha (\frac{\partial L_K}{\partial_\alpha h^k}) \sqrt{g_2} d^2 y \ . \tag{4.2.3}$$

8. The action exponential reads as

$$exp(iS_G + S_{braid} + S_c) \ . \tag{4.2.4}$$

   The resulting field equations couple stringy M^4 degrees of freedom to the second variation of Kähler action with respect to M^4 coordinates and involve third derivatives of M^4 coordinates at the right hand side. If the second variation of Kähler action with respect to M^4 coordinates vanishes, free string results. This is trivially the case if a vacuum extremal of Kähler action is in question.

9. An interesting question is whether the preferred extremal property boils down to the condition that the second variation of Kähler action with respect to M^4 coordinates vanishes so that gravitonic string is free. The physical interpretation would be in terms of quantum criticality which is the basic conjecture about the dynamics of quantum TGD. This is clear from the fact that in 1-D system criticality means that the potential $V(x) = ax + bx^2 + ..$ has $b = 0$. In field theory criticality corresponds to the vanishing of the term $m^2\phi^2/2$ so that massless situation corresponds to massless theory and criticality and long range correlations.

What does the equality of gravitational and inertial masses mean?

Consider next the question in what form Equivalence Principle could be realized in this framework.

1. Coset construction inspires the conjecture that gravitational and inertial four-momenta are identical. Also some milder form of it would make sense. What is clear is that the construction of preferred extremal involving the distribution of $M^2(x)$ implies that conserved four-momentum associated with Kähler action can be expressed formally as stringy four-momentum. The integral of the conserved inertial momentum current over X^3 indeed reduces to an integral over the curve defining string as one integrates over other two degrees of freedom. It would not be surprising if a stringy expression for four-momentum would result but with string tension depending on the point of string and possibly also on the component of four-momentum. If the dependence of string tension on the point of string and on the choice of the stringy world sheet is slow, the interpretation could be in terms of coupling constant evolution associated with the stringy coordinates. An alternative interpretation is that string tension corresponds to a scalar field. A quite reasonable option is that for given X^3_l T defines a scalar field and that the observed T corresponds to the average value of T over deformations of X^3_l.

2. The minimum option is that Kähler mass is equal to the sum gravitational masses assignable to strings connecting points of wormhole throat or two different wormhole throats. This hypothesis makes sense even for wormhole contacts having size of order Planck length.

3. The condition that gravitational mass equals to the inertial mass (rest energy) assigned to Kähler action is the most obvious condition that one can imagine. The breaking of Poincare invariance to Lorentz invariance with respect to the tip of CD supports this form of Equivalence Principle. This would predict the value of the ratio of the parameter R^2T and p-adic length scale hypothesis would allow only discrete values for this parameter. $p \simeq 2^k$ following from the quantization of the temporal distance $T(n)$ between the tips of CD as $T(n) = 2^n T_0$ would suggest string tension $T_n = 2^n R^2$ apart from a numerical factor. $G_p \propto 2^n R^2/\hbar_0$ would emerge as a prediction of the theory. G could be seen as a prediction or RG invariant input parameter fixed by quantum criticality. The arguments related to p-adic coupling constant evolution suggest $R^2/\hbar_0 G = 3 \times 2^{23}$ [A9].

4. The scalar field property of string tension should be consistent with the vacuum degeneracy of Kähler action. For instance, for the vacuum extremals of Kähler action stringy action is non-vanishing. The simplest possibility is that one includes the integral of the scalar $J^{\mu\nu}J_{\mu\nu}$ over the degrees transversal to M^2 to the stringy action so that string tension vanishes for vacuum extremals. This would be nothing but dimensional reduction of 4-D theory to a 2-D theory using the slicing of $X^4(X_l^3)$ to partonic 2-surfaces and stringy word sheets. For cosmic strings Kähler action reduces to stringy action with string tension $T \propto 1/g_K^2 R^2$ apart from a numerical constant. If one wants consistency with $T \propto 1/L_p^2$, one must have $T \propto 1/g_K^2 2^n R^2$ for the cosmic strings deformed to Kähler magnetic flux tubes. This looks rather plausible if the thickness of deformed string in M^4 degrees of freedom is given by p-adic length scale.

Should one introduce induced spinor fields at string world sheets?

In the previous section it was found that TGD should allow also dimensionally reduced descriptions in terms of either string world sheets or partonic 2-surfaces. This raises the question whether it makes sense to introduce induced spinor fields at string world sheets. This is indeed the case. The modified Dirac action would in this case correspond to the Dirac operator for the dimensionally reduced Kähler action. The effective minimal surface property of Y^2 would guarantee the conservation of the super current. The realization of the effective 3-dimensionality in turn means that the stringy coordinate u corresponds to a gauge degree of freedom or to the condition $D_u\Psi = 0$. There would no spinor waves propagating along this direction of string and only the deformations of string represented by symplectic and Kac-Moody algebras present also in the dynamics of Kähler action responsible for the p-adic thermodynamics would be present. Besides this there would be the fermionic excitations associated with the ends of the string and correspond to the eigenmodes of $D_K(X^2)$ or equivalently with $D_K(Y^1)$ so that the Dirac determinant would be the same as obtained for D_K. For the description in terms of partonic 2-surfaces the Dirac operator would be just $D_K(X^2)$ and also now the equivalence with the 4-D description follows trivially.

What is the connection with General Relativity?

The connection with the stringy description makes it easier to believe that General Relativity gives a reasonable approximate description of gravitational interactions in long length scales also in TGD framework. In short length scales paradoxes are obtained if the description in terms of curvature scalar is assumed.

The vacuum degeneracy of Kähler action is in key role. The topological condensation of CP_2 type vacuum extremals representing fermions and pieces of CP_2 type extremals (wormhole contacts) identified as gauge bosons deforms the vacuum extremals to non-vacuum extremals, and the resulting density of inertial momentum equals to the density of gravitational momentum in stringy sense. If stringy gravitational energy momentum density is proportional to $1/L_p^2$ and if G relates to L_p^2 in the proposed manner, the natural hypothesis is that Einstein tensor provides a good approximation for the density of gravitational four-momentum as non-conserved Noether currents for the curvature scalar action associated with the induced metric. In zero energy ontology the non-conservation of the density of gravitational momentum does not lead to a contradiction with the conservation of inertial four-momentum since inertial four-momentum is defined only for CD in given scale so that conservation laws hold also only in this scale and in finite measurement resolution.

What does one mean with the evolution of gravitational constant?

From above it is clear that although it is possible to speak about the evolution of string tension $T(x)$ for string space-time sheets inside given CD, it does not makes sense to speak about evolution of G inside CDs because the relationship between T and G is not so simple as one might naively expect. One can of course consider the possibility that $T(x)$ is RG invariant and thus constant for the preferred extremals of Kähler action. This could hold module finite measurement resolution for M^4 coordinates defined by the size of the sub-CDs of a given CD. Hence string model description would be exact under quantum criticality assumption in the sense that the second variation of Kähler action with respect to M^4 coordinates vanishes.

As found, gravitational constant can be understood as a product of L_p^2 with the exponential of Kähler action for the two pieces of CP_2 type vacuum extremals representing wormhole contacts assignable to graviton connected by string world sheet. The volume of the typical CP_2 type extremals associated with the graviton increases with L_p so that the exponential factor decreases reducing the growth due to the increase of L_p. Hence G could be RG invariant in p-adic coupling constant evolution: this requires that volume depends on logarithmically on L_p. This point will be discussed in more detail later.

Can one predict the value of gravitational constant?

A lot remains to be understood. The value of gravitational constant is one important example in this respect. For a given space-time sheet defined as a preferred extremal of Kähler action one can in principle calculate the value of G_{class}. Physical gravitational constant G is however expected to quantum average of G_{class} for a given quantum state.

For years ago I found a nice formula relating G to CP_2 length scale, the p-adic prime p characterizing gravitons and equal to M_{127} in the case of ordinary graviton, and Kähler coupling strength [C5, D3]. Quantum formula is in question since the exponent for the Kähler action for CP_2 type vacuum extremals appears in it. The task would be to calculate explicitly the G_{class} and its quantum expectation value.

What seems clear is that G is state dependent. For instance, for quantum states concentrated around almost vacuum extremals (such as hadronic strings) G should be large since they are almost Kähler vacua and the model for hadrons indeed leads to the identification of strong gravitons with G_{strong} characterized by corresponding p-adic length scale.

One can write the basic hypothesis for the relationship between Kähler coupling strength, CP_2 size R and gravitational constant G [C5, D3] as

$$\frac{exp(-2S_K(CP_2))}{G(p)} = \frac{1}{pR^2} \quad . \tag{4.2.5}$$

$S_K(CP_2)$ is Kähler action for CP_2 type vacuum extremals with small renormalization reflecting the fact that entire free CP_2 type extremal is not in question topological condensation. The two sides of this equation suggest an interpretation in terms of two thermodynamics. The vacuum functional defined by Kähler function would define the thermodynamics of the left hand side and Planck mass $M_{Pl}(p) = 1/\sqrt{G(p)}$ defining the fundamental mass equal to Planck mass for $p = M_{127}$ but depending on p as $1/\sqrt{p}$. Right hand side would correspond to p-adic thermodynamics with CP_2 mass $M_{CP_2} = 1/R$ defining the fundamental mass in this case. Thus the formula could be interpreted as stating as equivalence of two different approaches to the calculation of particle masses.

Equivalence Principle and zero energy ontology

In TGD framework Equivalence Principle has several formulations.

1. The fundamental quantum formulation is in terms of coset representation for super-symplectic and super Kac-Moody algebras and identifies the four-momenta associated with these representations.

2. Second formulation is at space-time level and is based on the dimensional reduction of Kähler action to stringy action if preferred extremals possess the properties required by number theoretical compactification. It is essential that the information about preferred extremal is feeded into the eigenvalues spectrum of the modified Dirac action.

3. String tension is not however equal to gravitational constant which is identified as gravitational coupling and is equal to inverse of string tension multiplied by a factor corresponding to exponent of Kähler action for CP_2 type vacuum extremals representing graviton. The third formulation corresponds to long length scale limit at which it is possible to identify the density of gravitational four-momentum in terms of Einstein tensor. This formulation predicts that gravitational mass defined by Einstein tensor is identical with inertial mass defined by Kähler action but in some average sense since length scale resolution is not ideal.

To make this picture more concrete, it is good to list some examples about paradoxes implied by the naive application of Equivalence Principle identifying the four-momenta defined by the curvature scalar and Kähler action.

1. For the imbeddings of Robertson-Walker cosmologies inertial four-momentum density associated with Kähler action vanishes unlike gravitational four-momentum density, which for a long time remained quite a mystery. The solution of the paradox is that real space-time surface is a deformation of the vacuum extremal representing Robertson-Walker cosmology. The deformation obtained by glueing fermions as CP_2 type vacuum extremals. Also gauge bosons represented as wormhole contacts connecting the space-time surface to a space-time sheet with opposite arrow of geometric time (negative energy state) are present. The gravitational and inertial four-momenta of these particles are equal to the four-momentum density characterized by Einstein tensor. The density of Kähler four-momentum is not visible since it resides in the details which are smoothed out.

2. The empirical fact is that inertial 4-momentum as measurement in laboratory time scales is conserved whereas gravitational momentum is not. Zero energy ontology resolves this paradox. One can speak of positive energy states only in a given length scale characterizing the size of causal diamond (CD). Improved measurement resolution brings visible new zero energy states in shorter time scales. In principle zero energy ontology allows generation of entire galaxies from vacuum so that energy conservation holds true only inside given CD and within measurement resolution associated with it. Hence Robertson-Walker cosmologies in which gravitational four-momentum is not conserved provides a statistical description for how the energy of positive energy state changes. As a matter fact, TGD strongly suggests a hierarchy of Robertson-Walker cosmologies corresponding to p-adic length scale hierarchy and dark matter hierarchy.

3. For cosmic strings of form $X^2 \times Y^2 \subset M^4 \times CP_2$ Einstein's equations hold true but with wrong value of gravitational constant. TGD predicts also a huge variety of string like vacuum extremals of form $X^2 \times Y^2$ metrically. The dimension of M^4 projection is smaller than 4. The gravitational mass of the object -if given by Einstein tensor- depends on the genus of Y^2 and is negative if the genus is larger than 1. Einstein's equations do not make sense in these cases and there is no reason to expect this since the length scale associated with this objects is of order CP_2 length since M^4 projection is not 4-dimensional.

Equivalence Principle at elementary particle level

The following concrete example about interpretation of Equivalence Principle at elementary particle level is included to illustrate how ideas have gradually evolved and also to show that one must still keep mind open.

Topologically condensed CP_2 type vacuum extremals define a model for elementary particle. Their gravitational four-momentum -if defined by Noether current associated with curvature scalar- is non-vanishing, light-like, and non-conserved. For free CP_2 type extremal the inertial four-momentum vanishes since Kähler currents vanish in M^4 degrees of freedom. In topological condensation CP_2 type vacuum extremal is necessarily deformed to a non-vacuum extremal. The induced four-metric becomes degenerate at the light-like wormhole throat(s) in the case of fermions (gauge bosons) since the Euclidian signature of metric is changed to Minkowskian one.

The natural expectation is that the inertial four-momentum associated with topologically condensed CP_2 type vacuum extremal equals to the gravitational four-momentum assignable to CP_2 type extremal. The question was what this gravitational four-momentum means.

1. The Einstein tensor associated with CP_2 type extremal gives rise to a non-conserved light-like four-momentum in the direction of the tangent light-like curve. The identification of gravitational four-momentum in terms of Einstein tensor however leads to difficulties with cosmic strings. For instance, gravitational mass can be negative.

2. The attempt to realize gravitational four-momentum as Noether current in the framework of almost-topological QFT based on Chern-Simons action led also to a difficulty since the four-momentum Noether current associated with $C-S$ action vanishes identically. Same is true for the Noether current associated with the modified Dirac action associated with $C-S$ action.

The proposed solution of the problem was the addition of pure gauge part $A_a = constant$ to the Kähler gauge potential of CP_2, where a refers to the light-cone proper time assignable to CD [B4]. This gives under some conditions constant mass squared but the four-momentum given by Noether current is of course non-conserved and the conserved four-momentum should correspond to average of this four-momentum (option I) or simply the integral over these four-momenta over 2-D sections of X_l^3 (option II). This approach led to a difficulty with the realization of the hierarchy of Planck constants in the most general sense.

3. After the realization that number theoretical compactification implies the slicing of preferred extremal $X^4(X_l^3)$ to light-like 3-surfaces Y_l^3 parallel to X_l^3 and also dual slicings to string worlds sheets Y^2 and partonic 2-surfaces X^2, it became clear that preferred extremals have the property that the slices Y_l^3 behave like independent dynamical units so that 3-dimensional dynamical objects become effectively 2-dimensional [D3, B4]. This made it also clear how to code information about the preferred extremal of Kähler action to the eigenvalue spectrum associated with the modified Dirac operator D_K associated with the Kähler action for the preferred extremal. This spectrum codes also for the conserved charges associated with the preferred extremal so that there is not need to assign the four-momentum to $C-S$ action. One can also assign conserved charges to the modified Dirac action if the first variation of D_K with respect to the imbedding space coordinates vanishes which means that the second variation of Kähler action vanishes. It is actually enough that the second variations representing symmetries giving rise to the conserved charges vanish. This gives a rather precise content for the notion of quantum criticality and for the notion of preferred extremal.

4. In this framework $C-S$ action is replaced with the imaginary part of Kähler action expressible as instanton density proportional to $J \wedge J$. This contribution does not affect Kähler function but gives rise to $C-S$ term at surfaces X_l^3. Modified Dirac operator receives an imaginary contribution from $J \wedge J$, and its spectrum becomes complex so that Dirac determinant can be equal to the exponent of Kähler action multiplied by the exponent imaginary instanton term. This provides a first principle explanation for CP breaking behind matter antimatter asymmetry and CKM mixing as well as anyonization and quantum Hall effect [F12].

5. The discovery of dual slicings of $X^4(X_l^3)$ by stringy world sheets and partonic two-surfaces lead also to the realization that dimensional reduction allows to assign to Kähler action stringy action and Equivalence Principle naturally follows at elementary particle level. In this framework both Kähler coupling strength and gravitational constant emerge as predictions of the theory.

The random light-like motion of partonic 2-surface provides justification for p-adic thermodynamics. The original interpretation was however partially wrong.

1. The random zitterwebegung of CP_2 type vacuum extremal with light velocity allows to understand heuristically the massivation of fermions in terms of p-adic thermodynamics. The first guess was that four-momentum would be simply the average of or sum over the non-conserved four-momenta associated with partonic 2-surface and led to the vision about the role of $C-S$ action. This vision must be given up.

2. p-Adic thermodynamics corresponds to thermodynamics for conformal weight. The basic dynamical object must be therefore 2-dimensional partonic surface. Also Lorentz invariance requires that it is thermal conformal weight which is generated by p-adic thermodynamics and mass squared is proportional to this. Light-like randomness implies the thermalization of conformal weight. Conformal symmetry indeed allows to identify conformal weight as quantum number and the squares of generalized eigenvalues of D_{C-S} have identification as conformal weights. One must of course remember also that it is not at all clear whether the masses as predicted by p-adic thermodynamics are identical with classical masses.

3. The equivalence of mass squared identified as thermal conformal weight with the square of inertial or gravitational momentum remains to be proven rigorously. The understanding of this connection might lead to unexpected progress.

4.2.3 Einstein's equations and second variation of volume element

Lubos Motl had an interesting blog posting about how Jacobsen [42] has derived Einstein's equations from thermodynamical considerations. The argument involves approximate Poincare invariance, Equivalence principle, and proportionality of entropy to area ($dS = kdA$) so that the result is perhaps not a complete surprise.

One starts from an expression for the variation of the area element dA for certain kind of variations in direction of light-like Killing vector field and ends up with Einstein's equations. Ricci tensor creeps in via the variation of dA expressible in terms of the analog of geodesic deviation involving curvature tensor in its expression. Since geodesic equation involves first variation of metric, the equation of geodesic deviation involves its second variation expressible in terms of curvature tensor.

The result raises the question whether it makes sense to quantize Einstein Hilbert action and in light of quantum TGD the worry is justified. In TGD (and also in string models) Einstein's equations result in long length scale approximation whereas in short length scales stringy description provides the space-time correlate for Equivalence Principle. In fact in TGD framework Equivalence Principle at fundamental level reduces to a coset construction for two super-conformal algebras: super-symplectic and super Kac-Moody. The four-momenta associated with these algebras correspond to inertial and gravitational four-momenta.

In the following I will consider different -more than 10 year old - argument implying that empty space vacuum equations state the vanishing of first and second variation of the volume element in freely falling coordinate system and will show how the argument implies empty space vacuum equations in the "world of classical worlds". I also show that empty space Einstein equations at space-time level allow interpretation in terms of criticality of volume element - perhaps serving as a correlate for vacuum criticality of TGD Universe. I also demonstrate how one can derive non-empty space Einstein equations in TGD Universe and consider the interpretation.

Vacuum Einstein's equations from the vanishing of the second variation of volume element in freely falling frame

The argument of Jacobsen leads to interesting considerations related to the second variation of the metric given in terms of Ricci tensor. In TGD framework the challenge is to deduce a good argument for why Einstein's equations hold true in long length scales and reading the posting of Lubos led to an idea how one might understand the content of these equations geometrically.

1. The first variation of the metric determinant gives rise to

$$\delta\sqrt{g} = \partial_\mu\sqrt{g}dx^\mu \propto \sqrt{g}\left(\begin{array}{c}\rho \\ \rho\ \mu\end{array}\right)dx^\mu .$$

   The possibility to find coordinates for which this variation vanishes at given point of space-time realizes Equivalence Principle locally.

2. Second variation of the metric determinant gives rise to the quantity

$$\delta^2\sqrt{g} = \partial_\mu\partial_\nu\sqrt{g}dx^\mu dx^\nu = \sqrt{g}R_{\mu\nu}dx^\mu dx^\nu .$$

   The vanishing of the second variation gives Einstein's equations in empty space. Einstein's empty space equations state that the second variation of the metric determinant vanishes in freely moving frame. The 4-volume element is critical in this frame.

The world of classical worlds satisfies vacuum Einstein equations

In quantum TGD this observation about second variation of metric led for two decades ago to Einstein's vacuum equations for the Kähler metric for the space of light-like 3-surfaces ("world of classical worlds"), which is deduced to be a union of constant curvature spaces labeled by zero modes of the metric. The argument is very simple. The functional integration over configuration space degrees of freedom (union of constant curvature spaces a priori: $R_{ij} = kg_{ij}$) involves second variation of the metric determinant. The functional integral over small deformations of 3-surface involves also second variation of the volume element $\sqrt{g}$. The propagator for small deformations around 3-surface is contravariant metric for Kähler metric and is contracted with $R_{ij} = \lambda g_{ij}$ to give the infinite-dimensional trace $g^{ij}R_{ij} = \lambda D = \lambda \times \infty$. The result is infinite unless $R_{ij} = 0$ holds. Vacuum Einstein's equations must therefore hold true in the world of classical worlds.

Non-vacuum Einstein's equations: light-like projection of four-momentum projection is proportional to second variation of four-volume in that direction

An interesting question is whether Einstein's equations in non-empty space-time could be obtained by generalizing this argument. The question is what interpretation one should give to the quantity

$$\sqrt{g_4}T_{\mu\nu}dx^\mu dx^\nu$$

at a given point of space-time.

1. If one restricts the consideration to variations for which dx^μ is of form $k^\mu\epsilon$, where k is light-like vector, one obtains a situation similar to used by Jacobsen in his argument. In this case one can consider the component dP_k of four-momentum in direction of k associated with 3-dimensional coordinate volume element $dV_3 = d^3x$. It is given by

$$dP_k = \sqrt{g_4}T_{\mu\nu}k^\mu k^\nu dV_3 .$$

2. Assume that dP_k is proportional to the second variation of the volume element in the deformation $dx^\mu = \epsilon k^\mu$, which means pushing of the volume element in the direction of k in second order approximation:

$$\frac{d^2\sqrt{g_4}}{d\epsilon^2}\sqrt{g_4}dV_3 = \frac{d^2\sqrt{g_4}}{\partial x^\mu \partial x^\nu}k^\mu k^\nu\sqrt{g_4}dV_3 = \sqrt{g_4}R_{\mu\nu}k^\mu k^\nu dV_3 .$$

   By light-likeness of k^μ one can replace $R_{\mu\nu}$ by $G_{\mu\nu}$ and add also $g_{\mu\nu}$ for light-like vector k^μ to obtained covariant conservation of four-momentum. Einstein's equations with cosmological term are obtained.

That light-like vectors play a key role in these arguments is interesting from TGD point of view since light-like 3-surfaces are fundamental objects of TGD Universe.

The interpretation of non-vacuum Einstein's equations as breaking of maximal quantum criticality in TGD framework

What could be the interpretation of the result in TGD framework.

1. In TGD one assigns to the small deformations of vacuum extremals average four-momentum densities (over ensemble of small deformations), which satisfy Einstein's equations. It looks rather natural to assume that statistical quantities are expressible in terms of the purely geometric gravitational energy momentum tensor of vacuum extremal (which as such is not physical). The question why the projections of four-momentum to light-like directions should be proportional to the second variation of 4-D metric determinant.

2. A possible explanation is the quantum criticality of quantum TGD. For induced spinor fields the modified Dirac equation gives rise to conserved Noether currents only if the second variation of Kähler action vanishes. The reason is that the modified gamma matrices are contractions of the first variation of Kähler action with ordinary gamma matrices.

3. A weaker condition is that the vanishing occurs only for a subset of deformations representing dynamical symmetries. This would give rise to an infinite hierarchy of increasingly critical systems and generalization of Thom's catastrophe theory would result. The simplest system would live at the V shaped graph of cusp catastrophe: just at the verge of phase transition between the two phases.

4. Vacuum extremals are maximally quantum critical since both the first and second variation of Kähler action vanishes identically. For the small deformations second variation could be non-vanishing and probably is. Could it be that vacuum Einstein equations would give gravitational correlate of the quantum criticality as the criticality of the four-volume element in the local freely falling frame. Non-vacuum Einstein equations would characterize the reduction of the criticality due to the presence of matter implying also the breaking of dynamical symmetries (symplectic transformations of CP_2 and diffeomorphisms of M^4 for vacuum extremals).

4.2.4 Various interpretations of Machian Principle in TGD framework

TGD allows several interpretations of Machian Principle and leads also to a generalization of the Principle.

1. Machian Principle is true in the sense that the notion of completely free particle is non-sensible. Free CP_2 type extremal (having random light-like curve as M^4 projection) is a pure vacuum extremal and only its topological condensation creates a wormhole throat (two of them) in the case of fermion (boson). Topological condensation to space-time sheet(s) generates all quantum numbers, not only mass. Both thermal massivation and massivation via the generation of coherent state of Higgs type wormhole contacts are due to topological condensation.

2. Machian Principle has also interpretation in terms of p-adic physics [E1]. Most points of p-adic space-time sheets have infinite distance from the tip light-cone in the real sense. The discrete algebraic intersection of the p-adic space-time sheet with the real space-time sheet gives rise to effective p-adicity of the topology of the real space-time sheet if the number of these points is large enough. Hence p-adic thermodynamics with given p also assigned to the partonic 3-surface by the modified Dirac operator makes sense. The continuity and smoothness of the dynamics corresponds to the p-adic fractality and long range correlations for the real dynamics and allows to apply p-adic thermodynamics in the real context. p-Adic variant of Machian Principle says that p-adic dynamics of cognition and intentionality in literally infinite scale in the real sense dictates the values of masses among other things.

3. A further interpretation of Machian Principle is in terms of number theoretic Brahman=Atman identity or equivalently, Algebraic Holography [E3]. This principle states that the number theoretic structure of the space-time point is so rich due to the presence of infinite hierarchy of real units obtained as ratios of infinite integers that single space-time point can represent the entire world of classical worlds. This could be generalized also to a criterion for a good mathematics: only those mathematical structures which are representable in the set of real units associated with the coordinates of single space-time point are really fundamental.

4.3 Imbedding of the Reissner-Nordström metric

In the following the imbedding of electromagnetically neutral Reissner-Nordström metric to $M^4_+ \times CP_2$ will be studied. The imbedding generalizes to an imbedding of any spherically symmetric metric. The imbeddings as vacuum extremals reduce to imbeddings into 6-dimensional $M^4 \times Y^2$, Y^2 Lagrange manifold (vanishing induced Kähler form). Any vacuum extremal defines a solution of Einstein's equations if energy momentum tensor is defined by Einstein's equations. Non-vacuum imbeddings of Reissner-Nordström solutions would correspond to homologically non-trivial geodesic sphere of CP_2, and it is implausible that non-vacuum imbeddings could be extremals. Whether the imbeddings of the metrics believed to describe rotating objects in GRT Universe are possible at all, is not known but it might well be that the dimension of the imbedding space is too low to allow them. This would mean that the predictions of TGD concerning gravi-magnetism can differ from those of GRT.

4.3.1 Two basic types of imbeddings

One can construct a large number of imbeddings for Reissner-Nordström metric. These imbeddings need not be extremals of Kähler action except when they are represent vacua.

1. X^4 could be a sub-manifold of $M^4 \times S_i^2$, $i = I, II$, where S_i^2 is one of the geodesic spheres of CP_2. For $i = II$ the imbeddings are vacuum extremals but this is not the case for $i = I$. The properties of these imbeddings are essentially those associated with the spherically symmetric stationary extremals of the Kähler action. Long range electromagnetic and Z^0 fields assignable to dark matter [A1, A2, F6] are present but the corresponding forces are by a factor 10^{-4} weaker than gravitational force, when the parameter ωR is of order one.

2. The vacuum extremals of the Kähler action are the physically most interesting candidates for the imbeddings of solutions of Einstein's equations. For these imbeddings electro-weak fields are in general non-vanishing. Em neutrality is possible to achieve only for $p = sin^2(\theta_W) = 0$. Long ranged W^+ and W^- fields can be present and they induce a small mixing between charged dark lepton and corresponding neutrino spinors.

4.3.2 The condition guaranteing the vanishing of em, Z^0, or Kähler fields

In order to obtain imbedding with vanishing em, Z^0, or Kähler field, one must pose the condition guaranteing the vanishing of corresponding field (see the Appendix of the book). For extremals of Kähler action em Z^0 fields are always simultaneously present unless Weinberg angle vanishes. In practice only the condition guaranteing vanishing of Kähler field is thus interesting.

Using coordinates $(r, u = cos(\Theta), \Psi, \Phi)$ for CP_2 the surfaces in question can be expressed as

$$\begin{aligned} r &= \sqrt{\frac{X}{1-X}} \ , \\ X &= D|k+u|^{\epsilon} \ , \\ u &\equiv cos(\Theta) \ , \ D = \frac{r_0^2}{1+r_0^2} \times \frac{1}{C} \ , \quad C = |k + cos(\Theta_0)|^{\epsilon} \ . \end{aligned} \tag{4.3.1}$$

Here C and D are integration constants. The value of the parameter ϵ characterizes which field vanishes:

$$\begin{aligned} a) \ \epsilon = \tfrac{3+p}{3+2p} \ , \ b) \ \epsilon = \tfrac{1}{2} \ , \ c) \ \epsilon = 1 \ , \\ p = sin^2(\Theta_W) \ . \end{aligned} \tag{4.3.2}$$

Here a/b/c corresponds to the vanishing of em/Z^0/Kähler field.

$0 \leq X \leq 1$ is required by the reality of r. $r = 0$ would correspond to $X = 0$ giving $u = -k$ achieved only for $|k| \leq 1$ and $r = \infty$ to $X = 1$ giving $|u + k| = [(1 + r_0^2)/r_0^2)]^{\epsilon}$ achieved only for

$$sign(u+k) \times [\frac{1+r_0^2}{r_0^2}]^{\epsilon} \leq k+1 \ ,$$

where $sign(x)$ denotes the sign of x.

These imbeddings obviously possess a 2-dimensional CP_2 projection. The generation of long range vacuum weak and color electric fields is a purely TGD based phenomenon related to the fact that gauge fields are not primary dynamical variables.

For future purposes it is convenient to list the explicit expressions of relevant gauge field when em or Kähler field vanishes.

1. Using coordinates $(u = cos(\Theta), \Phi)$ the expressions for the Kähler form and Z^0 field for space-time surfaces with vanishing em field read as

$$\begin{aligned} J &= -\frac{p}{3+2p} X du \wedge d\Phi \ , \ X = D|k+u|^{\frac{3+p}{3+2p}} \\ Z^0 &= -\frac{6}{p} J \ . \end{aligned} \tag{4.3.3}$$

2. For vacuum extremals ($\epsilon = 1$) classical em and Z^0 fields are proportional to each other:

$$\begin{aligned}
Z^0 &= 2e^0 \wedge e^3 = \frac{r}{F^2}(k+u)\frac{\partial r}{\partial u} du \wedge d\Phi = (k+u) du \wedge d\Phi \ , \\
r &= \sqrt{\frac{X}{1-X}} \ , \quad X = D|k+u| \ , \\
\gamma &= -\frac{p}{2} Z^0 \ . \qquad (4.3.4)
\end{aligned}$$

For a vanishing value of Weinberg angle ($p = 0$) em field vanishes and only Z^0 field remains as a long range gauge field. Vacuum extremals for which long range Z^0 field vanishes but em field is non-vanishing are not possible. The only reasonable physical interpretation seems to be in terms of a hierarchy of electro-weak physics with arbitrarily light weak boson mass scales.

The effective form of the CP_2 metric is given by

$$\begin{aligned}
ds^2_{eff} &= (s_{rr}(\frac{dr}{d\Theta})^2 + s_{\Theta\Theta})d\Theta^2 + (s_{\Phi\Phi} + 2ks_{\Phi\Psi})d\Phi^2 = \frac{R^2}{4}[s^{eff}_{\Theta\Theta} d\Theta^2 + s^{eff}_{\Phi\Phi} d\Phi^2] \ , \\
s^{eff}_{\Theta\Theta} &= X \times \left[\frac{\epsilon^2(1-u^2)}{(k+u)^2} \times \frac{1}{1-X} + 1 - X \right] \ , \\
s^{eff}_{\Phi\Phi} &= X \times \left[(1-X)(k+u)^2 + 1 - u^2 \right] \ . \qquad (4.3.5)
\end{aligned}$$

This expression is useful in the construction of electromagnetically neutral imbedding of, say Schwartchild metric. For $k \neq 1$ $u = \pm 1$ corresponds in general to circle rather than single point as is clear from the fact that $s^{eff}_{\Phi\Phi}$ is non-vanishing at $u = \pm 1$ so that u and Φ parameterize a piece of cylinder.

4.3.3 Imbedding of Reissner-Nordström metric

The imbedding of R-N metric to be discussed generalizes with minor modifications to an imbedding of a spherically symmetric star model characterized by a mass density $\rho(r_M)$ and pressure $p(r_M)$ since the corresponding line element can be written in the form $ds^2 = A(r_M)dt^2 - B(r_M)dr_M^2 - r_M^2 d\Omega^2$ [21]. For vacuum extremal a solution of field equations results.

Denote the coordinates of M^4_+ by (m^0, r_M, θ, ϕ) and those of X^4 by (t, r_M, θ, ϕ). The expression for Reissner-Nordström metric reads as

$$\begin{aligned}
ds^2 &= Adt^2 - Bdr_M^2 - r_M^2 d\Omega^2 \ , \\
A &= 1 - \frac{a}{r_M} - \frac{b}{r_M^2} \ , \quad B = \frac{1}{A} \ , \\
a &= 2GM \ , \quad b = G\pi q^2 \ . \qquad (4.3.6)
\end{aligned}$$

The imbedding is given by the expression

$$\begin{aligned}
\Phi &= \omega_1 t + f(r_M) \ , \\
\Psi &= k\Phi = \omega_2 t + kf(r_M) \ , \\
m^0 &= \lambda t + h(r_M) \ , \\
\lambda &= \sqrt{1 + \frac{R^2\omega_1^2}{4} s^{eff}_{\Phi\Phi}(\infty)} \ , \quad k = \frac{\omega_2}{\omega_1} \ . \qquad (4.3.7)
\end{aligned}$$

The components of s^{eff} are given by Eq. 6.2.13 and general form of imbedding by Eqs. 6.2.12 and 4.3.2.

The functions $f(r_M)$ and $h(r_M)$ are determined by the condition

$$\lambda \partial_{r_M} h = \frac{R^2}{4} s^{eff}_{\Phi\Phi} \omega_1 \partial_{r_M} f \tag{4.3.8}$$

resulting from the requirement $g_{tr_M} = 0$ and from the expression for $g_{r_M r_M} = -B$:

$$\begin{aligned} h &= \int dr_M \sqrt{Y} \ , \ Y = \frac{Y_1}{Y_2} \ , \\ Y_1 &= -B + 1 + \frac{R^2}{4} s^{eff}_{\Theta\Theta} \frac{(\partial_{r_M} u)^2}{(1-u^2)} \ , \\ Y_2 &= 1 - \frac{4\lambda^2}{R^2\omega_1^2} \frac{s^{eff}_{\Theta\Theta}}{s^{eff}_{\Phi\Phi}} \ . \end{aligned} \tag{4.3.9}$$

The condition $Y > 0$ at the limit $r \to \infty$ gives non-trivial conditions. Y_1 is positive at large values of r_M and this gives

$$Y_1 = -B + 1 + s^{eff}_{\Theta\Theta} \frac{(\partial_{r_M} u)^2}{(1-u^2)} \geq 0$$

for the allowed values of r_M. Y_1 can change sign at some critical radius above Schwartschild radius $r_S = 2GM$ since B becomes infinite at r_S: this can be avoided only provided one has $u \to 1$ at $r_M \to r_S$. Y_2 must preserve its sign and this is possible if the value of $R\omega_1$ is sufficiently large. Below $r = r_S$ Y_1 has positive and also Y_2 can be positive down to some critical radius. At $r = r_S$ Y_1 has infinite discontinuity in case that Y_1 approaches finite value from above and CP_2 coordinates are continuous. It is easy to see that square root singularity of Θ as a function of $r_M - r_S$ is in question so that the function h is continuous so that the solution is well-defined.

The dependence of $u \equiv cos(\Theta)$ on radial coordinate r_M is determined by the expression for $g_{tt} = A$ giving the condition

$$A = \lambda^2 - \frac{R^2\omega_1^2}{4} s^{eff}_{\Phi\Phi} \omega_1^2 \ . \tag{4.3.10}$$

The asymptotic behavior of the coordinate $u = cos(\Theta)$ is of form

$$u \simeq u_\infty + \frac{K}{r_M} \ , \tag{4.3.11}$$

u_∞ is fixed by the condition $A(\infty) = 1$:

$$\begin{aligned} \lambda^2 &- \frac{R^2\omega_1^2}{4} s^{eff}_{\Phi\Phi}(\infty) = 1 \ , \\ s^{eff}_{\Phi\Phi} &= X \times \left[(1-X)(k+u)^2 + 1 - u^2\right] \ , \ X = D|k+u|^\epsilon \ . \end{aligned} \tag{4.3.12}$$

The value of K is given by

$$K = \frac{8GM}{R^2\omega_1^2} \left[\frac{\partial s^{eff}_{\Phi\Phi}}{\partial u}(\infty)\right]^{-1} \ . \tag{4.3.13}$$

The values of K and u_∞ depend on parameters $\lambda, R\omega_1, k, D$.

For definiteness one can assume that the value of u at infinity is non-negative:

$$u_\infty \geq 0 \ . \tag{4.3.14}$$

There are two different solution types depending on the sign of the parameter K.

1. For $K < 0$ u decreases and approaches to $u_{min} \geq 0$ as r_M decreases.

2. For $K > 0$ u increases and approaches to $u_{max} \leq 1$. The requirement that the solution can be continued below Schwartshild radius allows only this option. Below Schwartshild radius u must transform to a solution of type a).

Imbeddability breaks for a critical value of the radial coordinate

The imbeddability breaks for some critical value of the coordinate r_M. The extremal value of u and the radius r_c below which the imbedding fails corresponds to the maximum possible value of $s^{eff}_{\Phi\Phi}$. This value corresponds either to $u = 0, 1$ or to a vanishing derivative of $s^{eff}_{\Phi\Phi}$

$$\frac{\partial s^{eff}_{\Phi\Phi}}{\partial u} = 0 \quad . \tag{4.3.15}$$

For $\epsilon = 1$ corresponding to vacuum extremals s_{eff} is a fourth order polynomial as a function of u depending on external parameters. One has

$$s^{eff}_{\Phi\Phi} = D|k+u| \times \left[(1 - D|k+u|)(k+u)^2 + 1 - u^2\right] \quad . \tag{4.3.16}$$

s_{eff} becomes negative for very large values of u. Hence a restriction of the standard form of the dual of the cusp catastrophe to the range $u \in (0, 1)$ results. Depending on the values of external parameters there are either 2 maxima or single maximum. For $k = 1$ the positive extremum correspond to $u = 1/|D|$.

In the case of the Schwartshild metric this gives for the critical radius the expression

$$\begin{aligned} r_c &= \frac{r_S}{\delta} \ , \\ \delta &= 1 - \lambda^2 + \frac{R^2\omega_1^2}{4} s^{eff}_{\Phi\Phi}(max) \ , \\ r_S &= 2GM \ . \end{aligned} \tag{4.3.17}$$

The existing evidence for black hole like objects suggests that it would be better to have $\delta >> 1$ in order to get imbeddings of the Schwartschild metric containing also horizon and part of the interior region. A sufficiently large value of $R\omega_1$ indeed allows to have arbitrarily small value of r_c. There the experimental evidence for the existence of black hole like objects leads to no problems.

The vacuum extremal imbeddings of Schwartschild metric possess electro-weak charges

The vacuum imbeddings of Reissner-Nodrström and Scwartshild metric necessarily possess some non-vanishing electro-weak charges. Consider first vacuum extremals. Z^0 electric field Z^0_{tr} is proportional to ω_1

$$Z^0_{tr_M} = \omega_1(k+u)\partial_{r_M} u \quad . \tag{4.3.18}$$

The gauge flux through a sphere with radius r_M depends on r_M so that Z^0 vacuum charge density is necessarily present.

The condition $\theta \propto \sqrt{r - r_S}$ allowing to continue the imbedding below $r_M < r_S$ implies that gauge fluxes, which are proportional to $sin(\Theta)\partial_{r_M}\Theta$, are finite at $r = r_S$ so that the renormalizations of gauge couplings remain finite at least down to Schwartschild radius.

At large distances the gauge flux approaches to

$$\begin{aligned} Q_Z(\infty) &= \frac{1}{g_Z}\int_{r_M\rightarrow\infty} Z^0_{tr_M} r_M^2 d\Omega \ , \\ &= \frac{4\pi}{g_Z}\omega_1(k+u_\infty)K = \frac{4\pi}{g_Z}(k+u_\infty)\frac{8GM}{R^2\omega_1}\left[\frac{\partial s^{eff}_{\Phi\Phi}}{\partial u}(\infty)\right]^{-1} \end{aligned} \tag{4.3.19}$$

at the limit $r_M \rightarrow \infty$. Z^0 charge is proportional to the gravitational mass. The gauge flux grows at small distances in accordance with the general wisdom about the coupling constant evolution of $U(1)$ gauge field.

The requirement that Z^0 force is weaker than gravitational force expressed as the condition

$$\frac{Q_Z^2}{GM^2} \ll 1$$

implies

$$\frac{32\pi}{R\omega_1 g_Z}(k+u_\infty)\left[\frac{\partial s^{eff}_{\Phi\Phi}}{\partial u}(\infty)\right]^{-1} \ll \frac{R}{\sqrt{G}} \ . \tag{4.3.20}$$

It seems that a sufficiently large value of $R\omega_1$ allows arbitrarily small values for both the Z^0 charge and the critical radius r_c. In the earliest scenario, which was based on the assumption that CP_2 radius is of order Planck length the situation was different. It is clear that the larger radius of CP_2 makes it possible to avoid too strong classical electro-weak forces.

The non-extremal imbedding to S^2_I studied in detail here is Kähler charged and therefore also Z^0 charged since the condition $Z^0 = 6J/p$ holds true by electromagnetic neutrality. The value of the Kähler charge for non-vacuum imbedding depends on the distance from the origin

$$\begin{aligned} Q_K(r_M) &= \frac{1}{g_K}\int_{r_M=const} J_{tr_M} r_M^2 d\Omega \ , \\ J_{tr_M} &= -\frac{p}{2(3+p)}\omega_1|k+u|^{\frac{3+p}{3+2p}}\partial_{r_M}u \ , \end{aligned} \tag{4.3.21}$$

The expression for the charge differs only in minor details from that for Z^0 charge for vacuum extremals. Essentially similar conclusions about the behavior of the gauge charges hold true also in the case of vacuum extremals and the expressions differ only by the value of the parameter ϵ characterizing whether em, Z^0, of Kähler field vanishes.

Equivalence Principle and critical radius

When one considers Equivalence Principle, one must keep in mind that the Kähler charged imbeddings of Reissner Nodström and Scwartschild metrics are *not* extremals of Kähler action.

1. Equivalence Principle and imbeddings as vacuum extremals

In the case of vacuum extremals the interpretation is that net inertial energy density of the space-time outside the topologically condensed space-time sheet representing charged system is vanishing but the density of gravitational energy is non-vanishing and non-conserved in general. The gravitational mass of the topologically condensed space-time sheet however consists of both inertial and purely gravitational contribution. For RN solution it is natural to interpret the gravitational mass as the gravitational energy of the classical gauge fields. For genuine RN case the densities of inertial color gauge charges vanish but those for gravitational color gauge charges in $SO(3) \subset SU(3)$ are in general non-vanishing. Schwartschild metric possesses necessarily a vacuum densities of some electro-weak gauge charges but the contribution to the gravitational energy momentum tensor vanishes.

2. Equivalence Principle and imbeddings as non-vacuum extremals

One can consider Equivalence Principle in the case of Kähler charged imbeddings only if one believes that the imbedding is in a reasonable approximation an extremal. Equivalence Principle requires that the Kähler mass of the solution should be smaller than its gravitational mass. This does not pose any conditions on the critical radius since the density of Kähler charge can change sign inside the critical radius (meaning that antimatter dominates inside the critical radius). Thus no constraints results.

The strongest form of Equivalence Principle would require that the Kähler mass of the solution equals to its gravitational mass. It is difficult to see how this could be implied by any deep principle. This requirement poses a lower limit to the critical radius since the Kähler energy outside the critical radius should be smaller than the gravitational mass of the system. In the lowest order approximation this energy is given by the expression

$$\begin{aligned} \frac{E_K}{M} &= \frac{1}{8\pi\alpha_K M}\int_{r_M\geq r_c}\lambda E_K^2 dV \\ &= \frac{\lambda Q_K^2}{GM^2}\frac{r_S}{r_c} \ . \end{aligned} \tag{4.3.22}$$

The requirement that electro-weak interactions are much weak than gravitational interaction imply the condition $Q_K^2/GM^2 \ll 1$ so that the ratio can be equal to 1 as Equivalence Principle requires only if $r_S/r_c \gg 1$ holds true.

Gravitational energy is not conserved for vacuum imbedding of Reissner-Nordström metric

The inertial energy associated with Kähler action inside a ball of given radius is not conserved for Reissner-Nordström metric imbedded as a non-vacuum extremal since extremal of Kähler action is not in question. This follows from the dependence $m^0 = \lambda t + h(r_M)$ implying that energy current has a radial component and from the non-vanishing of $T^{r_M r_M}$. The non-conservation is not due to the outflow of energy but due to the fact that in the case of Kähler charged imbedding field equations are not satisfied. The basic reason is that the contraction of the energy momentum tensor with the second fundamental form is non-vanishing.

For vacuum extremals it is gravitational energy which fails to be conserved. For instance, for the imbedding of Reissner-Nordström this happens. Only at the limit of Schwartshild metric gravitational energy is conserved. The vacuum extremals which are extremals of Einstein-Hilbert action for the induced metric conserve gravitational four momenta and color charges and are excellent candidates for models of the asymptotic state of star.

The simplest interpretation for the non-conservation of gravitational energy without losing Equivalence Principle is in terms of zero energy ontology. In zero energy ontology the extremals of curvature scalar have interpretation in terms of infinitely long time scale associated with the causal diamond.

The non-stationarity of the vacuum extremal imbedding ($m^0 = \lambda t + h(r_M)$) of R-N metric leads to the following expression for the rate of the change of gravitational energy per time inside a sphere of radius r

$$\begin{aligned} \frac{dE_{vap}/dt}{E(r_M)} &= \frac{dE(r_M)/dt}{E(r_M)} + X \ , \\ X &= \frac{\int T^{r_M r_M}\partial_{r_M} m^0\sqrt{g}d\Omega}{E(r_M)} \ , \\ E(r_M) &= \int T^{tt}\partial_0 m^0\sqrt{g}dV \ . \end{aligned} \tag{4.3.23}$$

The latter term depending on $T^{r_M r_M}$ takes into account the flow of gravitational energy through boundaries of the sphere and is in general non-vanishing for Reissner-Nordström metric.

Since the proposed solution ansatz works also in the more general case of a stationary spherically symmetric star model, characterized by the pressure $p(r_M)$ and the energy density $\rho(r_M)$, one can write a general order of magnitude estimate for the gravitational energy transfer associated with the boundary of the sphere approximating $h(r_M)$ with the corresponding function for the Schwartshild metric for large values of r_M as

$$X \simeq -\partial_{r_M} h(r_M)\frac{4\pi p r_M^2}{M} . \qquad (4.3.24)$$

The explicit expression for $\partial_{r_M} h(r_M)$ is given by

$$\begin{aligned}
\partial_{r_M} h(r_M) &\simeq \frac{1}{\lambda}\sqrt{\frac{Y_1}{Y_2}} , \\
Y_1 &= -B + 1 + \frac{R^2}{4} s^{eff}_{\Theta\Theta}\frac{(\partial_{r_M} u)^2}{(1-u^2)} , \\
Y_2 &= 1 - \frac{4\lambda^2}{R^2\omega_1^2}\frac{s^{eff}_{\Theta\Theta}}{s^{eff}_{\Phi\Phi}} .
\end{aligned} \qquad (4.3.25)$$

Here B is determined by the Einstein equations defining the star model and can be approximated with its value for Schwartshild metric.

At the surface of the Sun ($r_M \simeq 6\cdot 10^8\ m$, particle density $n \simeq 10^{21}/m^3$, $T \simeq 0.5\ eV$, $M \simeq 10^{57} m_p$ and pressure $p \simeq nT$) the order of magnitude of this term is about $X/E \simeq 2\pi K 10^{-13}/year$. For $K \sim 1$ (obtained if the radius of CP_2 is of order Planck length) the loss would be of the same order of magnitude as the inertial energy loss associated with the solar wind: $K \sim 1/k$, $10^4 < k << 10^8$, however implies that the loss is roughly four orders of magnitudes smaller.

It should be noticed that in the case of matter dominated cosmology shows that the rate for the reduction of the gravitational energy is of the order of $(dE/da)/E \simeq 1/a \simeq 10^{-11}/year$, which is of the same order as the fusion energy production of Sun. Thus it would seem that the rate for the change of gravitational energy in cosmological length scales is same as that for the inertial energy in the solar length scale.

4.4 A model for the final state of the star

As found, the energy production by fusion inside stars is of the same order of magnitude as the rate of change for the gravitational energy associated with the recent matter dominated cosmology. Since no energy is produced in the final state of the star, the stationary solutions provide a natural model for the final state of the star.

Besides stationarity, there is also a second new element, namely color and electro-weak long ranged forces coupling to the dark matter. For instance, for Kähler charged extremals one necessary has classical Z^0 force even when classical em force can vanish. For Schwartshild solution this force becomes very strong at small values of the radial distance. Therefore the presence of the Z^0 force, and presumably also other classical electro-weak forces, are expected play crucial role in the dynamics of the compact objects. The most plausible physical interpretation is in terms of dark matter.

The topics to be discussed in the following are:

1. Spherically symmetric stationary model for the final state of the star. It is found that the model cannot be completely realistic since the stationarity assumption fails at the origin and at the surface of the star.

2. Generalization of the model to what could be called dynamo model in order to achieve stationarity.

3. The possible consequences of long range weak and color forces associated with dark matter, in particular the Z^0 force, concerning the dynamics of the compact objects.

The original discussion was based on a different view about energy and motivated the study of Kähler charged solutions with the stationarity property. These 4-surfaces are *not* extremals of the Kähler action. The replacement of the stationary solutions with vacuum extremals requires however only the replacement of the geodesic sphere S^2_I with S^2_{II} implying that both em and Z^0 fields are unavoidably present (or even $W^{\pm}$ fields, depending on vacuum extremal). A serious limitation of the model is that it is single-sheeted. Indeed, the fact that the rotation axis and magnetic axis of super novae are different can be seen as a signal of many-sheeted-ness: the dominantly em and Z^0 fields would reside at different space-time sheets and would correspond to ordinary and dark matter. Of course, entire hierarchy of space-time sheets are expected to be present.

4.4.1 Spherically symmetric model

The simplest model for the final state of the star that one can imagine is obtained by assuming time translation invariance plus spherical symmetry and imbeddability to $M^4 \times S^2_i$, where S^2_i, $i = I, II$ is the geodesic sphere of CP_2. For the homologically non-trivial sphere S^2_I the solution is *not* an extremal whereas S^2_{II} gives an extremal with a vanishing density of inertial energy. In the original discussion cosmological constant was assumed to vanish. There are excellent reasons to assume that this constant is so small that it does not have any appreciable effects in the scale of the star and can thus be neglected. The nice feature of this kind of model is that symmetry assumptions plus stationarity requirement fix almost completely the model: no assumptions about the equation of state for the matter inside the star are needed.

The solution ansatz giving rise to vacuum extremal corresponds to a surface $X^4 \subset M^4_+ \times S^2_{II}$, where S^2_{II} is the homologically trivial geodesic sphere of CP_2. The solution ansatz has the same general form as the imbedding of spherically symmetric metric.

$$\begin{aligned}
m^0 &= \lambda t + h(r) \ , \\
\Theta &= \Theta(r) \ , \\
\Phi &= \omega t + k(r) \ .
\end{aligned} \tag{4.4.1}$$

The requirement that g_{tr} vanishes, implies a relationship between the functions $h(r)$ and $k(r)$. One might think that the simplest model is obtained, when the functions $h(r)$ and $k(r)$ vanish identically. One doesn't however obtain physically acceptable solutions in this manner: this is seen by expressing the g_{rr} component of the metric in terms of the mass function

$$-g_{rr} = 1 + \frac{R^2}{4}(\partial_r\Theta)^2 = \frac{1}{1 - \frac{2GM(r)}{r}} \ .$$

At the radii of order star radius (larger than Schwartshild radius $r_S = 2GM$) the gradient of Θ must be of the order of 1/R and this is inconsistent with the finite range of possible values for Θ.

As already shown the field equations $G^{\alpha\beta} D_\beta \partial_\alpha h^k = 0$ are obtained by varying the integral of the curvature scalar over the space time surface. Field equations reduce to conservation conditions for suitably chosen conserved current: for instance the relevant components of the gravitational 4-momentum and gravitational color currents and express the conservation of gravitational four-momentum current and corresponding color currents.

The expression for the induced metric is given by

$$\begin{aligned}
ds^2 &= Bdt^2 - Adr^2 - r^2 d\Omega^2 \ , \\
B &= \lambda^2 - \frac{R^2\omega^2}{4} sin^2\Theta \ , \\
A &= 1 + \frac{R^2}{4}(\partial_r\Theta)^2 + \frac{R^2}{4} sin^2\Theta (\partial_r k)^2 - (\partial_r h)^2 \ .
\end{aligned} \tag{4.4.2}$$

The vanishing of the g_{tr} component of the metric implies the condition

$$\lambda \partial_r h - \frac{R^2}{4} \sin^2\Theta \omega \partial_r k = 0 \ . \tag{4.4.3}$$

The expressions for the components of Einstein tensor for spherically symmetric stationary metric are given by

$$
\begin{aligned}
G^{rr} &= \frac{1}{A^2}(-\frac{\partial_r B}{Br} + \frac{(A-1)}{r^2}) \ , \\
G^{\theta\theta} &= \frac{1}{r^2}[-\frac{\partial_r^2 B}{2BA} + \frac{1}{2Ar}(\frac{\partial_r A}{A} - \frac{\partial_r B}{B}) \\
&+ \frac{\partial_r B}{4AB}(\frac{\partial_r A}{A} + \frac{\partial_r B}{B}] \ , \\
G^{tt} &= \frac{1}{AB}(-\frac{\partial_r A}{Ar} + \frac{(1-A)}{r^2}) \ .
\end{aligned} \tag{4.4.4}
$$

A solution of the field equations with one-dimensional CP_2 projection and vanishing gauge fields is obtained by specifying the solution ansatz in the following manner

$$
\begin{aligned}
\Theta &= \frac{\pi}{2} \ , \\
h(r) &= hr \ , \\
k(r) &= kr \ .
\end{aligned} \tag{4.4.5}
$$

The requirement that g_{rt} vanishes gives the condition

$$h\lambda = R^2\omega k/4 \ .$$

The functions A and B are in this case just constants. Since A differs from unity, the resulting metric is however non-flat and the non-vanishing components of the Einstein tensor are given by the expressions

$$
\begin{aligned}
G^{tt} &= \frac{(1-A)}{ABr^2} \ , \\
G^{rr} &= -\frac{(1-A)}{A^2r^2} \ .
\end{aligned} \tag{4.4.6}
$$

Field equations can be written as conservation conditions, say for the components of gravitational 4-momentum and the conserved "gravitational" color charges associated with the symmetry $\Phi \rightarrow \Phi + \varepsilon$. Quite generally, "gravitational" isometry currents have only time and radial components and radial component represent radial flow to or from the origin. Since the time component is time independent, the field equations state that radial flow is constant so that radial component of the current must behave as $1/r^2$. This is guaranteed provided the condition

$$\partial_r(G^{rr}\sqrt{g}) = 0 \tag{4.4.7}$$

holds true: this is indeed the case since G^{rr} is proportional to $1/r^2$.

The radial flow of gravitational energy is non-vanishing due to $m^0 = \lambda tt + h(r)$ behavior and given by the expression

$$J^r = \frac{G^{rr}h}{16\pi G} \ .$$

The conservation condition for J^r fails to be satisfied at origin, which acts as a source or a sink for the gravitational energy. Conservation law fails also at the surface of the star.

One can consider several interpretations.

1. Gravitational mass could be genuinely non-conserved at these locations. Dark particles *resp.* antiparticles with positive *resp.* negative energy would be created in the center of star such that the net density of inertial energy remains zero. Positive and negative energy particles would flow along their own space-time sheets to the outer surface and annihilate there so that there would be no net growth of the gravitational mass. The simplest possibility is that # contacts, which correspond to bound states of parton and negative energy antiparton [F6], split to give rise to particles of opposite inertial energy. At the outer surface # contacts fuse together again.

2. Second option assumes the conservation of gravitational four-momentum. At the surface the non-conservation could result from the flow of the gravitational 4-momentum to a larger space-time sheet via join along boundaries bonds. No net flow of inertial energy would be involved since positive and negative energy flows must cancel each other. For example, for a physically acceptable solution the gravitational energy might flow radially from or towards the z-axis, flow to say north pole at the surface of the object and return back along z-axis. Gravitational energy could also flow at origin to a second space-time sheet and return back at the surface of the star.

The (gravitational) mass function of the solution is given by the expression

$$M(r) = \frac{\lambda}{16\pi G}\frac{(A-1)}{AB}\sqrt{AB}r \ . \tag{4.4.8}$$

Mass is positive for Minkowskian metric with $B > 0$ and Euclidian metric but negative for the interior black hole metric ($A < 0, B < 0$). Mass is proportional to the radius of the star and in order to obtain an object with about Schwartshild radius one must assume that the parameter k is of the order of $1/R$.

Concerning the physical interpretation of the $\Theta = \pi/2$ solution following remarks are in order:

1. Various gauge fields vanish since CP_2 projection is actually a geodesic circle. The interpretation is that various gauge charges vanish. Note that one-dimensional CP_2 projection conforms with the similar property of Robertson Walker cosmologies.

2. Both gravitational, color and weak forces vanish inside the star and the motion along radial geodesics takes place with constant velocity. This is consistent with the radial flow of gravitational energy.

3. Solution ansatz allows generalizations. For example, the following modification is stationary with respect to energy: $m^0 = \lambda t,\ \Phi = \omega_1 t + k_1 r,\ \Psi = \omega_2 t + k_2 r,\ u = constant < \infty,\ \Theta = \pi/2$. By choosing the values of the parameters suitably all the field equations are satisfied but stationarity is not achieved.

4. The solution should allow gluing to the Schwartshild metric at $\Theta = \pi/2$. As found, for the imbedding of Schwartshild metric the $\Theta = 0$ correspond to the Schwartchild radius so that $\Theta = \pi/2$ would most naturally correspond to $r_M < r_S$. Since radial gauge fluxes are non-vanishing and finite at Schwartshild radius, they must be non-vanishing $\Theta = \pi/2$ surface too, so that the star would carry surface charges and behave somewhat like a conducting sphere.

4.4.2 Dynamo model

The previous considerations have shown that the spherically symmetric solution is probably not physically realistic as such and it seems also clear that spherical symmetry must be given up and be replaced with a symmetry with respect to rotations around z-axis in order to obtain more realistic solutions. Since realistic stars rotate and have strong magnetic fields it is natural to ask whether rotation and magnetic fields might provide remedy for the pathological features of the solution. The rotation of the gauge charged matter (in "gravitational" sense) indeed creates classical gauge magnetic fields, which become very strong near the surface of the star, where the condition $\Theta \simeq \pi/2$ holds. If matter is approximately gauge neutral in the interior, the gauge fields should vanish to a very good approximation in the interior and the previous solution should be a good approximation to the actual situation. The rotating star could therefore be regarded as a rotating electro-weak conductor. Both Z^0 and em fields are present for a vanishing Kähler field and the ratio of field strengths is $\gamma/Z^0 = -sin^2(\theta_W)/2 \simeq -1/8$ (see Appendix) so that Z^0 field dominates.

The generation of strong em and Z^0 electric and magnetic fields suggests a mechanism guaranteing the stability of the solution: star behaves like a dynamo. For solutions with a 2-dimensional CP_2 projection em and Z^0 electric and magnetic fields are automatically orthogonal. For $\Theta \simeq \pi/2$ they are very strong and dominate over gravitation and centrifugal force. Therefore the stability of the surface region naturally results from the cancellation of the electric and magnetic em and Z^0 forces ($\bar{E} + \bar{v} \times \bar{B} = 0$), which takes place, when the velocity field of the matter is suitably chosen. This condition is completely analogous to the vanishing of Kähler Lorentz 4-force which seems to be a general property of the solutions of field equations [D1] and there are reasons to hope non-vacuum extremals describing rotating star can be found.

Conditions for the vanishing of the induced Kähler field

Although the situation becomes too complicated in order to allow the finding of exact solutions describing rotating star, one can identify some general properties of the solution ansatz describing the rotating configuration with Kähler electric and magnetic fields. In order to study the general properties of the solution ansatz in its most general form the explicit expressions for the line element and Kähler form of CP_2 given by the expression

$$\begin{aligned} ds^2 &= \frac{dr^2}{F^2}+\frac{r^2}{4F^2}(d\Psi+cos(\Theta)d\Phi)^2+\frac{r^2}{4F}(d\Theta^2+sin^2(\Theta)d\Phi^2) \ , \\ J &= \frac{r}{2F^2}dr\wedge(d\Psi+cos(\Theta)d\Phi)+\frac{r^2}{2F}sin\Theta d\Theta\wedge d\Phi \ , \\ F &= 1+r^2 \ , \end{aligned} \tag{4.4.9}$$

0
are needed.

The vanishing of Kähler field is can be guaranteed by the conditions (not the most general ones, symplectic transformations generate new solutions)

$$\begin{aligned} \Phi &= q\Psi \ , \\ \frac{dr}{d\theta} &= -qrF\frac{sin(\theta)}{1+qcos(\theta)} \ . \end{aligned} \tag{4.4.10}$$

Note that this ansatz excludes the case $qcos(\Theta)=-1$ for which only $W^{\pm}$ fields are non-vanishing. For this ansatz the expressions for em and Z^0 fields (see Appendix for general formulas) are

$$\begin{aligned} &\gamma = -sin^2(\Theta_W)R_{03} \ , \qquad Z^0 = 2R_{03} \ , \\ &R_{03} = -qr^2Fsin(\theta)d\Theta\wedge d\Psi \ . \end{aligned} \tag{4.4.11}$$

Here R_{03} denotes a component of spinor curvature.

Topological quantum numbers

The crucial point is that the expansions for the angle coordinates Φ and Ψ using spherical coordinates contain linear terms in $t,\ r$ and ϕ

$$\begin{aligned} \Phi &= n_1\phi+\omega_1 t+k_1 \ , \\ \Psi &= n_2\phi+\omega_2 t+k_2 \ . \end{aligned} \tag{4.4.12}$$

The functions k_1 and k_2 corresponds to Fourier expansion in terms of the plane waves $exp(in\phi)$ with coefficients depending on the coordinates (t,r,θ).

The terms depending linearly on ϕ imply a nontrivial topological structure for the gauge fields not present for the ordinary Maxwell fields. What happens is that space-time divides into regions, which correspond to different values of the topological quantum numbers (n_1,n_2). In the boundaries of these regions the values of the coordinates u and Θ must be such that different values of Φ and Ψ correspond to same point of CP_2. From the expression of the line element one finds that for Ψ the point $u=0$ and the sphere $u=\infty$ corresponds to these kinds of points. For Φ the surfaces $u=0$ and $u=\infty,\ \Theta=0$ correspond to these kinds of surfaces. The form of Φ and Ψ implies that both electric and magnetic gauge fields are nontrivial and rather closely related as is clear from the expression for the Kähler form. Therefore the non-triviality of the winding numbers n_1 and n_2 is what seems to be the crucial, purely TGD based feature of rotating gauge field structures.

Stationary, axially symmetric ansatz with a non-vanishing Kähler field

To make the discussion more concrete, let us assume that the induced metric is invariant with respect to rotations around z-axis and time translations. This is achieved if CP_2 coordinates (apart from linear dependence on ϕ) depend on the coordinates r_M and θ only.

$$\begin{aligned} r &= r(r_M,\theta) \\ \Theta &= \Theta(r_M,\theta) \ , \\ k_i &= k_i(r_M,\theta) \ , \quad i=1,2 \ . \end{aligned} \tag{4.4.13}$$

This kind of ansatz is clearly consistent: field equations reduce to four equations since second fundamental form is orthogonal to the four-surface and there are four free functions of r and θ: one has effectively two dimensional field theory. Since the general solution ansatz for field equations relies on the vanishing of the Lorentz Kähler force central for the dynamo mechanism, it is of interest to study the general properties of the solution ansatz with a non-vanishing Kähler field. This ansatz can give as special cases space-time sheets carrying Z^0 and em fields with magnetic fields having different rotation axis.

In order to further simplify the discussion let us assume that X^4 corresponds to a sub-manifold of $M^4\times S^2_I$. For instance, the ansatz

$$\begin{aligned} r &= \infty \ , \\ \Theta &= \Theta(r_M,\theta) \ , \\ \Phi &= n\phi+\omega t+k(r_M,\theta) \ . \end{aligned} \tag{4.4.14}$$

is consistent with this assumption. A simpler ansatz is obtained by assuming $k(r_M,\theta)=0$. This ansatz has the following properties.

1. Induced Kähler (and Z^0-) electric and magnetic fields are automatically orthogonal since CP_2 projection is two-dimensional. In fact, the orthogonality holds to an excellent approximation also for the values of u different but near to $u=\infty$ since the resulting additional components of the Kähler field are extremely small. Kähler electric and magnetic fields are given by

$$\begin{aligned} E_{r_M} &= J_{r_M t} = -\partial_{r_M} cos(\Theta)\omega/2 \ , \\ E_\theta &= -\partial_\theta cos(\Theta)\omega/2 \ , \\ B_\theta &= -\partial_{r_M} cos(\Theta)n/2 \ , \\ B_{r_M} &= -\partial_\theta cos(\Theta)n/2 \ . \end{aligned} \tag{4.4.15}$$

The field strengths are related by

$$\begin{aligned} E &= vB \ , \\ v &= \frac{\omega}{n}\sqrt{-\frac{g_{\phi\phi}}{g_{tt}}} \simeq \frac{\omega}{n}\rho \ , \end{aligned} \tag{4.4.16}$$

where ρ denotes radial distance from the rotation axis. v can be interpreted as a velocity type parameter. The requirement that $v<1$ gives a lower bound for the value of n: $n>\omega r_0$, where r_0 denotes the radius of the star: the condition implies that n must be larger than the mass of the star using Planck mass as unit. Somewhat counter intuitively, small rotation velocities seem to correspond to large values of n.

2. Kähler electric and magnetic fields indeed provide a possible mechanism guaranteing the stability of the star at the surface, where Z^0 forces dominate over gravitation and centrifugal force. Star behaves like a dynamo: matter rotates with a velocity guaranteing the vanishing of the Z^0 force. It should be noticed that no upper bound for the rotation velocity except that resulting from causality is obtained ($\Omega < 1/r_0$). Therefore this mechanism might explain the observed very large rotation velocities (for instance in Super Nova SN1987A), which are hard to understand in GRT based models [24].

3. The ansatz indeed describes a rotating object. First, the dynamo mechanism for the stability necessitates the presence of rotation and determines rotation velocity also. Secondly, the presence of Kähler magnetic field can be understood as being created by the rotation of gauge charges. Thirdly, the $g_{t\phi}$ component of the induced metric and therefore the angular momentum density $J_z^t \propto G^{t\phi}r^2sin^2\theta$ is non-vanishing. A rough order of magnitude estimate for the angular momentum gives $J \simeq M\sqrt{G}n$. In order to obtain angular momentum of order $MR \simeq GM^2$ the order of magnitude for the parameter n must be $n \simeq M\sqrt{G}$ or the mass of the star using Planck mass as unit or: notice that also the Kähler charge of the star is of the same order of magnitude.

4. The gluing of the solution to Schwartshild solution realized as a vacuum extremal is possible at a surface $\Theta = 0$, which corresponds to Scwartschild radius, since at this surface different values of Φ correspond to same point of CP_2. The gluing condition gives additional constraint $u = \infty$ at $r_M = r_S$.

5. The experience with the radially symmetric solution ansatz suggests that Θ is very nearly constant $\Theta \simeq \pi/2$ in the interior and varies considerably only at the surface of the star where Θ must go to zero in order to allow gluing to Schwartshild metric at $r = r_S$. A possible picture is therefore the following. On z-axis there is a Z^0 charged vortex creating radial Z^0 electric field and Z^0 magnetic field in the direction of the vortex. In order to obtain cyclic energy flow matter velocity near the surface of the star must have besides the rotational component a component in θ direction (Z^0 force vanishes in this direction).

6. An interesting possibility is that the vortex actually corresponds to a Kähler charged cosmic string which has gradually lost its enormous inertial mass by a generating pairs of positive and negative energy particles, such that positive energy particles have left the string and participated in the formation of the star. The weakening of the magnetic field would have forced a gradual thickening of the cosmic string to an ordinary magnetic flux tube. This 'stars as pearls in necklace' picture would be consistent with the idea that cosmic strings serve as seeds of galaxy and star formation. Both negative and positive energy strings should be present in order to guarantee vanishing of net inertial energy and one can wonder whether the axis of Z^0 and em magnetic fields correspond to these two kinds of strings.

Does Sun have a solid surface?

The model for the asymptotic state of star predicts that mass at given space-time sheet is concentrated in a spherical shell so that star would have a multi-sheeted onion-like structure. This brings in mind the model for the formation of planetary systems in which spherical layers of quantum coherent dark matter serve as templates for the formation of visible matter which eventually condensed to planets [D6, J6]. It would not be surprising if also younger stars and also planets would possess similar structure. This picture is in conflict with the simplest model of Sun as a gas sphere.

Recently new satellites have begun to provide information about what lurks beneath the photosphere. The pictures produced by Lockheed Martin's Trace Satellite and YOHKOH, TRACE and SOHO satellite programs are publicly available in the web. SERTS program for the spectral analysis suggest a new picture challenging the simple gas sphere picture [56]. The visual inspection of the pictures combined with spectral analysis has led Michael Moshina to suggests that Sun has a solid, conductive spherical surface layer consisting of calcium ferrite. The article of Moshina [56] provides impressive pictures, which in my humble non-specialist opinion support this view. Of course, I have not worked personally with the analysis of these pictures so that I do not have the competence to decide how compelling the conclusions of Moshina are. In any case, I think that his web article [56] deserves a summary.

Before SERTS people were familiar with hydrogen, helium, and calcium emissions from Sun. The careful analysis of SERTS spectrum however suggest the presence of a layer or layers containing ferrite and other heavy metals. Besides ferrite SERTS found silicon, magnesium, manganese, chromium, aluminum, and neon in solar emissions. Also elevated levels of sulphur and nickel were observed during more active cycles of Sun. In the gas sphere model these elements are expected to be present only in minor amounts. As many as 57 different types of emissions from 10 different kinds of elements had to be considered to construct a picture about the surface of the Sun.

Moshina has visually analyzed the pictures constructed from the surface of Sun using light at wave lengths corresponding to three lines of ferrite ions (171, 195, 284 Angstroms). On basis of his analysis he concludes that the spectrum originates from rigid and fixed surface structures, which can survive for days. A further analysis shows that these rigid structure rotate uniformly.

The existence of rigid structures idealizable as spherical shells in the first approximation would conform with the model for the final state of star extrapolated to a qualitative picture about the structure younger stars.

4.4.3 Z^0 force and dynamics of compact objects

The fact that long ranged color fields and weak fields, in particular Z^0 electric fields, could become strong under certain conditions and in fact dominate over gravitation might have interesting consequences in the physics of compact objects. Besides the dynamo mechanism guaranteeing the stability of the compact object the following ideas come immediately into mind.

1. In GRT based models Super Nova explosion is explained in terms of the pressure of the collapsed matter. Numerical simulations however fail to produce the explosion [24] and it might even be that GRT based models in fact predict the collapse to black hole. Z^0 and em electric fields created by dark matter plus the existence of particles with Z^0 charge, which are suggested by TGD based model of nucleus and condensed matter to be present already in ordinary condensed matter, might provide a natural mechanism preventing the formation of the black hole (also excluded by the failure of complete imbeddability). When matter collapses to a sufficiently small volume the value of Θ approaches $\pi/2$ in the surface region and very strong repulsive radial Z^0 force is generated and could indeed lead to the explosion. Very light exotic variants of Higgs bosons identified as wormhole contacts having lefthanded weak charge provides a possible mechanism generating Z^0 charge.

2. The strong Z^0 fields at the surface of the star might provide energy source and acceleration mechanism for very high energy cosmic rays and a mechanism producing very high energy X-rays. These rays would be dark matter particles but could transform to ordinary matter by the mechanism discussed in [F9, J6]. For instance, one can imagine the ejection of a particle beam from the surface of a compact object: particles in dark matter phase gain very high energies in the Z^0 electric field and emit brehmstrahlung in the direction of their motion: most intense emission appears in the region very near the surface of the star, where the Z^0 electric field is strongest. This kind of mechanism might provide alternative explanation for the pulsars. In standard explanations the emission takes place in the direction of the magnetic axis, which does not coincide with the rotation axis. In present case the emission point could be anywhere on the surface of the star and magnetic and rotation axes might well coincide as they do in the simplest model. What one has to do is to invent a mechanism creating the surface instability pushing the matter from the surface of the star to the Kähler electric field.

3. The topological character of the magnetic structures might have applications also in the physics of the ordinary stars. It is known that solar magnetic fields correspond to definite isolated structures [25]. Since electromagnetic fields must be accompanied by Kähler fields it is tempting to assume that these structures indeed correspond to the structures predicted by TGD. At the surface of the Sun the value of Θ near $\pi/2$ are possible and therefore Z^0 force can be very strong inside the magnetic structures.

4.4.4 Correlation between gamma ray bursts and supernovae and dynamo model for the final state of the star

The correlation between gamma ray bursts and supernovae is certainly the cosmological discovery of the year 2003 [32, 33].

1. The first indications for supernova gamma ray burst connection came 1998 when a supernova was seen few days after the gamma ray burst in the same region of sky. In this case the intensity of the burst was however by four orders of magnitude weaker than for the typical gamma ray bursts so that the idea about the correlation was not taken seriously. On 29 March, observers recorded a burst christened as GRB030329. On 6 April, theorists at the Technion Institute of Technology in Israel and CERN in Geneva predicted that there would be signs of a supernova in the visible light and infrared spectra on 8 April [32]. On cue, two days later, observers picked up the telltale spectrum of a type Ic supernova in the same region of sky, triggered as the collapsing star lost hydrogen from its surface. It has now become clear that a large class of gamma ray bursts correlate with supernovae of type Ib and Ic [34], and that they could thus be powered by the mere core collapse leading to supernova. Recall that supernovae of type II involve hydrogen lines unlike those of type I. Supernovae of type Ib shows Helium lines, and Ic shows neither hydrogen nor helium but intermediate mass elements instead. Supernovae of type Ib and Ic are thought to result as core collapse of massive stars.

2. One of the most enigmatic findings were the "mystery spots" accompanying supernova SN1987A at a distance of few light weeks at the symmetry axis at opposite sides of the supernova [35]. Their luminosity was nearly 5 per cent of the maximal one. SN1987A was also accompanied by an expanding axi-symmetric remnant surrounded by three concentric rings.

3. The latest finding [36] is that the radiation associated with the gamma ray bursts is maximally polarized. The polarization degree is the incredible 80 ± 20 per cent, which tells that it must be generated in an extremely strong magnetic field rather than in a simple explosion. The magnetic field must have a strong component parallel to the eye sight direction.

According to the updated model discussed in detail in [D4], cosmic strings transform in topological condensation to magnetic flux tubes about which they represent a limiting case. Primordial magnetic flux tubes forming ferro-magnet like structures become seeds for gravitational condensation leading to the formation of stars and galaxies. The TGD based model for the asymptotic state of a rotating star as dynamo leads to the identification of the predicted magnetic flux tube at the rotation axis of the star as Z^0 magnetic flux tube of primordial origin and assignable to dark matter. Besides Z^0 magnetic flux tube structure also magnetic flux tube structure exists at different space-time sheet but is in general not parallel to the Z^0 magnetic structure. This structure cannot have primordial origin (the magnetic field of star can even flip its polarity).

The flow of matter along Z^0 magnetic (rotation) axis generates synchrotron radiation, which escapes as a precisely targeted beam along magnetic axis and leaves the star. The identification is as the rotating light beam associated with ordinary neutron stars. During the core collapse leading to the supernova this beam becomes gamma ray burst. The mechanism is very much analogous to the squeezing of the tooth paste from the tube.

TGD based models of nuclei [F8] and condensed matter [F9] suggests that the nuclei of dense condensed matter develop anomalous color and weak charges coupling to dark weak bosons having Compton length L_w of order atomic size. Also lighter copies of weak bosons can be important in living matter. This weak charge is vacuum screened above L_w and by dark particles below it. Dark neutrinos, which according to TGD based explanation of tritium beta decay anomaly [F8] should have the same mass scale as ordinary neutrinos, are good candidates for screening dark particles. The Z^0 charge unbalance caused by the ejection of screening dark neutrinos hinders the gravitational collapse. The strong radial compression amplifies the tooth paste effect in this kind of situation so that there are hopes to understand the observed incredibly high polarization of 80 ± 20 per cent [36].

4.4.5 Z^0 force and Super Nova explosion

The mechanism behind Super Nova explosion is not completely understood. The general picture is roughly the following.

1. The formation of iron means the end of the nuclear processes. The inner parts of the star contract and the degeneracy pressure of the non-relativistic electrons ($E_F \propto \rho^{2/3}$) increases and compensates the gravitational force. The equilibrium state is not stable. When the mass of the iron core approaches Chandrasekhar mass $1.4M_{Sun}$ electrons become relativistic. The milder dependence of the electron Fermi energy on density $E_F \propto \rho^{1/3}$ at the relativistic limit leads to the loss of stability. The high Fermi energy of the electrons allows also the reactions $p+e^- \rightarrow n+\nu_e$ implying decrease of the electronic pressure and neutronization of nuclear matter in the core. Gravitational collapse starts.

2. Collapse stops, when the density of the core reaches the density of the nuclear matter. The degeneracy pressure of the neutrons stops contraction, a shock wave is created and the shock wave and neutrino radiation blow the outer regions of the star away so that Super Nova explosion results.

The problem of this scenario is that numerical simulations do not lead to a strong enough Super Nova explosion and the star tends to collapse into a black hole. A repulsive long ranged Z^0 force predicted by TGD based model of atomic nuclei [F8] generating an additional pressure provides a possible mechanism hindering the collapse and leading to the explosion.

1. The TGD based model for nuclei [F8] and condensed matter [F9] suggests that the nuclei of dense condensed matter develop anomalous color and weak charges coupling to dark weak bosons having Compton length L_w of order atomic size. Weak charge is due to the charged color bonds between nucleons: for instance, tetraneutron can be understood as an alpha particle containing two negatively charged color bonds [F8]. This weak charge is vacuum screened above L_w and by dark particles below it. The charged bonds could exist and also generated between nucleons of different nuclei during collapse.

   Dark neutrinos, which according to the TGD based explanation of tritium beta decay anomaly [F8] should have the same mass scale as ordinary neutrinos, are good candidates for screening dark weak force partially below length scale L_w. In equilibrium color force compensates the partially screened Z^0 force in the bonds. For the ordinary condensed matter densities vacuum screening effectively eliminates the force between neighboring nuclei, and the force makes it visible only via low compressibility. The gravitational collapse could be hindered by the strong additional pressure created by the repulsive L_w-ranged weak interaction between nucleons becoming manifest in the resulting dense phase.

2. In the initial state Z^0 charge is screened by dark neutrinos below L_w so that the repulsive Z^0 force is weaker than gravitational force and attractive color force associated with the bonds. Neutronization reactions $p+e^- \rightarrow n+\nu_e$ trigger the collapse. During collapse density increases so that dark neutrinos are not able to screen the anomalous Z^0 charge density. The dark neutrino radiation escaping from the star can also reduce the Z^0 screening. The resulting repulsive weak force implies a rapid increase of pressure with increasing density and thus a very low compressibility as it is proposed to imply also in the case of ordinary condensed matter[F9]. The repulsive weak force thus stops the collapse to black-hole.

3. The study of the spherically symmetric star models as 4-surfaces imbedded in $M^4_+ \times CP_2$ shows that the extreme nonlinearity of Kähler action implies that Z^0 force dominates over gravitation near the surface of the star.

4.4.6 Microscopic description of black-holes in TGD Universe

In TGD framework the imbedding of the metric for the interior of Schwartshild black-hole fails below some critical radius. This strongly suggests that only the exterior metric of black-hole makes sense in TGD framework and that TGD must provide a microscopic description of black-holes. Somewhat unexpectedly, I ended up with this description from a model of hadrons.

Super-symplectic algebra is a generalization of Kac-Moody algebra obtained by replacing the finite-dimensional group G with the group of symplectic transformations of $\delta M^4_\pm \times CP_2$. This algebra defines the group of isometries for the "world of classical worlds" and together with the Kac-Moody algebra assignable to the deformations of light-like 3-surfaces representing orbits of 2-D partonic surfaces it defines the mathematical backbone of quantum TGD as almost topological QFT.

From the point of view of experimentalist the basic question is how these super-symplectic degrees of freedom reflect themselves in existing physics and the pleasant surprise was that super-symplectic bosons explain what might be called the missing hadronic mass and spin. The point is that quarks explain only about 170 MeV of proton mass. Also the spin puzzle of proton is known for years. Also precise mass formulas for hadrons emerge.

Super-symplectic degrees of freedom represent dark matter in electro-weak sense and highly entangled hadronic strings in Hagedorn temperature are very much analogous to black-holes. This indeed generalizes to a microscopic model for black-holes created when hadronic strings fuse together in high density.

Super-symplectic bosons

TGD predicts also exotic bosons which are analogous to fermion in the sense that they correspond to single wormhole throat associated with CP_2 type vacuum extremal whereas ordinary gauge bosons corresponds to a pair of wormhole contacts assignable to wormhole contact connecting positive and negative energy space-time sheets. These bosons have super-conformal partners with quantum numbers of right handed neutrino and thus having no electro-weak couplings. The bosons are created by the purely bosonic part of super-symplectic algebra [B2, B3, B4], whose generators belong to the representations of the color group and 3-D rotation group but have vanishing electro-weak quantum numbers. Their spin is analogous to orbital angular momentum whereas the spin of ordinary gauge bosons reduces to fermionic spin. Recall that super-symplectic algebra is crucial for the construction of configuration space Kähler geometry. If one assumes that super-symplectic gluons suffer topological mixing identical with that suffered by say U type quarks, the conformal weights would be (5,6,58) for the three lowest generations. The application of super-symplectic bosons in TGD based model of hadron masses is discussed in [F4] and here only a brief summary is given.

As explained in [F4], the assignment of these bosons to hadronic space-time sheet is an attractive idea.

1. Quarks explain only a small fraction of the baryon mass and that there is an additional contribution which in a good approximation does not depend on baryon. This contribution should correspond to the non-perturbative aspects of QCD. A possible identification of this contribution is in terms of super-symplectic gluons. Baryonic space-time sheet with $k = 107$ would contain a many-particle state of super-symplectic gluons with net conformal weight of 16 units. This leads to a model of baryons masses in which masses are predicted with an accuracy better than 1 per cent.

2. Hadronic string model provides a phenomenological description of non-perturbative aspects of QCD and a connection with the hadronic string model indeed emerges. Hadronic string tension is predicted correctly from the additivity of mass squared for $J = 2$ bound states of super-symplectic quanta. If the topological mixing for super-symplectic bosons is equal to that for U type quarks then a 3-particle state formed by 2 super-symplectic quanta from the first generation and 1 quantum from the second generation would define baryonic ground state with 16 units of conformal weight. A very precise prediction for hadron masses results by assuming that the spin of hadron correlates with its super-symplectic particle content.

3. Also the baryonic spin puzzle caused by the fact that quarks give only a small contribution to the spin of baryons, could find a natural solution since these bosons could give to the spin of baryon an angular momentum like contribution having nothing to do with the angular momentum of quarks.

4. Super-symplectic bosons suggest a solution to several other anomalies related to hadron physics. The events observed for a couple of years ago in RHIC [31] suggest a creation of a black-hole like state in the collision of heavy nuclei and inspire the notion of color glass condensate of gluons, whose natural identification in TGD framework would be in terms of a fusion of hadronic space-time sheets containing super-symplectic matter materialized also from the collision energy. In the collision, valence quarks connected together by color bonds to form separate units would

evaporate from their hadronic space-time sheets in the collision, and would define TGD counterpart of Pomeron, which experienced a reincarnation for few years ago [30]. The strange features of the events related to the collisions of high energy cosmic rays with hadrons of atmosphere (the particles in question are hadron like but the penetration length is anomalously long and the rate for the production of hadrons increases as one approaches surface of Earth) could be also understood in terms of the same general mechanism.

Are ordinary black-holes replaced with super-symplectic black-holes in TGD Universe?

Some variants of super string model predict the production of small black-holes at LHC. I have never taken this idea seriously but in a well-defined sense TGD predicts black-hole like states associated with super-symplectic gravitons with strong gravitational constant defined by the hadronic string tension. The proposal is that super-symplectic black-holes have been already seen in Hera, RHIC, and the strange cosmic ray events.

Baryonic super-symplectic black-holes of the ordinary M_{107} hadron physics would have mass 934.2 MeV, very near to proton mass. The mass of their M_{89} counterparts would be 512 times higher, about 478 GeV. "Ionization energy" for Pomeron, the structure formed by valence quarks connected by color bonds separating from the space-time sheet of super-symplectic black-hole in the production process, corresponds to the total quark mass and is about 170 MeV for ordinary proton and 87 GeV for M_{89} proton. This kind of picture about black-hole formation expected to occur in LHC differs from the stringy picture since a fusion of the hadronic mini black-holes to a larger black-hole is in question.

An interesting question is whether the ultrahigh energy cosmic rays having energies larger than the GZK cut-off of 5×10^{10} GeV are baryons, which have lost their valence quarks in a collision with hadron and therefore have no interactions with the microwave background so that they are able to propagate through long distances.

In neutron stars the hadronic space-time sheets could form a gigantic super-symplectic black-hole and ordinary black-holes would be naturally replaced with super-symplectic black-holes in TGD framework (only a small part of black-hole interior metric is representable as an induced metric). This obviously means a profound difference between TGD and string models.

1. Hawking-Bekenstein black-hole entropy would be replaced with its p-adic counterpart given by

$$S_p = (\frac{M}{m(CP_2)})^2\times log(p) \ , \tag{4.4.17}$$

where $m(CP_2)$ is CP_2 mass, which is roughly 10^{-4} times Planck mass. M is the contribution of p-adic thermodynamics to the mass. This contribution is extremely small for gauge bosons but for fermions and super-symplectic particles it gives the entire mass.

2. If p-adic length scale hypothesis $p\simeq 2^k$ holds true, one obtains

$$S_p = klog(2)\times (\frac{M}{m(CP_2)})^2, \tag{4.4.18}$$

$m(CP_2)=\hbar/R$, R the "radius" of CP_2, corresponds to the standard value of $\hbar_0$ for all values of $\hbar$.

3. Hawking-Bekenstein area law gives in the case of Schwartschild black-hole

$$S = \frac{A}{4G}\times\hbar = \pi GM^2\times\hbar \ . \tag{4.4.19}$$

For the p-adic variant of the law Planck mass is replaced with CP_2 mass and $klog(2)\simeq log(p)$ appears as an additional factor. Area law is obtained in the case of elementary particles if k is prime and wormhole throats have M^4 radius given by p-adic length scale $L_k = \sqrt{k}R$ which is exponentially smaller than L_p. For macroscopic super-symplectic black-holes modified area law results if the radius of the large wormhole throat equals to Schwartschild radius. Schwartschild radius is indeed natural: a simple deformation of the Schwartschild exterior metric to a metric representing rotating star transforms Schwartschild horizon to a light-like 3-surface at which the signature of the induced metric is transformed from Minkowskian to Euclidian.

4. The formula for the gravitational Planck constant appearing in the Bohr quantization of planetary orbits and characterizing the gravitational field body mediating gravitational interaction between masses M and m [D6] reads as

$$\hbar_{gr} = \frac{GMm}{v_0}\hbar_0 \ .$$

$v_0 = 2^{-11}$ is the preferred value of v_0. One could argue that the value of gravitational Planck constant is such that the Compton length $\hbar_{gr}/M$ of the black-hole equals to its Schwartshild radius. This would give

$$\hbar_{gr} = \frac{GM^2}{v_0}\hbar_0 \ , \quad v_0 = 1/2 \ . \tag{4.4.20}$$

The requirement that $\hbar_{gr}$ is a ratio of ruler-and-compass integers expressible as a product of distinct Fermat primes (only four of them are known) and power of 2 would quantize the mass spectrum of black hole [D6]. Even without this constraint M^2 is integer valued using p-adic mass squared unit and if p-adic length scale hypothesis holds true this unit is in an excellent approximation power of two.

5. The gravitational collapse of a star would correspond to a process in which the initial value of v_0 , say $v_0 = 2^{-11}$, increases in a stepwise manner to some value $v_0 \leq 1/2$. For a supernova with solar mass with radius of 9 km the final value of v_0 would be $v_0 = 1/6$. The star could have an onion like structure with largest values of v_0 at the core as suggested by the model of planetary system. Powers of two would be favored values of v_0. If the formula holds true also for Sun one obtains $1/v_0 = 3 \times 17 \times 2^{13}$ with 10 per cent error.

6. Black-hole evaporation could be seen as means for the super-symplectic black-hole to get rid of its electro-weak charges and fermion numbers (except right handed neutrino number) as the antiparticles of the emitted particles annihilate with the particles inside super-symplectic black-hole. This kind of minimally interacting state is a natural final state of star. Ideal super-symplectic black-hole would have only angular momentum and right handed neutrino number.

7. In TGD light-like partonic 3-surfaces are the fundamental objects and space-time interior defines only the classical correlates of quantum physics. The space-time sheet containing the highly entangled cosmic string might be separated from environment by a wormhole contact with size of black-hole horizon.

This looks the most plausible option but one can of course ask whether the large partonic 3-surface defining the horizon of the black-hole actually contains all super-symplectic particles so that super-symplectic black-hole would be single gigantic super-symplectic parton. The interior of super-symplectic black-hole would be a space-like region of space-time, perhaps resulting as a large deformation of CP_2 type vacuum extremal. Black-hole sized wormhole contact would define a gauge boson like variant of the black-hole connecting two space-time sheets and getting its mass through Higgs mechanism. A good guess is that these states are extremely light.

Anyonic view about blackholes

A new element to the model of black hole comes from the vision that black hole horizon as a light-like 3-surface corresponds to a light-like orbit of light-like partonic 2-surface. This allows two kinds of black holes. Fermion like black hole would correspond to a deformed CP_2 type extremal which Euclidian signature of metric and topologically condensed at a space-time sheet with a Minkowskian signature. Boson like black hole would correspond to a wormhole contact connecting two space-time sheets with Minkowskian signature. Wormhole contact would be a piece deformed CP_2 type extremal possessing two light-like throats defining two black hole horizons very near to each other. It does not seem absolutely necessary to assume that the interior metric of the black-hole is realized in another space-time sheet with Minkowskian signature.

Second new element relates to the value of Planck constant. For $\hbar_{gr} = 4GM^2$ the Planck length $L_P(\hbar) = \sqrt{\hbar G}$ equals to Schwartschild radius and Planck mass equals to $M_P(\hbar) = \sqrt{\hbar/G} = 2M$. If the mass of the system is below the ordinary Planck mass: $M \leq m_P(\hbar_0)/2 = \sqrt{\hbar_0/4G}$, gravitational Planck constant is smaller than the ordinary Planck constant.

Black hole surface contains ultra dense matter so that perturbation theory is not expected to converge for the standard value of Planck constant but do so for gravitational Planck constant. If the phase transition increasing Planck constant is a friendly gesture of Nature making perturbation theory convergent, one expects that only the black holes for which Planck constant is such that $GM^2/4\pi\hbar < 1$ holds true are formed. Black hole entropy -being proportional to $1/\hbar$- is of order unity so that TGD black holes are not very entropic. $\hbar = GM^2/v_0$, $v_0 = 1/4$, would hold true for an ideal black hole with Planck length $(\hbar G)^{1/2}$ equal to Schwartshild radius $2GM$. Since black hole entropy is inversely proportional to $\hbar$, this would predict black hole entropy to be of order single bit. This of course looks totally non-sensible if one believes in standard thermodynamics. For the star with mass equal to 10^{40} Planck masses the entropy associated with the initial state of the star would be roughly the number of atoms in star equal to about 10^{60}. Black hole entropy proportional to $GM^2/\hbar$ would be of order 10^{80} provided the standard value of $\hbar$ is used as unit. This stimulates some questions.

1. Does second law pose an upper bound on the value of $\hbar$ of dark black hole from the requirement that black hole has at least the entropy of the initial state. The maximum value of $\hbar$ would be given by the ratio of black hole entropy to the entropy of the initial state and about 10^{20} in the example consider to be compared with $GM^2/v_0 \sim 10^{80}$.

2. Or should one generalize thermodynamics in a manner suggested by zero energy ontology by making explicit distinction between subjective time (sequence of quantum jumps) and geometric time? The arrow of geometric time would correlate with that of subjective time. One can argue that the geometric time has opposite direction for the positive and negative energy parts of the zero energy state interpreted in standard ontology as initial and final states of quantum event. If second law would hold true with respect to subjective time, the formation of ideal dark black hole would destroy entropy only from the point of view of observer with standard arrow of geometric time. The behavior of phase conjugate laser light would be a more mundane example. Do self assembly processes serve as example of non-standard arrow of geometric time in biological systems? In fact, zero energy state is geometrically analogous to a big bang followed by big crunch. One can however criticize the basic assumption as ad hoc guess. One should really understand the the arrow of geometric time. This is discussed in detail in [MPb].

If the partonic 2-surface surrounds the tip of causal diamond CD, the matter at its surface is in anyonic state with fractional charges. Anyonic black hole can be seen as single gigantic elementary particle stabilized by fractional quantum numbers of the constituents preventing them from escaping from the system and transforming to ordinary visible matter. A huge number of different black holes are possible for given value of $\hbar$ since there is infinite variety of pairs (n_a, n_b) of integers giving rise to same value of $\hbar$.

One can imagine that the partonic surface is not exact sphere except for ideal black holes but contains large number of magnetic flux tubes giving rise to handles. Also a pair of spheres with different radii can be considered with surfaces of spheres connected by braided flux tubes. The braiding of these handles can represent information and one can even consider the possibility that black hole can act as a topological quantum computer. There would be no sharp difference between the dark parts of black holes and those of ordinary stars. Only the volume containing the complex flux tube structures associated with the orbits of planets and various objects around star would become very small for black hole so that the black hole might code for the topological information of the matter collapsed into it.

4.5 TGD based model for cosmic strings

The model for cosmic strings has forced to question all cherished assumptions including positive energy ontology, Equivalence Principle, and positivity of gravitational energy.

4.5.1 Zero energy ontology and cosmic strings

There are two kinds of cosmic strings: free and topological condensed ones.

1. Free cosmic strings are not absolute minima of the Kähler action (the action has wrong sign). $P3$ would favor cosmic strings and also their electric duals if they exist. Since the magnetic field of cosmic string corresponds to CP_2 degrees of freedom with Euclidian signature electric duals do not probably exist.

2. In long enough length and time scales Kähler action per volume must vanish so that the idealization of cosmology as a vacuum extremal becomes possible and there must be some mechanism compensating the positive action of the free cosmic strings. The mechanism need not be local.

The most convincing cancelation mechanism relies on zero energy ontology. If the sign of the Kähler action depends on time orientation it would be opposite for positive and negative energy space-time sheets and the actions associated with them would cancel if the field configurations are identical. Hence zero energy states would naturally have small Kähler action. Obviously this mechanism is non-local.

In this framework zero energy states correspond to cosmologies leading from big bang to big crunch separated by some time interval T of geometric time. Quantum jumps can gradually increase the value T and TGD inspired theory of consciousness suggests that the increase of T might relate to the shift for the contents of conscious experience towards geometric future. In particular, what is usually regarded as cosmology could have started from zero energy state with a small value of T.

The earlier picture was based on dynamical cancellation mechanism involving generation of strong Kähler electric fields in the condensation whose action compensated for Kähler magnetic action [16].

4.5.2 Topological condensation of cosmic strings

1. Exterior metrics of topologically condensed $g > 1$ strings

If the sign of the gravitational string tension is negative the simple imbedding of the metric existing for positive string tension ceases to exist. There exists however a different imbedding for which angle excess is in a good approximation same as for the flat solution. The solution is not flat anymore and this implies outwards radial gravitational acceleration. The imbedding of the exterior metric also fails beyond a critical radius. This is not the only possible exterior metric: also non-flat exterior metric are possible and look actually more plausible and also this metric implies radial outwards acceleration as one might indeed expect. What remains to be shown that these metrics do not only yield small angle defect but are also consistent with Newtonian intuitions as the constant velocity spectrum for distant stars around galaxies suggests.

The natural interpretation would be as a mechanism generating large void around a central cosmic string having $g > 1$ and negative string tension and containing at its boundary $g = 1$ positive energy cosmic strings with string tension equal to Kähler string tension. Since angle surplus instead of angle deficit is predicted for $g > 1$ strings, lense effect transforms in this case to angle divergence and one avoids the basic objection against big cosmic strings. The emergence of preferred axes defined by $g > 1$ strings in the scale of large void could relate to the anomalies observed in Cosmic Microwave Background.

Negative gravitational energy of $g > 1$ cosmic strings could be regarded as that part of gravitational energy which causes the accelerated cosmic expansion by driving galactic strings to the boundaries of large voids which then induces phase transition increasing the size of the voids. This kind of acceleration is encountered already at the level of Newton's equations when some of the gravitational masses are negative.

2. Exterior metrics of topologically condensed $g = 1$ strings

One cannot assume that the exterior metric of the galactic $g = 1$ strings is the one predicted by assuming $G = 0$ in the exterior region. This would mean that metric decomposes as $g = g_2(X^2) + g_2(Y^2)$. $g(X^2)$ would be flat as also $g_2(Y^2)$ expect at the position of string. The resulting angle defect due to the replacement of plane Y^2 with cone would be large and give rise to lense effect of same magnitude as in the case of GUT cosmic strings. This lensing has not been observed.

The constant velocity spectrum for distant stars of galaxies and the fact that galaxies are organized along strings suggests that these string generate in a good approximation Newtonian potential. This potential predicts constant velocity spectrum with a correct value velocity.

In the stationary situation one expects that the exterior metric of galactic string corresponds to a small deformation of vacuum extremal of Kähler action which is also extremal of the curvature scalar in the induced metric. This allows a solution ansatz which conforms with Newtonian intuitions and for which metric decomposes as $g = g_1 + g_3$, where g_1 corresponds to axis in the direction of string and g_3 remaining $1 + 2$ directions.

4.5.3 Dark energy is replaced with dark matter in TGD framework

The first thing that comes in mind is that negative gravitational energy could be the TGD counterpart for the positive dark vacuum energy known to dominate over the mass density in cosmological length scales and believed to cause the accelerated cosmic expansion. This argument is wrong.

1. The gigantic value of gravitational Planck constant implies that dark matter makes TGD Universe a macroscopic quantum system even in cosmological length scales. Astrophysical systems become stationary quantum systems which participate in cosmic expansion only via quantum phase transitions increasing the value of gravitational Planck constant. Critical cosmologies, which are determined apart from a single parameter in TGD Universe, are natural during all quantum phase transitions, in particular the phase transition periods increasing the size of large voids and having interpretation in terms of an increase of gravitational Planck constant. Cosmic expansion is predicted to be accelerating during these periods. The mere criticality requires that besides ordinary matter there is a contribution $\Omega_\Lambda \simeq .74$ to the mass density besides visible matter and dark matter.

2. The essential characteristic of dark energy is its negative pressure. Negative gravitational energy could effectively create this negative pressure during phase transitions increasing the size of large voids. Since negative gravitational mass would be basically responsible for the accelerated expansion, one can assume that dark energy is actually dark matter.

3. Note that the pressure is negative during critical period. This is however interpreted as a correlate for the expansion caused by the phase transition increasing Planck constant rather than being due to positive cosmological constant or quintessence with negative pressure.

4.5.4 The values for the TGD counterpart of cosmological constant

One can introduce a parameter characterizing the contribution of dark mass to the mass density during critical periods and call it cosmological constant recalling however that the contribution does not correspond to negative pressure now. The value of this parameter is same as in the standard cosmology from mere criticality assumption.

What is new that p-adic fractality predicts that Λ scales as $1/L^2(k)$ as a function of the p-adic scale characterizing the space-time sheet implying a series of phase transitions reducing Λ. The order of magnitude for the recent value of the cosmological constant comes out correctly. The gravitational energy density assignable to the cosmological constant is identifiable as that associated with topologically condensed cosmic strings and magnetic flux tubes to which they are gradually transformed during cosmological evolution.

The naive expectation would be the density of cosmic strings would behave as $1/a^2$ as function of M^4_+ proper time. The vision about dark matter as a phase characterized by gigantic Planck constant however implies that large voids do not expand in continuous manner during cosmic evolution but in discrete quantum jumps increasing the value of the gravitational Planck constant and thus increasing the size of the large void as a quantum state. Since the set of preferred values of Planck constant is closed under multiplication by powers of 2, p-adic length scales L_p, $p \simeq 2^k$ form a preferred set of sizes scales for the large voids.

Classically one can understand the occurrence of the phase transitions increasing the size of the void as resulting when the galactic strings end up to the boundary of the large void in the repulsive gravitational field of the big string.

4.5.5 Matter-antimatter asymmetry and cosmic strings

Despite huge amount of work done during last decades (during the GUT era the problem was regarded as being solved!) matter-antimatter asymmetry remains still an unresolved problem of cosmology. A possible resolution of the problem is matter-antimatter asymmetry in the sense that cosmic strings contain antimatter and their exteriors matter. The challenge would be to understand the mechanism generating this asymmetry. The vanishing of net gauge charges of cosmic string allows this symmetry since electro-weak charges of quarks and leptons can cancel each other.

The challenge is to identify the mechanism inducing the CP breaking necessary for the matter-antimatter asymmetry. Quite a small CP breaking inside cosmic strings would be enough. The key observation is that vacuum extremals as such are not physically acceptable: small deformations of vacuum extremals to non-vacua are required. The simplest deformation of this kind would induce a radial Kähler electric field and thus a small Kähler electric charge inside cosmic string. This in turn would induce CP breaking inside cosmic string inducing matter antimatter asymmetry by the minimization of the ground state energy. Conservation of Kähler charge in turn would induce asymmetry outside cosmic string and the annihilation of matter and antimatter would then lead to a situation in which there is only matter.

This model is not the only one that one can imagine. Antimatter could reside also at other p-adic space-time sheets and at the dark space-time sheets with different values of Planck constant. Most importantly, a first principle justification for the needed CP breaking is lacking. This justification comes from the fundamental formulation of quantum TGD in terms of the modified Dirac action associated with Kähler action and its generalization allowing include instanton term as imaginary part of Kähler action [B4].

1. The key idea in the formulation of quantum TGD in terms of modified Dirac equation associated with Kähler action is that the Dirac determinant defined by the generalized eigenvalues assignable to the Dirac operator D_K equals to the vacuum functional defined as the exponent of Kähler function in turn identifiable as Kähler action for a preferred extremal for which the second variation of Kähler action vanishes at least for the variations responsible for dynamical symmetries. The interpretation is in terms of quantum criticality with the hierarchy of symmetries defining a hierarchy of criticalities analogous to the hierarchy defined by the rank of the matrix defined by the second derivatives of potential function in Thom's catastrophe theory.

2. This representation generalizes. One can add an imaginary instanton term to the Kähler function and corresponding modified Dirac operator D_K so that the generalized eigenvalues assignable to D_K (analogous to Higgs vacuum expectation) become complex. The natural conjecture is that the resulting Dirac determinant equals to the exponent of Kähler action and imaginary instanton term for the preferred extremal. The instanton term does not contribute to the configuration space metric but provides a first principle description for CP breaking and anyonic effects. It also predicts the dependence of these effects on the page of the book like structure defined by the generalized imbedding space realizing the dark matter hierarchy with levels labeled by the value of Planck constant.

4.6 Allais effect and TGD

Allais effect represents one of the anomalies associated with gravitational interaction discarded by the average theoretician. In TGD framework this effect can be interpreted as an interference effect made possible by the gigantic value of gravitational Planck constant. As an interference effect it is extremely sensitive to the parameters of the problem and this explains why the sign and size of the effects varies so much.

4.6.1 The effect

Allais effect [55, 56] is a fascinating gravitational anomaly associated with solar eclipses. It was discovered originally by M. Allais, a Nobelist in the field of economy, and has been reproduced in several experiments but not as a rule. The experimental arrangement uses so called paraconical pendulum, which differs from the Foucault pendulum in that the oscillation plane of the pendulum can rotate in certain limits so that the motion occurs effectively at the surface of sphere.

Experimental findings

Consider first a brief summary of the findings of Allais and others [56].

1. In the ideal situation (that is in the absence of any other forces than gravitation of Earth) paraconical pendulum should behave like a Foucault pendulum. The oscillation plane of the paraconical pendulum however begins to rotate.

2. Allais concludes from his experimental studies that the orbital plane approach always asymptotically to a limiting plane and the effect is only particularly spectacular during the eclipse. During solar eclipse the limiting plane contains the line connecting Earth, Moon, and Sun. Allais explains this in terms of what he calls the anisotropy of space.

3. Some experiments carried out during eclipse have reproduced the findings of Allais, some experiments not. In the experiment carried out by Jeverdan and collaborators in Romania it was found that the period of oscillation of the pendulum decreases by $\Delta f/f \simeq 5\times 10^{-4}$ [55, 57] which happens to correspond to the constant $v_0 = 2^{-11}$ appearing in the formula of the gravitational Planck constant. It must be however emphasized that the overall magnitude of $\Delta f/f$ varies by five orders of magnitude. Even the sign of $\Delta f/f$ varies from experiment to experiment.

4. There is also quite recent finding by Popescu and Olenici, which they interpret as a quantization of the plane of oscillation of paraconical oscillator during solar eclipse [58]. There is also evidence that the effect is present also before and after the full eclipse. The time scale is 1 hour.

TGD based models for Allais effect

I have already earlier proposed an explanation of the effect in terms of classical Z^0 force [G1]. If the Z^0 charge to mass ratio of pendulum varies and if Earth and Moon are Z^0 conductors, the resulting model is quite flexible and one might hope it could explain the high variation of the experimental results.

The rapid variation of the effect during the eclipse is however a problem for this approach and suggests that gravitational screening or some more general interference effect might be present. Gravitational screening alone cannot however explain Allais effect. Also the combination of gravitational screening and Z^0 force assuming Z^0 conducting structures causing screening fails to explain the discontinuous behavior when massive objects are collinear.

A model based on the idea that gravitational interaction is mediated by topological light rays (MEs) and that gravitons correspond to a gigantic value of the gravitational Planck constant however explains the Allais effect as an interference effect made possible by macroscopic quantum coherence in astrophysical length scales. Equivalence Principle fixes the model to a high degree and one ends up with an explicit formula for the anomalous gravitational acceleration and the general order of magnitude and the large variation of the frequency change as being due to the variation of the distance ratio $r_{S,P}/r_{M,P}$ (S, M,and P refer to Sun, Moon, and pendulum respectively). One can say that the pendulum acts as an interferometer.

4.6.2 Could gravitational screening explain Allais effect

The basic idea of the screening model is that Moon absorbs some fraction of the gravitational momentum flow of Sun and in this manner partially screens the gravitational force of Sun in a disk like region having the size of Moon's cross subsection. The screening is expected to be strongest in the center of the disk. Screening model happens to explain the findings of Jevardan but fails in the general case. Despite this screening model serves as a useful exercise.

Constant external force as the cause of the effect

The conclusions of Allais motivate the assumption that quite generally there can be additional constant forces affecting the motion of the paraconical pendulum besides Earth's gravitation. This means the replacement $\overline{g} \rightarrow \overline{g} + \Delta\overline{g}$ of the acceleration g due to Earth's gravitation. $\Delta\overline{g}$ can depend on time.

The system obeys still the same simple equations of motion as in the initial situation, the only change being that the direction and magnitude of effective Earth's acceleration have changed so that the definition of vertical is modified. If $\Delta\overline{g}$ is not parallel to the oscillation plane in the original situation, a torque is induced and the oscillation plane begins to rotate. This picture requires that the friction in the rotational degree of freedom is considerably stronger than in oscillatory degree of freedom: unfortunately I do not know what the situation is.

The behavior of the system in absence of friction can be deduced from the conservation laws of energy and angular momentum in the direction of $\overline{g} + \Delta\overline{g}$. The explicit formulas are given by

$$\begin{aligned} E &= \frac{ml^2}{2}(\frac{d\Theta}{dt})^2 + sin^2(\Theta)(\frac{d\Phi}{dt})^2 + mglcos(\Theta) \ , \\ L_z &= ml^2 sin^2(\Theta)\frac{d\Phi}{dt} \ . \end{aligned} \tag{4.6.1}$$

and allow to integrate Θ and Φ from given initial values.

What causes the effect in normal situations?

The gravitational accelerations caused by Sun and Moon come first in mind as causes of the effect. Equivalence Principle implies that only relative accelerations causing analogs of tidal forces can be in question. In GRT picture these accelerations correspond to a geodesic deviation between the surface of Earth and its center. The general form of the tidal acceleration would thus the difference of gravitational accelerations at these points:

$$\Delta\overline{g} = -2GM[\frac{\Delta\overline{r}}{r^3} - 3\frac{\overline{r}\cdot\Delta\overline{r}\overline{r}}{r^5}] \ . \tag{4.6.2}$$

Here $\overline{r}$ denotes the relative position of the pendulum with respect to Sun or Moon. $\Delta\overline{r}$ denotes the position vector of the pendulum measured with respect to the center of Earth defining the geodesic deviation. The contribution in the direction of $\Delta\overline{r}$ does not affect the direction of the Earth's acceleration and therefore does not contribute to the torque. Second contribution corresponds to an acceleration in the direction of $\overline{r}$ connecting the pendulum to Moon or Sun. The direction of this vector changes slowly.

This would suggest that in the normal situation the tidal effect of Moon causes gradually changing force $m\Delta\overline{g}$ creating a torque, which induces a rotation of the oscillation plane. Together with dissipation this leads to a situation in which the orbital plane contains the vector $\Delta\overline{g}$ so that no torque is experienced. The limiting oscillation plane should rotate with same period as Moon around Earth. Of course, if effect is due to some other force than gravitational forces of Sun and Earth, paraconical oscillator would provide a manner to make this force visible and quantify its effects.

What would happen during the solar eclipse?

During the solar eclipse something exceptional must happen in order to account for the size of effect. The finding of Allais that the limiting oscillation plane contains the line connecting Earth, Moon, and Sun implies that the anomalous acceleration $\Delta|g$ should be parallel to this line during the solar eclipse.

The simplest hypothesis is based on TGD based view about gravitational force as a flow of gravitational momentum in the radial direction.

1. For stationary states the field equations of TGD for vacuum extremals state that the gravitational momentum flow of this momentum. Newton's equations suggest that planets and moon absorb a fraction of gravitational momentum flow meeting them. The view that gravitation is mediated by gravitons which correspond to enormous values of gravitational Planck constant in turn supports Feynman diagrammatic view in which description as momentum exchange makes sense and is consistent with the idea about absorption. If Moon absorbs part of this momentum, the region of Earth screened by Moon receives reduced amount of gravitational momentum and the gravitational force of Sun on pendulum is reduced in the shadow.

2. Unless the Moon as a coherent whole acts as the absorber of gravitational four momentum, one expects that the screening depends on the distance travelled by the gravitational flux inside Moon. Hence the effect should be strongest in the center of the shadow and weaken as one approaches its boundaries.

3. The opening angle for the shadow cone is given in a good approximation by $\Delta\Theta = R_M/R_E$. Since the distances of Moon and Earth from Sun differ so little, the size of the screened region has same size as Moon. This corresponds roughly to a disk with radius $.27 \times R_E$.

   The corresponding area is 7.3 per cent of total transverse area of Earth. If total absorption occurs in the entire area the total radial gravitational momentum received by Earth is in good approximation 92.7 per cent of normal during the eclipse and the natural question is whether this effective repulsive radial force increases the orbital radius of Earth during the eclipse.

   More precisely, the deviation of the total amount of gravitational momentum absorbed during solar eclipse from its standard value is an integral of the flux of momentum over time:

$$\begin{aligned} \Delta P^k_{gr} &= \int \frac{\Delta P^k_{gr}}{dt}(S(t))dt \ , \\ \frac{\Delta P^k_{gr}}{dt}(S(t)) &= \int_{S(t)} J^k_{gr}(t)dS \ . \end{aligned} \tag{4.6.3}$$

   This prediction could kill the model in classical form at least. If one takes seriously the quantum model for astrophysical systems predicting that planetary orbits correspond to Bohr orbits with gravitational Planck constant equal to GMm/v_0, $v_0 = 2^{-11}$, there should be not effect on the orbital radius. The anomalous radial gravitational four-momentum could go to some other degrees of freedom at the surface of Earth.

4. The rotation of the oscillation plane is largest if the plane of oscillation in the initial situation is as orthogonal as possible to the line connecting Moon, Earth and Sun. The effect vanishes when this line is in the the initial plane of oscillation. This testable prediction might explain why some experiments have failed to reproduce the effect.

5. The change of $|\overline{g}|$ to $|\overline{g}+\Delta\overline{g}|$ induces a change of oscillation frequency given by

$$\frac{\Delta f}{f} = \frac{\overline{g}\cdot\Delta\overline{g}}{g^2} = \frac{\Delta g}{g} cos(\theta) \ . \tag{4.6.4}$$

   If the gravitational force of the Sun is screened, one has $|\overline{g}+\Delta\overline{g}| > g$ and the oscillation frequency should increase. The upper bound for the effect corresponds to vertical direction is obtained from the gravitational acceleration of Sun at the surface of Earth:

$$\frac{|\Delta f|}{f} \leq \frac{\Delta g}{g} = \frac{v_E^2}{r_E} \simeq 6.0\times 10^{-4} \ . \tag{4.6.5}$$

What kind of tidal effects are predicted?

If the model applies also in the case of Earth itself, new kind of tidal effects are predicted due to the screening of the gravitational effects of Sun and Moon inside Earth. At the night-side the paraconical pendulum should experience the gravitation of Sun as screened. Same would apply to the "night-side" of Earth with respect to Moon.

Consider first the differences of accelerations in the direction of the line connecting Earth to Sun/Moon: these effects are not essential for tidal effects. The estimate for the ratio for the orders of magnitudes of the these accelerations is given by

$$\frac{|\Delta\overline{g}_{\perp}(Moon)|}{|\Delta\overline{g}_{\perp}(Sun)|} = \frac{M_S}{M_M}(\frac{r_M}{r_E})^3 \simeq 2.17 \ . \tag{4.6.6}$$

The order or magnitude follows from $r(Moon) = .0026$ AU and $M_M/M_S = 3.7\times 10^{-8}$. These effects are of same order of magnitude and can be compensated by a variation of the pressure gradients of atmosphere and sea water. The effects caused by Sun are two times stronger. These effects are of same order of magnitude and can be compensated by a variation of the pressure gradients of atmosphere and sea water.

The tangential accelerations are essential for tidal effects. They decompose as

$$\frac{1}{r^3}\left[\Delta\overline{r} - 3|\Delta\overline{r}|cos(\Theta)\frac{\overline{r}}{r}\right] \ .$$

$\pi/4 \leq \Theta \leq \pi/2$ is the angle between $\Delta\overline{r}$ and $\overline{r}$. The above estimate for the ratio of the contributions of Sun and Moon holds true also now and the tidal effects caused by Sun are stronger by a factor of two.

Consider now the new tidal effects caused by the screening.

1. Tangential effects on day-side of Earth are not affected (night-time and night-side are of course different notions in the case of Moon and Sun). At the night-side screening is predicted to reduce tidal effects with a maximum reduction at the equator.

2. Second class of new effects relate to the change of the normal component of the forces and these effects would be compensated by pressure changes corresponding to the change of the effective gravitational acceleration. The night-day variation of the atmospheric and sea pressures would be considerably larger than in Newtonian model.

The intuitive expectation is that the screening is maximum when the gravitational momentum flux travels longest path in the Earth's interior. The maximal difference of radial accelerations associated with opposite sides of Earth along the line of sight to Moon/Sun provides a convenient manner to distinguish between Newtonian and TGD based models:

$$\begin{aligned} |\Delta\overline{g}_{\perp,N}| &= 4GM\times\frac{R_E}{r^3} \ , \\ |\Delta\overline{g}_{\perp,TGD}| &= 4GM\times\frac{1}{r^2} \ . \end{aligned} \tag{4.6.7}$$

The ratio of the effects predicted by TGD and Newtonian models would be

$$\begin{aligned} \frac{|\Delta\overline{g}_{\perp,TGD}|}{|\Delta\overline{g}_{\perp,N}|} &= \frac{r}{R_E} \ , \\ \frac{r_M}{R_E} &= 60.2 \ , \ \frac{r_S}{R_E} = 2.34\times 10^4 \ . \end{aligned} \tag{4.6.8}$$

The amplitude for the oscillatory variation of the pressure gradient caused by Sun would be

$$\Delta|\nabla p_S| = \frac{v_E^2}{r_E} \simeq 6.1\times 10^{-4}g$$

and the pressure gradient would be reduced during night-time. The corresponding amplitude in the case of Moon is given by

$$\frac{\Delta|\nabla p_s|}{\Delta|\nabla p_M|} = \frac{M_S}{M_M} \times (\frac{r_M}{r_S})^3 \simeq 2.17 \ .$$

$\Delta|\nabla p_M$ is in a good approximation smaller by a factor of 1/2 and given by $\Delta|\nabla p_M| = 2.8 \times 10^{-4} g$. Thus the contributions are of same order of magnitude.

M_M/M_S	M_E/M_S	R_M/R_E	d_{E-S}/AU	d_{E-M}/AU
3.0×10^{-6}	3.69×10^{-8}	.273	1	.00257
R_E/d_{E-S}	R_E/d_{E-M}	g_S/g	g_M/g	
4.27×10^{-5}	01.7×10^{-7}	6.1×10^{-4}	2.8×10^{-4}	

Table 1. The table gives basic data relevant for tidal effects. The subscript E, S, M refers to Earth, Sun, Moon; R refers to radius; d_{X-Y} refers to the distance between X and Y g_S and g_M refer to accelerations induced by Sun and Moon at Earth surface. $g = 9.8$ m/s^2 refers to the acceleration of gravity at surface of Earth. One has also $M_S = 1.99 \times 10^{30}$ kg and $AU = 1.49 \times 10^{11}$ m, $R_E = 6.34 \times 10^6$ m.

One can imagine two simple qualitative killer predictions assuming maximal gravitational screening.

1. Solar eclipse should induce anomalous tidal effects induced by the screening in the shadow of the Moon.

2. The comparison of solar and moon eclipses might kill the scenario. The screening would imply that inside the shadow the tidal effects are of same order of magnitude at both sides of Earth for Sun-Earth-Moon configuration but weaker at night-side for Sun-Moon-Earth situation.

An interesting co-incidence

The value of $\Delta f/f = 5 \times 10^{-4}$ in experiment of Jeverdan is exactly equal to $v_0 = 2^{-11}$, which appears in the formula $\hbar_{gr} = GMm/v_0$ for the favored values of the gravitational Planck constant. The predictions are $\Delta f/f \leq \Delta p/p \simeq 3 \times 10^{-4}$. Powers of $1/v_0$ appear also as favored scalings of Planck constant in the TGD inspired quantum model of bio-systems based on dark matter [M3]. This co-incidence would suggest the quantization formula

$$\frac{g_E}{g_S} = \frac{M_S}{M_E} \times \frac{R_E^2}{r_E^2} = v_0 \tag{4.6.9}$$

for the ratio of the gravitational accelerations caused by Earth and Sun on an object at the surface of Earth.

It must be however admitted that the larger variation in the magnitude and even sign of the effect does not favor this kind of interpretation.

Summary of the predicted new effects

Let us sum up the basic predictions of the model assuming maximal gravitational screening.

1. The first prediction is the gradual increase of the oscillation frequency of the conical pendulum by $\Delta f/f \leq 3 \times 10^{-4}$ to maximum and back during night-time in case that the pendulum has vanishing Z^0 charge. Also a periodic variation of the frequency and a periodic rotation of the oscillation plane with period co-inciding with Moon's rotation period is predicted. Already Allais observed both 24 hour cycle and cycle which is slightly longer and due to the fact that Moon rates around Earth.

2. A paraconical pendulum with initial position, which corresponds to the resting position in the normal situation should begin to oscillate during solar eclipse. This effect is testable by fixing

the pendulum to the resting position and releasing it during the eclipse. The amplitude of the oscillation corresponds to the angle between $\overline{g}$ and $\overline{g}+\Delta\overline{g}$ given in a good approximation by

$$sin[\Theta(\overline{g},\overline{g}+\Delta\overline{g})] = \frac{\Delta g}{g} sin[\Theta(\overline{g},\Delta\overline{g})] \ . \quad (4.6.10)$$

An upper bound for the amplitude would be $\Theta \leq 3\times 10^{-4}$, which corresponds to .015 degrees. Z^0 charge of the pendulum would modify this simple picture.

3. Gravitational screening should cause a reduction of tidal effects at the "night-side" of Moon/Sun. The reduction should be maximum at "midnight". This reduction together with the fact that the tidal effects of Moon and Sun at the day side are of same order of magnitude could explain some anomalies know to be associated with the tidal effects [62]. A further prediction is the day-night variation of the atmospheric and sea pressure gradients with amplitude which is for Sun $3\times 10^{-4}g$ and for Moon $1.3\times 10^{-3}g$.

To sum up, the predicted anomalous tidal effects and the explanation of the limiting oscillation plane in terms of stronger dissipation in rotational degree of freedom could kill the model assuming only gravitational screening.

Comparison with experimental results

The experimental results look mutually contradictory in the context provided by the model assuming only screening. Some experiments find no anomaly at all as one learns from [55]. There are also measurements supporting the existence of an effect but with varying sign and quite different orders of magnitude. Either the experimental determinations cannot be trusted or the model is too simple.

1. The *increase* (!) of the frequency observed by Jeverdan and collaborators reported in Wikipedia article [55] for Foucault pendulum is $\Delta f/f \simeq 5\times 10^{-4}$ would support the model even quantitatively since this value is only by a factor 5/3 higher than the maximal effect allowed by the screening model. Unfortunately, I do not have an access to the paper of Jeverdan *et al* to find out the value of $cos(\Theta)$ in the experimental arrangement and whether there is indeed a decrease of the period as claimed in Wikipedia article. In [61] two experiments supporting an effect $\Delta g/g = x\times 10^{-4}$, $x = 1.5$ or 2.6 but the sign of the effect is different in these experiments.

2. Allais reported an anomaly $\Delta g/g \sim 5\times 10^{-6}$ during 1954 eclipse [60]. According to measurements by authors of [61] the period of oscillation increases and one has $\Delta g/g \sim 5\times 10^{-6}$. Popescu and Olenici report a decrease of the oscillation period by $(\Delta g/g)cos(\Theta) \simeq 1.4\times 10^{-5}$.

3. In [59] a *reduction* of vertical gravitational acceleration $\Delta g/g = (7.0\pm 2.7)\times 10^{-9}$ is reported: this is by a factor 10^{-5} smaller than the result of Jeverdan.

4. Small pressure waves with $\Delta p/p = 2\times 10^{-5}$ are registered by some micro-barometers [60] and might relate to the effect since pressure gradient and gravitational acceleration should compensate each other. $\Delta g cos(\Theta)/g$ would be about 7 per cent of its maximum value for Earth-Sun system in this case. The knowledge of the sign of pressure variation would tell whether effective gravitational force is screened or amplified by Moon.

4.6.3 Allais effect as evidence for large values of gravitational Planck constant?

One can represent rather general counter arguments against the models based on Z^0 conductivity and gravitational screening if one takes seriously the puzzling experimental findings concerning frequency change.

1. Allais effect identified as a rotation of oscillation plane seems to be established and seems to be present always and can be understood in terms of torque implying limiting oscillation plane.

2. During solar eclipses Allais effect however becomes much stronger. According to Olenici's experimental work the effect appears always when massive objects form collinear structures.

3. The behavior of the change of oscillation frequency seems puzzling. The sign of the frequency increment varies from experiment to experiment and its magnitude varies within five orders of magnitude.

What one an conclude about general pattern for $\Delta f/f$?

The above findings allow to make some important conclusions about the nature of Allais effect.

1. Some genuinely new dynamical effect should take place when the objects are collinear. If gravitational screening would cause the effect the frequency would always grow but this is not the case.

2. If stellar objects and also ring like dark matter structures possibly assignable to their orbits are Z^0 conductors, one obtains screening effect by polarization and for the ring like structure the resulting effectively 2-D dipole field behaves as $1/\rho^2$ so that there are hopes of obtaining large screening effects and if the Z^0 charge of pendulum is allow to have both signs, one might hope of being to able to explain the effect. It is however difficult to understand why this effect should become so strong in the collinear case.

3. The apparent randomness of the frequency change suggests that interference effect made possible by the gigantic value of gravitational Planck constant is in question. On the other hand, the dependence of $\Delta g/g$ on pendulum suggests a breaking of Equivalence Principle. It however turns out that the variation of the distances of the pendulum to Sun and Moon can explain the experimental findings since the pendulum turns out to act as a sensitive gravitational interferometer. An apparent breaking of Equivalence Principle could result if the effect is partially caused by genuine gauge forces, say dark classical Z^0 force, which can have arbitrarily long range in TGD Universe.

4. If topological light rays (MEs) provide a microscopic description for gravitation and other gauge interactions one can envision these interactions in terms of MEs extending from Sun/Moon radially to pendulum system. What comes in mind that in a collinear configuration the signals along S-P MEs and M-P MEs superpose linearly so that amplitudes are summed and interference terms give rise to an anomalous effect with a very sensitive dependence on the difference of S-P and M-P distances and possible other parameters of the problem. One can imagine several detailed variants of the mechanism. It is possible that signal from Sun combines with a signal from Earth and propagates along Moon-Earth ME or that the interferences of these signals occurs at Earth and pendulum.

5. Interference suggests macroscopic quantum effect in astrophysical length scales and thus gravitational Planck constants given by $\hbar_{gr} = GMm/v_0$, where $v_0 = 2^{-11}$ is the favored value, should appear in the model. Since $\hbar_{gr} = GMm/v_0$ depends on both masses this could give also a sensitive dependence on mass of the pendulum. One expects that the anomalous force is proportional to $\hbar_{gr}$ and is therefore gigantic as compared to the effect predicted for the ordinary value of Planck constant.

Model for interaction via gravitational MEs with large Planck constant

Restricting the consideration for simplicity only gravitational MEs, a concrete model for the situation would be as follows.

1. The picture based on topological light rays suggests that the gravitational force between two objects M and m has the following expression

$$\begin{aligned} F_{M,m} &= \frac{GMm}{r^2} = \int |S(\lambda,r)|^2 p(\lambda) d\lambda \\ p(\lambda) &= \frac{h_{gr}(M,m)2\pi}{\lambda} \ , \ \hbar_{gr} = \frac{GMm}{v_0(M,m)} \ . \end{aligned} \tag{4.6.11}$$

$p(\lambda)$ denotes the momentum of the gravitational wave propagating along ME. v_0 can depend on (M,m) pair. The interpretation is that $|S(\lambda,r)|^2$ gives the rate for the emission of gravitational waves propagating along ME connecting the masses, having wave length λ, and being absorbed by m at distance r.

2. Assume that $S(\lambda,r)$ has the decomposition

$$\begin{aligned} S(\lambda,r) &= R(\lambda)exp\left[i\Phi(\lambda)\right]\frac{exp\left[ik(\lambda)r\right]}{r} \ , \\ exp\left[ik(\lambda)r\right] &= exp\left[ip(\lambda)r/\hbar_{gr}(M,m)\right] \ , \\ R(\lambda) &= |S(\lambda,r)| \ . \end{aligned} \tag{4.6.12}$$

The phases $exp(i\Phi(\lambda))$ might be interpreted in terms of scattering matrix. The simplest assumption is $\Phi(\lambda)=0$ turns out to be consistent with the experimental findings. The substitution of this expression to the above formula gives the condition

$$\int |R(\lambda)|^2\frac{d\lambda}{\lambda} = v_0 \ . \tag{4.6.13}$$

Consider now a model for the Allais effect based on this picture.

1. In the non-collinear case one obtains just the standard Newtonian prediction for the net forces caused by Sun and Moon on the pendulum since $Z_{S,P}$ and $Z_{M,P}$ correspond to non-parallel MEs and there is no interference.

2. In the collinear case the interference takes place. If interference occurs for identical momenta, the interfering wavelengths are related by the condition

$$p(\lambda_{S,P}) = p(\lambda_{M,P} \ . \tag{4.6.14}$$

This gives

$$\frac{\lambda_{M,P}}{\lambda_{S,P}} = \frac{\hbar_{M,P}}{\hbar_{S,P}} = \frac{M_M}{M_S}\frac{v_0(S,P)}{v_0(M,P)} \ . \tag{4.6.15}$$

3. The net gravitational force is given by

$$\begin{aligned} F_{gr} &= \int |Z(\lambda,r_{S,P})+Z(\lambda/x,r_{M,P})|^2p(\lambda)d\lambda \\ &= F_{gr}(S,P)+F_{gr}(M,P)+\Delta F_{gr} \ , \\ \Delta F_{gr} &= 2\int Re\left[S(\lambda,r_{S,P})\overline{S}(\lambda/x,r_{M,P}))\right]\frac{\hbar_{gr}(S,P)2\pi}{\lambda}d\lambda \ , \\ x &= \frac{\hbar_{S,P}}{\hbar_{M,P}} = \frac{M_S}{M_M}\frac{v_0(M,P)}{v_0(S,P)} \ . \end{aligned} \tag{4.6.16}$$

Here $r_{M,P}$ is the distance between Moon and pendulum. The anomalous term ΔF_{gr} would be responsible for the Allais effect and change of the frequency of the oscillator.

4. The anomalous gravitational acceleration can be written explicitly as

$$\begin{aligned}\Delta a_{gr} &= 2\frac{GM_S}{r_S r_M}\frac{1}{v_0(S,P)}\times I \ ,\\ I &= \int R(\lambda)R(\lambda/x)cos\left[\Phi(\lambda)-\Phi(\lambda/x)+2\pi\frac{(y_S r_S - x y_M r_M)}{\lambda}\right]\frac{d\lambda}{\lambda} \ ,\\ y_M &= \frac{r_{M,P}}{r_M} \ , \ y_S = \frac{r_{S,P}}{r_S} \ . \end{aligned} \quad (4.6.17)$$

Here the parameter y_M (y_S) is used express the distance $r_{M,P}$ ($r_{S,P}$) between pendulum and Moon (Sun) in terms of the semi-major axis r_M (r_S)) of Moon's (Earth's) orbit. The interference term is sensitive to the ratio $2\pi(y_S r_S - x y_M r_M)/\lambda$. For short wave lengths the integral is expected to not give a considerable contribution so that the main contribution should come from long wave lengths. The gigantic value of gravitational Planck constant and its dependence on the masses implies that the anomalous force has correct form and can also be large enough.

5. If one poses no boundary conditions on MEs the full continuum of wavelengths is allowed. For very long wave lengths the sign of the cosine terms oscillates so that the value of the integral is very sensitive to the values of various parameters appearing in it. This could explain random looking outcome of experiments measuring $\Delta f/f$. One can also consider the possibility that MEs satisfy periodic boundary conditions so that only wave lengths $\lambda_n = 2r_S/n$ are allowed: this implies $sin(2\pi y_S r_S/\lambda) = 0$. Assuming this, one can write the magnitude of the anomalous gravitational acceleration as

$$\begin{aligned}\Delta a_{gr} &= 2\frac{GM_S}{r_{S,P} r_{M,P}}\times\frac{1}{v_0(S,P)}\times I \ ,\\ I &= \sum_{n=1}^{\infty} R(\frac{2r_{S,P}}{n})R(\frac{2r_{S,P}}{nx})(-1)^n cos\left[\Phi(n)-\Phi(xn)+n\pi\frac{x y_M}{y_S}\frac{r_M}{r_S}\right] \ . \end{aligned} \quad (4.6.18)$$

If $R(\lambda)$ decreases as λ^k, $k>0$, at short wavelengths, the dominating contribution corresponds to the lowest harmonics. In all terms except cosine terms one can approximate $r_{S,P}$ *resp.* $r_{M,P}$ with r_S *resp.* r_M.

6. The presence of the alternating sum gives hopes for explaining the strong dependence of the anomaly term on the experimental arrangement. The reason is that the value of xyr_M/r_S appearing in the argument of cosine is rather large:

$$\frac{x y_M}{y_S}\frac{r_M}{r_S} = \frac{y_M}{y_S}\frac{M_S}{M_M}\frac{r_M}{r_S}\frac{v_0(M,P)}{v_0(S,P)} \simeq 6.95671837\times 10^4 \times \frac{y_M}{y_S}\times\frac{v_0(M,P)}{v_0(S,P)} \ .$$

The values of cosine terms are very sensitive to the exact value of the factor $M_S r_M/M_M r_S$ and the above expression is probably not quite accurate value. As a consequence, the values and signs of the cosine terms are very sensitive to the values of y_M/y_S and $\frac{v_0(M,P)}{v_0(S,P)}$.

The value of y_M/y_S varies from experiment to experiment and this alone could explain the high variability of $\Delta f/f$. The experimental arrangement would act like interferometer measuring the distance ratio $r_{M,P}/r_{S,P}$. Hence it seems that the condition

$$\frac{v_0(S,P)}{v_0(M,P)} \neq const. \quad (4.6.19)$$

implying breaking of Equivalence Principle is not necessary to explain the variation of the sign of $\Delta f/f$ and one can assume $v_0(S,P) = v_0(M,P) \equiv v_0$. One can also assume $\Phi(n) = 0$.

Scaling law

The assumption of the scaling law

$$R(\lambda) = R_0(\frac{\lambda}{\lambda_0})^k \tag{4.6.20}$$

is very natural in light of conformal invariance and masslessness of gravitons and allows to make the model more explicit. With the choice $\lambda_0 = r_S$ the anomaly term can be expressed in the form

$$\begin{aligned} \Delta a_{gr} &\simeq \frac{GM_S}{r_S r_M}\frac{2^{2k+1}}{v_0}(\frac{M_M}{M_S})^k R_0(S,P)R_0(M,P) \times \sum_{n=1}^{\infty}\frac{(-1)^n}{n^{2k}} cos\left[\Phi(n) - \Phi(xn) + n\pi K\right] \ , \\ K &= x \times \frac{r_M}{r_S} \times \frac{y_M}{y_S} \ . \end{aligned} \tag{4.6.21}$$

The normalization condition of Eq. 4.6.13 reads in this case as

$$R_0^2 = v_0 \times \frac{1}{2\pi\sum_n(\frac{1}{n})^{2k+1}} = \frac{v_0}{\pi\zeta(2k+1)} \ . \tag{4.6.22}$$

Note the shorthand $v_0(S/M,P) = v_0$. The anomalous gravitational acceleration is given by

$$\begin{aligned} \Delta a_{gr} &= \sqrt{\frac{v_0(M,P)}{v_0(S,P)}}\frac{GM_S}{r_S^2} \times XY \times \sum_{n=1}^{\infty}\frac{(-1)^n}{n^{2k}} cos\left[\Phi(n) - \Phi(xn) + n\pi K\right] \ , \\ X &= 2^{2k} \times \frac{r_S}{r_M} \times (\frac{M_M}{M_S})^k \ , \\ Y &= \frac{1}{\pi\sum_n(\frac{1}{n})^{2k+1}} = \frac{1}{\pi\zeta(2k+1)} \ . \end{aligned} \tag{4.6.23}$$

It is clear that a reasonable order of magnitude for the effect can be obtained if k is small enough and that this is essentially due to the gigantic value of gravitational Planck constant.

The simplest model consistent with experimental findings assumes $v_0(M,P) = v_0(S,P)$ and $\Phi(n) = 0$ and gives

$$\begin{aligned} \frac{\Delta a_{gr}}{gcos(\Theta)} &= \frac{GM_S}{r_S^2 g} \times XY \times \sum_{n=1}^{\infty}\frac{(-1)^n}{n^{2k}} cos(n\pi K) \ , \\ X &= 2^{2k} \times \frac{r_S}{r_M} \times (\frac{M_M}{M_S})^k \ , \\ Y &= \frac{1}{\pi\sum_n(\frac{1}{n})^{2k+1}} = \frac{1}{\pi\zeta(2k+1)} \ , \\ K &= x \times \frac{r_M}{r_S} \times \frac{y_M}{y_S} \ , \ x = \frac{M_S}{M_M} \ . \end{aligned} \tag{4.6.24}$$

Numerical estimates

To get a numerical grasp to the situation one can use $M_S/M_M \simeq 2.71 \times 10^7$, $r_S/r_M \simeq 389.1$, and $(M_S r_M/M_M r_S) \simeq 1.74 \times 10^4$. The overall order of magnitude of the effect would be

$$\begin{aligned} \frac{\Delta g}{g} &\sim XY \times \frac{GM_S}{R_S^2 g} cos(\Theta) \ , \\ \frac{GM_S}{R_S^2 g} &\simeq 6 \times 10^{-4} \ . \end{aligned} \tag{4.6.25}$$

The overall magnitude of the effect is determined by the factor XY.

1. For $k=0$ the normalization factor is proportional to $1/\zeta(1)$ and diverges and it seems that this option cannot work.

2. The table below gives the predicted overall magnitudes of the effect for $k=1,2/2$ and $1/4$.

k	1	1/2	1/4
$\frac{\Delta g}{gcos(\Theta)}$	1.1×10^{-9}	4.3×10^{-6}	1.97×10^{-4}

   For $k=1$ the effect is too small to explain even the findings of [59] since there is also a kinematic reduction factor coming from $cos(\Theta)$. Therefore $k<1$ suggesting fractal behavior is required. For $k=1/2$ the effect is of same order of magnitude as observed by Allais. The alternating sum equals in a good approximation to -.693 for $y_S/y_M=1$ so that it is not possible to explain the finding $\Delta f/f \simeq 5\times 10^{-4}$ of Jeverdan.

3. For $k=1/4$ the expression for Δa_{gr} reads as

$$\begin{aligned}\frac{\Delta a_{gr}}{gcos(\Theta)} &\simeq 1.97\times 10^{-4}\sum_{n=1}^{\infty}\frac{(-1)^n}{n^{1/2}}cos(n\pi K) \quad , \\ K &= \frac{y_M}{y_S}u \ , \ u=\frac{M_S}{M_M}\frac{r_M}{r_S}\simeq 6.95671837\times 10^4 \ .\end{aligned} \tag{4.6.26}$$

   The sensitivity of cosine terms to the precise value of y_M/y_S gives good hopes of explaining the strong variation of $\Delta f/f$ and also the findings of Jeverdan. Numerical experimentation indeed shows that the cosine sum alternates and increases as y_M/y_S increases in the range $[1,2]$.

The eccentricities of the orbits of Moon *resp.* Earth are $e_M=.0549$ *resp.* $e_E=.017$. Denoting semimajor and semiminor axes by a and b one has $\Delta=(a-b)/a=1-\sqrt{1-e^2}$. $\Delta_M=15\times 10^{-4}$ *resp.* $\Delta_E=1.4\times 10^{-4}$ characterizes the variation of y_M *resp.* y_M due to the non-circularity of the orbits of Moon *resp.* Earth. The ratio $R_E/r_M=.0166$ characterizes the range of the variation of $\Delta y_M=\Delta r_{M,P}/r_M\leq R_E/r_M$ due to the variation of the position of the laboratory. All these numbers are large enough to imply large variation of the argument of cosine term even for $n=1$ and the variation due to the position at the surface of Earth is especially large.

The duration of full eclipse is of order 8 minutes which corresponds to angle $\phi=\pi/90$ and at equator roughly to a $\Delta y_N=(\sqrt{r_M^2+R_E^2sin^2(\pi/90)}-r_M)/r_M\simeq(\pi/90)^2R_E^2/2r_M^2\simeq 1.7\times 10^{-7}$. Thus the change of argument of $n=1$ cosine term during full eclipse is of order $\Delta\Phi=.012\pi$ at equator. The duration of the eclipse itself is of order two 2 hours giving $\Delta y_M\simeq 3.4\times 10^{-5}$ and the change $\Delta\Phi=2.4\pi$ of the argument of $n=1$ cosine term.

Other effects

There are also other strange effects involved.

1. One should explain also the recent finding by Popescu and Olenici, which they interpret as a quantization of the plane of oscillation of paraconical oscillator during solar eclipse [58]. A possible TGD based explanation would be in terms of quantization of $\Delta\overline{g}$ and thus of the limiting oscillation plane. This quantization could reflect the quantization of the angular momentum of the dark gravitons decaying into bunches of ordinary gravitons and providing to the pendulum the angular momentum inducing the change of the oscillation plane. The knowledge of friction coefficients associated with the rotation of the oscillation plane would allow to deduce the value of the gravitational Planck constant if one assumes that each dark gravitons corresponds to its own approach to asymptotic oscillation plane. The flux would be reduced in a stepwise manner during the solar eclipse as the distance traversed by the flux through Moon increases and reduced in a similar manner after the maximum of the eclipse.

2. There is also evidence for the effect before and after the main eclipse [58]. The time scale is 1 hour. A possible explanation is in terms of a dark matter ring analogous to rings of Jupiter surrounding Moon. From the average orbital velocity $v = 1.022$ km/s of the Moon one obtains that the distance traversed by moon during 1 hour is $R_1 = 3679$ km. The mean radius of moon is $R = 1737.10$ km so that one has $R_1 = 2R$ with 5 per cent accuracy ($2 \times R = 3474$ km). The Bohr quantization of the orbits of inner planets discussed in [D6] with the value $\hbar_{gr} = GMm/v_0$ of the gravitational Planck constant predicts $r_n \propto n^2 GM/v_0^2$ and gives the orbital radius of Mercury correctly for the principal quantum number $n = 3$ and $v_0/c = 4.6 \times 10^{-4} \simeq 2^{-11}$. From the proportionality $r_n \propto n^2 GM/v_0^2$ one can deduce by scaling that in the case of Moon with $M(moon)/M(Sun) = 3.4 \times 10^{-8}$ the prediction for the radius of $n = 1$ Bohr orbit would be $r_1 = (M(Moon)/M(Sun)) \times R_M/9 \simeq .0238$ km for the same value of v_0. This is too small by a factor 6.45×10^{-6}. $r_1 = 3679$ km would require $n \sim 382$ or $n = n(Earth) = 5$ and $v_0(Moon)/v_0(Sun) \simeq 2^{-4}$.

4.6.4 Could Z^0 force be present?

One can understand the experimental results without a breaking of Equivalence Principle if the pendulum acts as a quantum gravitational interferometer. One cannot exclude the possibility that there is also a dependence on pendulum. In this case one would have a breaking of Equivalence Principle, which could be tested using several penduli in the same experimental arrangement. The presence of Z^0 force could induce an apparent breaking of Equivalence Principle. The most plausible option is Z^0 MEs with large Planck constant. One can consider also an alternative purely classical option, which does not involve large values of Planck constant.

Could purely classical Z^0 force allow to understand the variation of $\Delta f/f$?

In the earlier model of the Allais effect (see the Appendix of [G1]) I proposed that the classical Z^0 force could be responsible for the effect. TGD indeed predicts that any object with gravitational mass must have non-vanishing em and Z^0 charges but leaves their magnitude and sign open.

1. If both Sun, Earth, and pendulum have Z^0 charges, one might even hope of understanding why the sign of the outcome of the experiment varies since he ratio of Z^0 charge to gravitational mass and even the sign of Z^0 charge of the pendulum might vary. Constant charge-to-mass ratio is of course the simplest hypothesis so that only an effective scaling of gravitational constant would be in question. A possible test is to use several penduli in the same experiment and find whether they give rise to same effect or not.

2. If Moon and Earth are Z^0 conductors, a Z^0 surface charge cancelling the tangential component of Z^0 force at the surface of Earth is generated and affects the vertical component of the force experienced by the pendulum. The vertical component of Z^0 force is $2F_Z cos(theta)$ and thus proportional to $cos(\Theta)$ as also the effective screening force below the shadow of Moon during solar eclipse. When Sun is in a vertical direction, the induced dipole contribution doubles the radial Z^0 force near surface and the effect due to the gravitational screening would be maximal. For Sun in horizon there would be no Z^0 force and gravitational tidal effect of Sun would vanish in the first order so that over all anomalous effect would be smallest possible: for a full screening $\Delta f/f \simeq \Delta g^2/4g^2 \simeq 4.5 \times 10^{-8}$ would be predicted. One might hope that the opposite sign of gravitational and Z^0 contributions could be enough to explain the varying sign of the overall effect.

3. It seems necessary to have a screening effect associated with gravitational force in order to understand the rapid variation of the effect during the eclipse. The fact that the maximum effect corresponds to a maximum gravitational screening suggests that it is present and determines the general scale of variation for the effect. If the maximal Z^0 charge of the pendulum is such that Z^0 force is of the same order of magnitude as the maximal screening of the gravitational force and of opposite sign (that is attractive), one could perhaps understand the varying sign of the effect but the effect would develop continuously and begin before the main eclipse. If the sign of Z^0 charge of pendulum can vary, there is no difficulty in explaining the varying sign of the effect. An interesting possibility is that Moon, Sun and Earth have dark matter halos

so that also gravitational screening could begin before the eclipse. The real test for the effect would come from tidal effects unless one can guarantee that the pendulum is Z^0 neutral or its Z^0 charge/mass ratio is always the same.

4. As noticed also by Allais, Newtonian theory does not give a satisfactory account of the tidal forces and there is possibility that tides give a quantitative grasp on situation. If Earth is Z^0 conductor tidal effects should be determined mainly by the gravitational force and modified by its screening whereas Z^0 force would contribute mainly to the pressure waves accompanying the shadows of Moon and Sun. The sign and magnitude of pressure waves below Sun and Moon could give a quantitative grasp of Z^0 forces of Sun and Moon. Z^0 surface charge would have opposite signs at the opposite sides of Earth along the line connecting Earth to Moon *resp.* Sun and depending on sign of Z^0 force the screening and Z^0 force would tend to amplify or cancel the net anomalous effect on pressure.

5. A strong counter argument against the model based on Z^0 force is that collinear configurations are reached in continuous manner from non-collinear ones in the case of Z^0 force and the fact that gravitational screening does not conform with the varying sign of the discontinuous effect occurring during the eclipse. It would seem that the effect in question is more general than screening and perhaps more like quantum mechanical interference effect in astrophysical length scale.

Could Z^0 MEs with large Planck constant be present?

The previous line of arguments for gravitational MEs generalizes in a straightforward manner to the case of Z^0 force. Generalizing the expression for the gravitational Planck constant one has $\hbar_{Z^0} = g_Z^2 Q_Z(M) Q_Z(m)/v_0$. Assuming proportionality of Z^0 charge to gravitational mass one obtains formally similar expression for the Z^0 force as in previous case. If Q_Z/M ratio is constant, Equivalence Principle holds true for the effective gravitational interaction if the sign of Z^0 charge is fixed. The breaking of Equivalence Principle would come naturally from the non-constancy of the $v_0(S,P)/v_0(M,P)$ ratio also in the recent case. The variation of the sign of $\Delta f/f$ would be explained in a trivial manner by the variation of the sign of Z^0 charge of pendulum but this explanation is not favored by Occam's razor.

4.7 Gravimagnetism and TGD

Gravimagnetism is one of the predictions of GRT which is being tested experimentally. TGD predicts deviations from the predictions of GRT which unfortunately are not seen in the satellite experiment to be discussed below. The claimed discovery of gravimagnetic effect in super-conductors having strength 20 orders of magnitude larger than predicted by GRT raises the question whether TGD might explain the effect.

4.7.1 Gravity Probe B and TGD

Gravity Probe B experiment tests the predictions o General Relativity related to gravimagnetism. Only the abstract [31] of the talk C. W. Francis Everitt summarizing the results is available when I am writing this.

The NASA Gravity Probe B (GP-B) orbiting gyroscope test of General Relativity, launched from Vandenberg Air Force Base on 20 April, 2004, tests two consequences of Einstein's theory: 1) the predicted 6.6 arc-s/year geodetic effect due to the motion of the gyroscope through the curved space-time around the Earth; 2) the predicted 0.041 arc-s/year frame-dragging effect due to the rotating Earth. The mission has required the development of cryogenic gyroscopes with drift-rates 7 orders of magnitude better than the best inertial navigation gyroscopes. These and other essential technologies, for an instrument which once launched must work perfectly, have come into being as the result of an intensive collaboration between Stanford physicists and engineers, NASA and industry. GP-B entered its science phase on August 27, 2004 and completed data collection on September 29, 2005. Analysis of the data has been in continuing progress during and since the mission. This paper will describe the main features and challenges of the experiment and announce the first results.

The article [32] gives an excellent summary of various test of GRT. The predictions tested by GP-B relate to gravimagnetic effects. The field equations of general relativity in post-Newtonian approximation with a choice of a preferred frame can in good approximation ($g_{ij} = -\delta_{ij}$) be written in a form highly reminiscent of Maxwell's questions with g_{tt} component of metric defining the counterpart of the scalar potential giving rise to gravito-electric field and g_{ti} the counterpart of vector potential giving rise to the gravimagnetic field.

Rotating body generates a gravimagnetic field so that bodies moving in the gravimagnetic field of a rotating body experience the analog of Lorentz force and gyroscope suffers a precession similar to that suffered by a magnetic dipole in magnetic field (Thirring-Lense effect or frame-drag). Besides this there is geodetic precession due to the motion of the gyroscope in the gravito-electric field present even in the case of non-rotating source which might be perhaps understood in terms of gravito-Faraday law. Both these effects are tested by GP-B.

In the following I represent some general comments about how TGD and GRT differs and also say something about the predictions of TGD concerning GP-B experiment.

TGD and GRT

Consider first basic differences between TGD and GRT.

1. In TGD local Lorentz invariance is replaced by exact Poincare invariance at the level of the imbedding space $H = M^4 \times CP_2$. Hence one can use unique global Minkowski coordinates for the space-time sheets and gets rids of the problems related to the physical identification of the preferred coordinate system.

2. General coordinate invariance holds true in both TGD and GRT.

3. The basic difference between GRT and TGD is that in TGD framework gravitational field is induced from the metric of the imbedding space. One important cosmological implication is that the imbeddings of the Robertson-Walker metric for which the gravitational mass density is critical or overcritical fail after some value of cosmic time. Also classical gauge potentials are induced from the spinor connection of H so that the geometrization applies to all classical fields. Very strong constraints between fundamental interactions at the classical level are implied since CP_2 are the fundamental dynamical variables at the level of macroscopic space-time.

4. Equivalence Principle holds in TGD only in a weak form in the sense that gravitational energy momentum currents (rather than tensor) are not identical with inertial energy momentum currents. Inertial four-momentum currents are conserved but not gravitational ones. This explains the non-conservation of gravitational mass in cosmological time scales. At the more fundamental parton level (light-like 3-surfaces to which an almost-topological QFT is assigned) inertial four-momentum can be regarded as the time-average of the non-conserved gravitational four-momentum so that equivalence principle would hold in average sense. The non-conservation of gravitational four-momentum relates very closely to particle massivation.

TGD and GP-B

There are excellent reasons to expect that Maxwellian picture holds true in a good accuracy if one uses Minkowski coordinates for the space-time surface. In fact, TGD allows a static solutions with 2-D CP_2 projection for which the prerequisites of the Maxwellian interpretation are satisfied (the deviations of the spatial components g_{ij} of the induced metric from $-\delta_{ij}$ are negligible).

Schwartschild and Reissner-Norström metrics allow imbeddings as 4-D surfaces in H but Kerr metric [33] assigned to rotating systems probably not. If this is indeed the case, the gravimagnetic field of a rotating object in TGD Universe cannot be identical with the exact prediction of GRT but could be so in the Post-Newtonian approximation. Scalar and vector potential correspond to four field quantities and the number of CP_2 coordinates is four. Imbedding as vacuum extremals with 2-D CP_2 projection guarantees automatically the consistency with the field equations but requires the orthogonality of gravito-electric and -magnetic fields. This holds true in post-Newtonian approximation in the situation considered.

Hence apart from restrictions caused by the failure of the global imbedding at short distances it *might* be possible to imbed Post-Newtonian approximations into H in the approximation $g_{ij} = -\delta_{ij}$.

If so, the predictions for Thirring-Lense effect would not differ measurably from those of GRT. The predictions for the geodesic precession involving only scalar potential would be identical in any case.

The imbeddability in the post-Newtonian approximation is however questionable if one assumes vacuum extremal property and small deformations of Schwartschild metric indeed predict a gravimagnetic field differing from the dipole form.

1. Simplest candidate for the metric of a rotating star

The simplest situation for the metric of rotating start is obtained by assuming that vacuum extremal imbeddable to $M^4 \times S^2$, where S^2 is the geodesic sphere of CP_2 with vanishing homological charge and induce Kähler form. Use coordinates (Θ, Φ) for S^2 and spherical coordinates (t, r, θ, ϕ) in space-time identifiable as M^4 spherical coordinates apart from scaling and r-dependent shift in the time coordinate.

1. For Schwartschild metric one has

$$\Phi = \omega t \ , \ sin(\Theta) = f(r) \ . \tag{4.7.1}$$

   f is fixed highly uniquely by the imbedding of Schwartschild metric and asymptotically one must have

$$f = f_0 + \frac{C}{r}$$

   in order to obtain $g_{tt} = 1 - 2GM/r$ $(\equiv 1 + \Phi_{gr})$ behavior for the induced metric.

2. The small deformation giving rise to the gravimagnetic field and metric of rotating star is given by

$$\Phi = \omega t + n\phi \tag{4.7.2}$$

   There is obvious analogy with the phase of Schödinger amplitude for angular momentum eigenstate with $L_z = n$ which conforms with the quantum classical correspondence.

3. The non-vanishing component of A^g is proportional to gravitational potential Φ_{gr}

$$A^g_\phi = g_{t\phi} = (n/\omega)\Phi_{gr} \ . \tag{4.7.3}$$

4. A little calculation gives for the magnitude of B^θ_g from the curl of A^g the expression

$$B^\theta_g = \frac{n}{\omega} \times \frac{1}{sin(\theta)} \times \frac{2GM}{r^3} \ . \tag{4.7.4}$$

   In the plane $\theta = \pi/2$ one has dipole field and the value of n is fixed by the value of angular momentum of star.

5. Quantization of angular momentum is obtained for a given value of ω. This becomes clear by comparing the field with dipole field in $\theta = \pi/2$ plane. Note that GJ, where J is angular momentum, takes the role of magnetic moment in B_g [32] appears as a free parameter analogous to energy in the imbedding and means that the unit of angular momentum varies. In TGD framework this could be interpreted in terms of dynamical Planck constant having in the most general case any rational value but having a spectrum of number theoretically preferred values. Dark matter is interpreted as phases with large value of Planck constant which means possibility of macroscopic quantum coherence even in astrophysical length scales. Dark matter would induce quantum like effects on visible matter. For instance, the periodicity of small n states might be visible as patterns of visible matter with discrete rotational symmetry.

2. Comparison with the dipole field

The simplest candidate for the gravimagnetic field differs in many respects from a dipole field.

1. Gravitomagnetic field has $1/r^3$ dependence so that the distance dependence is same as in GRT.

2. Gravitomagnetic flux flows along z-axis in opposite directions at different sides of $z = 0$ plane and emanates from z-axis radially and flows along spherical surface. Hence the radial component of B_g would vanish whereas for the dipole field it would be proportional to $cos(\theta)$.

3. The dependence on the angle θ of spherical coordinates is $1/sin(\theta)$ (this conforms with the radial flux from z-axis whereas for the dipole field the magnitude of B_g^θ has the dependence $sin(\theta)$. At $z = 0$ plane the magnitude and direction coincide with those of the dipole field so that satellites moving at the gravimagnetic equator would not distinguish between GRT and TGD since also the radial component of B_g vanishes here.

4. For other orbits effects would be non-trivial and in the vicinity of the flux tube formally arbitrarily large effects are predicted because of $1/sin(\theta)$ behavior whereas GRT predicts $sin(\theta)$ behavior. Therefore TGD could be tested using satellites near gravito-magnetic North pole.

5. The strong gravimagnetic field near poles causes gravi-magnetic Lorentz force and could be responsible for the formation of jets emanating from black hole like structures. This additional force might have also played some role in the formation of planetary systems and the plane in which planets move might correspond to the plane $\theta = \pi/2$ where gravimagnetic force has no component orthogonal to the plane. Same applies in the case of galaxies.

3. Consistency with the model for the asymptotic state of star

In TGD framework natural candidates for the asymptotic states of the star are solutions of field equations for which gravitational four-momentum is locally conserved. Vacuum extremals must therefore satisfy the field equations resulting from the variation of Einstein's action (possibly with cosmological constant) with respect to the induced metric. Quite remarkably, the solution representing asymptotic state of the star is necessarily rotating.

The proposed picture is consistent with the model of the asymptotic state of star. Also the magnetic parts of ordinary gauge fields have essentially similar behavior. This is actually obvious since CP_2 coordinates are fundamental dynamical variables and the field line topologies of induced gauge fields and induced metric are therefore very closely related.

As already discussed, the physicists M. Tajmar and C. J. Matos and their collaborators working in ESA (European Satellite Agency) have made an amazing claim of having detected strong gravimagnetism with gravimagnetic field having a magnitude which is about 20 orders of magnitude higher than predicted by General Relativity [48, 49, 50]. Hence there are some reasons to think that gravimagnetic fields might have a surprise in store.

When I am writing this (day later than what is above I have learned that the error bars for the frame-dragging effect are still twice the size of the effect as predicted by GRT. Already this information would have killed TGD inspired model unless the satellite would have been at the equator.

4.7.2 Does horizon correspond to a degenerate four-metric for the rotating counterpart of Schwartshild metric?

The metric determinant at Schwartschild radius is non-vanishing. This does not quite conform with the interpretation as an analog of a light-like partonic 3-surface identifiable as a wormhole throat for which the determinant of the induced 4-metric vanishes and at which the signature of the induced metric changes from Minkowskian to Euclidian.

An interesting question is what happens if one makes the vacuum extremal representing imbedding of Schwartshild metric a rotating solution by a very simple replacement $\Phi \rightarrow \Phi + n\phi$, where Φ is the angle angle coordinate of homologically trivial geodesic sphere S^2 for the simplest vacuum extremals, and ϕ the angle coordinate of M^4 spherical coordinates. It turns out that Schwartshild horizon is transformed to a surface at which $det(g_4)$ vanishes so that the interpretation as a wormhole throat makes sense.

The modification implies that the components $g_{t\phi}$ and $g_{r\phi}$ of the Schwartschild metric become non-vanishing and $g_{\phi\phi}$ component receives a small modification. Using the notations of the subsection *"Imbedding of Reissner-Nordström metric"*, one has

$$
\begin{aligned}
g_{t\phi} &= \omega_1 n \times \frac{R^2}{4} s_{\phi\phi}^{eff} \ , \\
g_{r\phi} &= \partial_{r_M} f n \times \frac{R^2}{4} s_{\phi\phi}^{eff} \ , \\
\Delta g_{\phi\phi} &= n^2 \times \frac{R^2}{4} s_{\phi\phi}^{eff} \ .
\end{aligned}
\tag{4.7.5}
$$

It is easy to see that $g_{r\phi}/g_{t\phi}$ is of order $\sqrt{r_S/r}$, $r_S = 2GM$, so that in an excellent approximation $g_{r\phi} = 0$ holds true at large distances and previous considerations related to gravimagnetic fields remain true.

The vanishing of the 4-D metric determinant reduces to that for 3-D metric determinant $det(g_3)$ associated with (t, r, ϕ). In the case of the Scwartshild metric this determinant is given by

$$
\begin{aligned}
det(g_3) &= -g_{\phi\phi} - A g_{r\phi}^2 + \frac{g_{t\phi}^2}{A} \ , \\
A &= 1 - \frac{2GM}{r} \equiv 1 - u \ .
\end{aligned}
\tag{4.7.6}
$$

Since A changes sign at Schwartchild radius $r_s = 2GM$, the determinant can indeed vanish near r_s. In a good approximation can neglect the contribution of $g_{r\phi}$ in the equation and put $r = r_S$ in the slowly varying functions. This gives

$$
\frac{R^2}{4} \omega_1^2 s_{\phi\phi}^{eff} \simeq \lambda^2
\tag{4.7.7}
$$

from the condition $u = r_S/r = 1$ applied to the induced metric. This gives

$$
\begin{aligned}
g_{\phi\phi} &\simeq -r_S^2 sin^2(\theta) - \frac{n^2}{\omega^2}\lambda^2 \ , \\
g_{t\phi} &\simeq -\frac{n}{\omega}\lambda^2 \ .
\end{aligned}
\tag{4.7.8}
$$

The singular surface for which $det(g_3)$ vanishes satisfies the approximate equation

$$
u - 1 = \frac{g_{t\phi}^2}{g_{\phi\phi}}(r = r_S) = \frac{n^2\lambda^4}{\omega^2 r_S^2 sin^2(\theta) - n^2\lambda^2} \ .
\tag{4.7.9}
$$

Since the left hand side can have both signs, the solution certainly exists but it can happen that part of it is inside and part outside Schwartshild radius.

$\theta = 0$ allows solution only for $r > r_S$: hence some portion of the surface is always outside r_S. If the condition

$$
\lambda^2 > \frac{\omega^2 r_S^2}{n^2}
\tag{4.7.10}
$$

is satisfied, the surface belongs belongs as a whole to the region $r > r_S$. The singular surface has a cigar like shape approaching sphere $r = \lambda^2 r_S$, $\lambda > 1$ at large quantum number limit $n \to \infty$. For $n = 0$ no solution is obtained. If one assumes that black hole horizon is analogous to a wormhole contact, only rotating black hole like structures with quantized angular momentum are possible in TGD Universe.

4.7.3 Has strong gravimagnetism been observed?

Physicists M. Tajmar and C. J. Matos and their collaborators working in ESA (European Satellite Agency) have made an amazing claim of having detected strong gravimagnetism with gravimagnetic field having a magnitude which is about 20 orders of magnitude higher than predicted by General Relativity [49]. If the findings are replicable they mean a revolution in the science of gravity and, as one might hope, force a long-waited serious reconsideration of the basic assumptions of the dominating super-string approach.

The starting point of the theory of Tajmar and Matos [48] is the so called Thomson magnetic moment generated in rotating charged super-conductors adding a constant contribution to the exponentially damped Meissner contribution to the magnetic field. This contribution can be understood as being due to the massivation of photons in super-conductors. The modified Maxwell equations are obtained by just adding scalar potential mass term to Gauss law and vector potential mass term to the equation related the curl of the magnetic field to the em current.

The expression for the Thomson magnetic field is given by

$$B = 2\omega_R n_s \times \lambda_\gamma^2 \ , \quad (4.7.11)$$

where ω_R is the angular velocity of superconductor, n_s is charge density of super-conducting particles and $\lambda_\gamma = \hbar/m_\gamma$ is the wave length of a massive photon at rest. In the case of ordinary superconductor one has $\lambda_\gamma = \sqrt{m^*/q^* n_s}$, where $m^* \simeq 2m_e$ and $q^* = -2e$ are the mass and charge of Cooper pair. Hence one has

$$B = -2\frac{m^*}{2e}\omega_R \ . \quad (4.7.12)$$

Magnetic field extends also outside the super-conductor and by measuring it with a sufficient accuracy outside the super-conductor one can determine the value of the electron mass. Instead of the theoretical value $m^*/2m_e = .999992$ which is smaller than one due to the binding energy of the Cooper pair the value $m^*/2m_e = 1.000084$ was found by Tate [50]. This inspired the theoretical work generalizing the notion of Thomson field to gravimagnetism and the attemnpt to explain the anomaly in terms of the effects caused by the gravimagnetic field.

Note that in the case of ordinary matter the equations would lead to an inconsistency at the limit $m_\gamma = 0$ since the value of Thomson magnetic field would become infinite. The resolution of the problem proposed in [48] is based on the replacement of rotation frequency ω with electron's spin precession frequency $\omega_L = -eB/2m$ so that the consistency equation becomes $B = -B = 0$ for a unique choice $1/\lambda_\gamma^2 = -\frac{q}{m}n$. One could also consider the replacement of ω with electron's cyclotron frequency $\omega_c = 2\omega_L$. To my opinion there is no need to assume that the modified Maxwell's equations hold true in the case of ordinary matter.

Gravimagnetic field

The perturbative approach to the Einstein equations leads to equations which are essentially identical with Maxwell's equations. The g_{tt} component of the metric plays the role of scalar potential and the components g_{ti} define gravitational vector potential. Also the generalization to the super-conducting situation in which graviphotons develop a mass is straightforward. Just add the scalar potential mass term to the counterpart of Gauss law and vector potential mass term to the equation relating the curl of the gravimagnetic field to the gravitational mass current.

In the case of a rotating superconductor Thomson magnetic moment is replaced with its gravimagnetic counterpart

$$B_{gr} = -2\omega_R \rho_m \lambda_g^2 \ . \quad (4.7.13)$$

Obviously this formula would give rise to huge gravimagnetic fields in ordinary matter approaching infinite values at the limit of vanishing gravitational mass. Needless to say, these kind of fields have not been observed.

Equivalence Principle however suggests that the gravimagnetic field must be assigned with the rotating coordinate frame of the super-conductor. Equivalence principle would state that seing the things in a rotating reference frame is equivalent of being in a gravimagnetic field $B_{gr} = -2\omega_R$ in the rest frame. This fixes the graviphoton mass to

$$\frac{1}{\lambda_{gr}^2} = (\frac{m_{gr}}{\hbar})^2 = G\rho_m \quad . \tag{4.7.14}$$

For a typical condensed matter density parameterized as $\rho_m = Nm_p/a^3$, $a = 10^{-10}$ m this gives the order of magnitude estimate $m_{gr} \sim N^{1/2}10^{-21}/a$ so that graviton mass would be extremely small.

If this is all what is involved, gravimagnetic field should have no special effects. In [48] it is however proposed that in superconductors a small breaking of Equivalence Principle occurs. The basic assumptions are following.

1. Super-conducting phase and the entire system obey separately their gravitational analogs of Maxwell field equations.
2. The ad hoc assumption is that for super-conducting phase the sign of the gravimagnetic field is opposite to that for the ordinary matter. If purely kinematic effect were in question so that graviphotons were pure gauge degrees of freedom, the value of m_{gr}^2 should should be proportional to ρ_m^* and $\rho_m - \rho_m^*$ respectively.
3. Graviphoton mass is same for both ordinary and super-conducting matter and corresponds to the net density ρ_m of matter. This is essential for obtaining the breaking of Equivalence Principle.

With these assumptions the gravimagnetic field giving rise to acceleration field detected in the rest system would be given by

$$B_{gr}^* = \frac{\rho_m^*}{\rho} \times 2\omega \tag{4.7.15}$$

This is claimed to give rise to a genuine acceleration field

$$g^* = -\frac{\rho_m^*}{\rho} a \tag{4.7.16}$$

where a is the radial acceleration due to the rotational motion.

Explanation for the too high value of measured electron mass in terms of gravimagnetic field

A possible explanation of the anomalous value of the measured electron mass [50] is in terms of gravimagnetic field affecting the flux Bohr quantization condition for electrons by adding to the electromagnetic vector potential term q^*A_{em} gravitational vector potential m^*A_{gr}. By requiring that the quantization condition

$$\oint (m^*v + q^*A_{em} + m^*A_{gr})dl = 0 \tag{4.7.17}$$

is satisfied for the superconducting ring, one obtains

$$B = -\frac{2m}{e}\omega - \frac{m}{e}B_{gr} \quad . \tag{4.7.18}$$

This means that the magnetic field is slightly stronger than predicted and it has been known that this is indeed the case experimentally.

The higher value of the magnetic field could explain the slightly too high value of electron mass as determined from the magnetic field. This gives

$$B_{gr} = \frac{\Delta m_e}{m_e} \times 2\omega = \frac{\Delta m_e}{m_e} \times e m_e \times B \ . \tag{4.7.19}$$

The measurement implies $\Delta m_e/m_e = 9.2 \times 10^{-5}$. The model discussed in [48] predicts $\Delta m_e/m_e \sim \rho^*/\rho$. The prediction is about 23 time smaller than the experimental result.

4.7.4 Is the large gravimagnetic field possible in TGD framework?

TGD allows top consider several alternative solutions for the claimed effect.

1. TGD predicts the possibility of classical electro-weak fields at larger space-time sheets. If these couple to Cooper pairs generate exotic weak charge at super-conducting space-time sheets the Bohr quantization conditions modify the value of the magnetic field. Exotic weak charge would however mean also exotic electronic em charge so that this option is excluded. It would also require that the Z^0 charge of test bodies used to measure the acceleration field is proportional to their gravitational mass.

2. TGD suggests a hierarchy of strong gravities analogous to those generated by spin 2 mesons. These gravitons behave like massless particles below the appropriate Compton length. This Compton length can be arbitrarily long at higher levels of dark matter hierarchy. Electrons do not however couple to these gravitons so that this option soes not seem to work.

3. The rotation of the super-conductor would correspond quite concretely to a rotation of the corresponding space-time sheet. Also the space-time sheet defining the magnetic and gravito-magnetic body of the system could participate to the rotation. Since the rotation affects the shape of the space-time surface the breaking of the Equivalence Principle is unavoidable. This predicts gravitational analogs of the effects found in rotating magnetic systems [35], for instance the radial gravitational field $E^{gr} = vB^{gr}$ but does not seem to be enough to understand what is involved.

4. As already noticed, the failure of Equivalence Principle could be understood if the gravimagnetic fields of super-conducting and ordinary matter do not interfere. Many-sheeted space-time suggest the lack of interference is caused by the fact that super-conducting and ordinary matter reside at different space-time sheets. If the measurement of the gravimagnetic field (or rather its change causing Faraday effect and tangential acceleration) is carried out at either space-time sheet a breaking of Equivalence Principle is observed. In the similar manner magnetic field is affected via Bohr rules for angular momentum and gives rise to the desired effect. In this framework the model of [48] looks rather plausible one.

5. Induced field concept implies extremely tight correlations between induced classical gauge fields and induced gravitational field and one expects that the magnetic field associated with the rotating super-conductor gives rise to a gravimagnetic field so that ordinary Meissner and Thompson effects would force their gravitational counterparts. This is not at all obvious in standard physics framework. It turns out however that the predicted gravimagnetic field is far two small in the simplest model.

6. The dependence of the mass of graviphoton on magnetic penetration length involves Planck constant. TGD predicts a hierarchy of Planck constants $\hbar(k) = \lambda^k \hbar_0$. This means that for given value of m_γ and m_{gr} there is a hierarchy of increasing photon graviton rest Compton length defining the penetration depths for superconductors. It turns out that if graviphotons are dark, one can indeed understand the huge value of gravimagnetic field in TGD framework.

Key observations

Two observations are essential for what follows.

1. It would seem that the superposition of the of the gravimagnetic fields of the superconducting and ordinary ordinary matter gives the net gravimagnetic field which would not give any anomalous effects. The breaking of Equivalence Principle could be understood if these fields do not interfere in the experimental situation. In TGD framework the separation of ordinary matter and Cooper pairs at separate space-time sheets can explain the absence of the interference.

2. In order to obtain large enough an effect one must assume that ρ_m^* contains an additional contribution besides Cooper pairs. In TGD framework the presence of also other particles besides Cooper pairs at super-conducting space-time sheets could increase the value of ρ_m^* by a factor of order 23. For instance, the space-time sheet could contain $23m_e/m_p$ protons $23m_e/Am_p$ heavier atoms per electron.

Could gravimagnetism and breaking of Equivalence Principle be forced by the induced field concept?

The safest starting point seems to be that the separation of super-conducting phase to its own space-time sheet induces the reduction $\rho_m \rightarrow \rho_m - \rho_m^*$ at the space-time of ordinary matter. If the photograviton is not modified correspondingly one has in inertial frame effective B_{gr} obtained by the replacement $\rho - \rho_m \rightarrow -\rho_m^*$ in the defining formula as one goes to rest system. This gives also the sign of the gravimagnetic field correctly. The task is to find whether the notion of induced gauge field is consistent with or can even predict the generation of B_{gr}.

TGD predicts an extremely tight correlation between various kinds of classical fields so that the Thomson magnetic field associated with super-conductor is expected to be accompanied by a gravimagnetic field which need not have a value consistent with the Equivalence Principle.

The assumption that the space-time sheet in question has a CP_2 projection belonging to either Lagrange manifold Y^2 of CP_2, say homologically trivial geodesic sphere, or to a non-trivial geodesic sphere allows to model the situation in a simple manner. For the homologically trivial sphere field equations are identically satisfied by the vacuum extremal property. The treatments are essentially identical so that the consideration is restricted to the non-vacuum case for definiteness.

For the simplest cylindrically symmetric situations CP_2 coordinates can be expressed as $(\Theta = f(\rho), \Phi = \omega t - n\phi)$ cylindrical coordinates for M^4. Kähler magnetic field would be $g_K B^K_{\rho\phi} = sin(\Theta)\rho n$ and gravimagnetic vector potential would have the non-vanishing component $A^{gr}_{\phi} = g_{t\phi} = -R^2\sin^2(\Theta)n\omega$. This would give $B^{gr}_{\rho\phi} = -2R^2\omega sin(\Theta)g_K B^K_{\rho\phi}$. For the ratio $2m_eB_{gr}/g_KB^K$ one would obtain

$$\frac{2m_eB^{gr}}{g_KB^K} = -2R^2\omega m_e sin(\Theta) \ . \tag{4.7.20}$$

Equivalence Principle would require $2m_eB_{gr}/eB_{em} = 1$ so that one would have

$$2R^2\omega m_e sin(\Theta) = -x \ . \tag{4.7.21}$$

where one has $eB_{em} \equiv xg_KB_K$. The value of x is completely fixed for homologically non-trivial geodesic sphere. In the appendix of [TGDview] it is shown to be $x = 3-2sin^2(\theta_W)$, where $sin^2(\theta_W) \simeq .23$ denotes Weinberg angle.

The condition is impossible to satisfy in precise sense since $sin(\Theta)$ cannot be constant so that at least a small breaking of Equivalence Principle is unavoidable but probably does not offer an explanation of the effect. The assumption that that B^K is constant implies $sin(\Theta) = \alpha + \beta\rho^2$ and implies that also B_{gr} is constant in the lowest order approximation.

The condition above would require an extremely large value of the parameter ω of order $\omega \sim 1/m_eR^2 \sim 10^{19}/R$. This would imply that the induced metric has Euclidian signature by $g_{tt} < 1 - R^2\omega^2sin^2(\Theta) < 0$. It would also imply a huge Kähler electric field $g_KE^K = g_KB^K_{\rho\phi}\omega/n$. The situation is obviously same also in the case that the value gravimagnetic field has the value needed to explain the experimental findings of Tate.

Could the large gravimagnetic field correspond to dark graviphotons?

A possible way out of the difficulty is based on the assumption that the graviphotons are dark and have a large value of Planck constant increasing in turn the value of λ_{gr} and thus gravimagnetic field.

The TGD based model for the hierarchy of Planck constants associated with the dark matter hierarchy assumes that the various values $\hbar = \lambda^k\hbar_0$, $\lambda \simeq 2^{11}$ correspond at the level of imbedding space to a book like structure. Different algebraic extensions of rational numbers and p-adic numbers correspond to different values of Planck constant and copies of imbedding space. The metrics for these different copies differ by a scaling in M^4 degrees of freedom and are glued together by along a subset of rationals such that the distances of the glued points from the common origin of glued copies of M^4 are identical. The configuration space of 3-surfaces decomposes into sectors labeled by unions of future and past light cones and the dips of these light cones define the preferred origins.

The key observation is that the role of Planck constant in the d'Alembertian at the level of the imbdding space is to multiply M^4 part of the d'Alembertian but leave CP_2 part unaffected. This is in accordance with the fact that induced spinor connection corresponds to gauge couplings not involving $\hbar$ and also with the fact that the scaling of CP_2 spinor connection does not make sense. At the level of induced spinor fields Planck constant in turn corresponds to the scaling factor of the M^4 part of the induced metric.

Hence it is natural to assume that contravariant M^4 metric scales as $\hbar^2(k) \propto \lambda^{2k}$. $\lambda \simeq 2^{11}$ as a function of $\hbar$ whereas CP_2 metric is not affected. This would mean that M^4 contribution to the induced covariant metric scales as λ^{-2k}: this implies that Kähler action can be seen as a function of the value of Planck constant and thus codes for the higher level corrections in powers of $\hbar$. This allows to have TGD to predict a series of higher order corrections in powers of $\hbar$ although the perturbation theory defined by the configuration space functional integral could reduce to the lowest order approximation as the general number theoretic and integrability arguments inspired by symmetric space property of the zero mode constant sectors of the configuration space suggest.

Using scaled coordinates in which M^4 metric is represented by a unit tensor, this geometrization of the dynamics of Planck constant would mean an effective scaling $R^2 \rightarrow \lambda^{2k}R^2$ for the CP_2 radius R increasing the contribution of the CP_2 metric to the induced metric. This is just what is needed to preserve the Minkowskian signature of the induced metric in ultrastrong gravimagnetic fields.

For a dynamical Planck constant the expression for ω would become $\omega \sim 1/m_e\lambda^{2k}R^2 \sim 10^{19}/\lambda^{2k}R$. The requirement that the signature of the induced metric is Minkowskian gives $g_{tt} = 1 - R^2\lambda^{2k}\omega^2 > 0$. This boils down to the conditions

$$\begin{aligned} \lambda^k &> \frac{x}{Rm_e} \sim 10^{19}x \ , \\ \omega &\leq \frac{m_e}{x^2} \ , \end{aligned} \tag{4.7.22}$$

where x is the numerical constant defined earlier. Using $\lambda \simeq 2^{11}$ this would give $k \geq 6$. The hierarchy of dark matter levels associated with living matter contains $k = 7$ levels relevant to human consciousness and $k = 7$ corresponds to a characteristic time scale of about 50 years [M3].

One can deduce an estimate for the dark graviphoton mass by assuming the value for λ_{gr} implied by B_{gr} necessary to explain the anomaly observed by Tate [50]. This would give

$$m_{gr} \sim \sqrt{\frac{N}{10}} \times \frac{1}{10^2 a} \ , \tag{4.7.23}$$

where gravitational mass density has been parameterized as $\rho_m = Nm_p/a^2$, $a = 10^{-10}$ m. Note that the rest energy is above the thermal threshold at room temperature. The mass corresponds to an ordinary Compton length of order 10 nm, size scale for Cooper pairs and cell membrane thickness which emerges as a fundamental length scale characterizing Cooper pairs in the TGD based model for high T_c super-conductor [J1, J2, J3]. TGD inspired model of living matter predicts that also the magnetic structures corresponding to scaled up variants of cell membrane having sizes scaled up by λ^k are fundamental [M3].

A possible physical interpretation for the origin of the ordinary graviphoton mass would be that the confinement of longitudinal graviton inside a magnetic flux tube of thickness $L(151) = 10$ nm gives its a non-vanishing effective rest mass due to the confinement in transversal degrees of freedom which is same for all scaled up variants. The effect would be completely analogous to the generation effective photon mass in waveguide. For $k = 6$ level the Compton length of the dark graviphoton would be about 10^{11} m, the size scale of the solar system, so that a genuine long range interaction would be in question.

The gravitational mass of the photon associated with super-conductivity would be enormous for ordinary value of Planck constant. For the ordinary value of Planck constant the mass would be around $m_\gamma \simeq 10^{-3} m_e$ and for $k = 6$ one would have $m_\gamma \simeq 10^{16} m_e$. This weird implication suggests that super-conducting photons are ordinary. In this case the wavelength would be of order one nanometer and of the same order of magnitude as the wavelength of ordinary graviphoton, which supports the interpretation that transversal confinement to magnetic flux tubes gives rise to the mass in both cases.

The model ties together both electron mass scale, the order of magnitude for the size of Cooper pairs, cell membrane thickness crucial for high T_c super-conductivity, and the size scale of the solar system which in the case finite space-time sheets would give natural estimate for the much lower mass scale of the ordinary graviphoton. This raises the hope that the model might have at least something to do with reality. The model also suggest that dark gravimagnetism might be of importance in living systems.

Other explanations

One can consider also other explanations for the strong gravimagnetic effect.

1. Are p-adically scaled variants of graviton in question?

The recent view about coupling constant evolution assumes that Kähler coupling strength is invariant under p-adic coupling constant evolution whereas gravitational constant is proportional to L_p^2 [C5]. In this framework gravitons correspond to the Mersenne prime $M_{127} = 2^{127} - 1$ defining the p-adic length scale of electron. The motivation comes from the hypothesis that gauge bosons in general correspond to Mersenne primes and that M_{127} is the largest Mersenne prime, which does not correspond to completely super-astrophysical p-adic length scale.

One can however consider the possibility that in some situations -perhaps in the case of super-conductor - the space-time sheet mediating gravitational interaction - gravitonic field body - corresponds to some larger prime. The scaling of G by a factor 10^{20} would require scaling of electronic p-adic length scale by a factor of order 10^{10} to give 2.5 cm length scale.

2. Super-symplectic strong gravitation

TGD predicts also super-symplectic spin two quanta and these give rise to strong gravitation with G or order L_p^2. Super-symplectic bosons are responsible for the non-perturbative aspects of hadron physics [F4, F5] and super-symplectic strong gravitation relates very closely to the stringy description of hadrons. There are good reasons to believe that strong gravitation prevails only at the hadronic space-time sheet. Also black-holes would in TGD framework correspond to gigantic hadron like structures resulting when the hadronic space-time sheets have fused together to form single highly entangled string like structure [F5]. Thus it would seem that super-symplectic strong gravitation cannot give rise to a gravimagnetic effect.

4.8 Some differences between GRT and TGD

In the following some effects possibly differentiating between GRT and TGD are discussed.

4.8.1 Anomalous time dilation effects due to warping as basic distinction between TGD and GRT

TGD predicts the possibility of large anomalous time dilation effects due to the warping of space-time surfaces, and the experimental findings of Russian physicist Chernobrov about anomalous changes in the rate of flow of time [43, 44] provide indirect support for this prediction.

Anomalous time dilation effect due to the warping

Consider first the ordinary gravitational time dilation predicted by GRT. For simplicity consider a stationary spherically symmetric metric $ds^2 = g_{tt}dt^2 - g_{rr}dr^2 - r^2d\Omega^2$ in spherical coordinates. The time dilation is characterized by the difference $\Delta = \sqrt{g_{tt}} - 1$. In the weak field approximation one has $g_{tt} = 1 + 2\Phi_{gr}$, where Φ_{gr} is gravitational potential. The ordinary time dilation is given by $\Delta = \sqrt{g_{tt}} - 1 \simeq 2\Phi_{gr}$. At the Earth's surface the gravitational potential of the Earth is about $\Phi_{gr} = GM/R_E \simeq 10^{-9}$.

Consider next the situation for space-time surfaces. There exists an infinite number of warped imbeddings of M^4 to $M^4 \times CP_2$ given by $s^k = s^k(m^0)$, which are metrically equivalent with the canonical imbedding with CP_2 coordinates constant. New M^4 time coordinate is related by a diffeomorphism to the standard one. By restricting the imbedding to $M^4 \times S^1$, where S^1 a geodesic circle with radius $R/2$ (using the chosen convention for the definition CP_2 radius), the time component of the induced metric is $g_{m^0m^0} = 1 - R^2\omega^2/4$. The identification of M^4 coordinates as the preferred natural standard coordinate frame allows to overcome the difficulties related to the identification of the preferred time coordinate in general relativity in the case the metric does not approach asymptotically flat metric. For this choice an anomalous time dilation $\sqrt{1 - R^2\omega^2/4}$ due to the warping results even when gravitational fields are absent. Moreover, the dilation can be large.

The study of the imbeddings of Scwhartshild metric as vacuum extremals demonstrates that this vacuum warping is also seen as the degeneracy of the imbeddings of stationary spherically symmetric metrics. If m^0 is used as a time coordinate, anomalous time dilation is obtained also at $r_M \to \infty$ and is given by

$$\sqrt{g_{m^0m^0}} = \frac{1}{\lambda} \ . \tag{4.8.1}$$

This time dilation is seen only if the clocks to be compared are at different space-time sheets. The anomalous time dilation can be quite large since the order of magnitude for the parameter ωR is naturally of order one for the imbeddings of R-N metrics.

Mechanisms producing anomalous time dilation

Anomalous time dilation could result in many manners.

1. An adiabatic variation of the parameters λ and ω_1 of the space-time sheet containing the clock could be induced by some physical mechanism. For instance, X^4_c could move "over" a large space-time sheet X^4 and gradually form # and $\#_B$ contacts with it. Topological light rays (MEs) define a good candidate for X^4. The parameter values λ and ω could change quasi-continuously if X^4_c gradually generates CP_2 sized wormhole contacts or join along boundaries bonds connecting it to X^4. This process would not affect the gravitational flux feeded to X^4_c.

   For instance, if X^4 is at rest with respect to Earth, this motion would result from the rotation of Earth and the effect should appear periodically from day to day. If it is at rest with respect to Sun, the effect should appear once a year.

   The generation of vacuum extremals X^4_{vac} (not gravitational vacua), which is in principle possible even by intentional action since conservation laws are not broken, could induce anomalous time dilation by this mechanism.

2. A phase transition increasing the value of $\hbar$ increases the size of the space-time sheet in the same proportion. This transition could quite well affect also the parameter λ. If this phase transition occurs for the space-time sheet X^4_c at which the clock feeds its gravitational flux, this mechanism could provide a feasible manner to induce an anomalous time dilation.

3. The system containing the clock could suffer a temporary topological condensation to a smaller space-time sheet and thus feed its gravitational flux to this space-time sheet. This would require coherently occurring splitting of # contacts and their regeneration. It is not possible to say anything definite about the probability of this kind of process except that it does not look very feasible.

The findings of Chernobrov

The findings claimed by Russian researcher V. Chernobrov support anomalous time dilation effect [43, 44]. Chernobrov has studied anomalies in the rate of time flow defined operationally by comparing the readings of clocks enclosed inside a spherical volume with the readings of clocks outside this volume. The experimental apparatus involves a complex Russian doll like structure of electromagnets.

Chernobrov reports a slowing down of time by about 30 seconds per hour inside his experimental apparatus [43] so that the average dilation factor during hour would be about $\Delta = 1/120$. If the dilation is present all the time, the anomalous contribution to the gravitational potential would be by a factor $\sim 10^7$ larger than that of Earth's gravitational potential and huge gravitational perturbations would be required to produce this kind of effect.

The slowing of the time flow is reported to occur gradually whereas the increase for the rate of time flow is reported to occur discontinuously. Time dilation effects were observed in connection with the cycles of moon, diurnal fluctuations, and even the presence of operator.

Consider now the explanation of the basic qualitative findings of Chernobrov.

1. The gradual slowing of the time flow suggests that the parameter values of λ and ω change adiabatically. This favors option 1) since the formation of # contacts occurs with some finite rate.

2. Also the sudden increase of the rate of time flow is consistent with option 1) since the splitting of # contacts occurs immediately when the sheets X^4_c and X^4 are not "over" each other.

3. The occurrence of the effect in connection with the cycles of moon, diurnal fluctuations, and in the presence of operator support this interpretation. The last observation would support the view that intentional generation of almost vacuum space-time sheets is indeed possible.

Vacuum extremals as means of generating time dilation effects intentionally?

Field equations allow a gigantic family of vacuum extremals: any 4-surface having CP_2 projection, which belongs to a 2-dimensional Lagrange manifold with a vanishing induced Kähler form, is a vacuum extremal. Symplectictransformations and diffeomorphisms of CP_2 produce new vacuum extremals. Vacuum extremals carry non-vanishing classical electro-weak and color fields which are reduced to some $U(1)$ subgroup of the full gauge group and also classical gravitational field. Although the vacuum extremals are not absolute minima, their small deformations could define such. These vacuum extremals, call them X^4_{vac} for brevity, could be generated by intentional action. In the first quantum jump the p-adic variant of the vacuum extremal representing an intention to create X^4_{vac} would appear and in some subsequent quantum jump it would be transformed to a real space-time sheet.

The creation of these almost vacuum extremals could generate time dilation effects. The material system would gradually generate CP_2 sized wormhole contacts and/or join along boundaries connecting its space-time sheet to X^4_{vac} and this could change the values of the vacuum parameters λ, ω.

Could warping have something to do with condensed matter physics?

Warping predicts the reduction of the effective light velocity. There is a report [75] of an experimental study of a condensed-matter system (graphene, a single atomic layer of carbon, in which electron transport is essentially governed by massless Dirac's equation. According to the report, the charge carriers in graphene mimic relativistic particles with zero rest mass and have an effective 'speed of light' $c_1 = c/300 = 10^6$ m/s.

The study reveals a variety of unusual phenomena that are characteristic of two-dimensional Dirac fermions. Graphene's conductivity never falls below a minimum value corresponding to the quantum unit of conductance, even when the concentrations of charge carriers tend to zero. The integer quantum Hall effect in graphene is anomalous in that it occurs at half-integer filling factors. The cyclotron mass m_c of massless current carriers in graphene is defined in terms of the energy of current carrier as $E = m_c c_1^2$.

The authors believe that these phenomena can be understood in the framework of the ordinary QED and this might be the case. One can however wonder whether the massless Dirac equation for the 2-dimensional system could correspond to the modified Dirac equation for the induced spinor fields and whether the reduction of the maximal signal velocity to c_1 could have the warping of the space-time sheet as a space-time correlate. In the idealization that the CP_2 projection of the space-time surface is a geodesic circle of CP_2, and using M^4 coordinates for space-time surface, so that one would have $\Phi = \omega t$ for S^2 coordinate Φ, one would have $g_{tt} = c_1^2 = 1 - R^2\omega^2/4 = 10^{-4}/9$.

4.8.2 Evidence for many-sheeted space-time from gamma ray flares

MAGIC collaboration has found evidence for a gamma ray anomaly. Gamma rays in different energy ranges seem to arrive with different velocities from Mkn 501 [63]. The delay in arrival times is about 4 minutes. The proposed explanation is in terms of broken Lorentz invariance. TGD allows to explain the finding in terms of many-sheeted space-time and there is no need to invoke breaking of Lorentz invariance.

TGD based explanation at qualitative level

One of the oldest predictions of many-sheeted space-time is that the time for photons to propagate from point A to B along given space-time sheet depends on space-time sheet because photon travels along lightlike geodesic of space-time sheet rather than lightlike geodesic of the imbedding space and thus increases so that the travel time is in general longer than using maximal signal velocity.

Many-sheetedness predicts a spectrum of Hubble constants and gamma ray anomaly might be a demonstration for the many-sheetedness. The spectroscopy of arrival times would give information about how many sheets are involved.

Before one can accept this explanation, one must have a good argument for why the space-time sheet along which gamma rays travel depends on their energy and why higher energy gamma rays would move along space-time sheet along which the distance is longer.

1. Shorter wavelength means that that the wave oscillates faster. Space-time sheet should reflect in its geometry the the matter present at it. Could this mean that the space-time sheet is more "wiggly" for higher energy gamma rays and therefore the distance travelled longer? A natural TGD inspired guess is that the p-adic length scales assignable to gamma ray energy defines the p-adic length scale assignable to the space-time sheet of gamma ray connecting two systems so that effective velocities of propagation would correspond to p-adic length scales coming as half octaves. Note that there is no breaking of Lorentz invariance since gamma ray connects the two system and the rest system of receiver defines a unique coordinate system in which the energy of gamma ray has Lorentz invariant physical meaning.

2. One can invent also an objection. In TGD classical radiation field decomposes into topological light rays ("massless extremals", MEs) which could quite well be characterized by a large Planck constant in which case the decay to ordinary photons would take place at the receiving end via de-coherence. Gamma rays could propagate very much like a laser beam along the ME. For the simplest MEs the velocity of propagation corresponds to the maximal signal velocity and there would be no variation of propagation time.

   One can imagine two manners to circumvent to the counter argument.

   i) Also topological light rays for which light-like geodesics are replaced with light-like curves of M^4 are highly suggestive as solutions of field equations. For these MEs the distance travelled would be in general longer than for the simplest MEs.

   ii) The gluing of ME to background space-time by wormhole contacts (actually representation for photons!) could force the classical signal to propagate along a zigzag curve formed by simple MEs with maximal signal velocity. The length of each piece would be of order p-adic length scale. The zigzag character of the path of arrival would increase the distance between source and receiver.

Quantitative argument

A quantitative estimate runs as follows.

1. The source in question is quasar Makarian 501 with redshift $z = .034$. Gamma flares of duration about 2 minutes were observed with energies in bands .25-.6 TeV and 1.2-10 TeV. The gamma rays in the higher energy band were near to its upper end and were delayed by about $\Delta\tau = 4$ min with respect to those in the lower band. Using Hubble law $v = Hct$ with $H = 71$ km/Mparsec/s, one obtains the estimate $\Delta\tau/\tau = 1.6 \times 10^{-14}$.

2. A simple model for the induced metric of the space-time sheet along which gamma rays propagate is as a flat metric associated with the flat imbedding $\Phi = \omega t$, where Φ is the angle coordinate of the geodesic circle of CP_2. The time component of the metric is given by

$$g_{tt} = 1 - R^2\omega^2 \quad .$$

ω appears as a parameter in the model. Also the imbeddings of Reissner-Norström and Schwartschild metrics contain frequency as free parameter and space-time sheets are quite generally parameterized by frequencies and momentum or angular momentum like vacuum quantum numbers.

3. ω is assumed to be expressible in terms of the p-adic prime characterizing the space-time sheet. The parametrization to assumed in the following is

$$\omega^2 R^2 = Kp^{-r} \quad .$$

It turns out that $r = 1/2$ is the only option consistent with the p-adic length scale hypothesis. The naive expectation would have been $r = 1$. The result suggests the formula

$$\omega^2 = m_0 m_p \ \text{ with } \ m_0 = \frac{K}{R} \quad .$$

ω would be the geometric mean of a slowing varying large p-adic mass scale and p-adic mass scale m_p.

The explanation for the p-adic length scale hypothesis leading also to a generalization of Hawking-Bekenstein formula assumes that for the strong form of p-adic length scale hypothesis stating $p \simeq 2^k$, k prime, there are two p-adic length scales involved with given elementary particle. L_p characterizes particle's Compton length and L_k characterizes the size of the wormhole contact or throat representing the elementary particle. The guess is that ω is proportional to the geometric mean of these two p-adic length scales:

$$\omega^2 R^2 = \frac{x}{2^{k/2}\sqrt{k}} \quad .$$

4. A relatively weak form of the p-adic length scale hypothesis would be $p \simeq 2^k$, k an odd integer. M_{127} corresponds to the mass scale $m_e 5^{-1/2}$ in a reasonable approximation. Using $m_e \simeq .5$ MeV one finds that the mass scales $m(k)$ for $k = 89 - 2n$, $n = 0, 1, 2..., 6$ are $m(k)/TeV = x$, with $x = 0.12, 0.23, 0.47, 0.94, 1.88, 3.76, 7.50$. The lower energy range contains the scales $k = 87$ and 85. The higher energy range contains the scales $k = 83, 81, 79, 77$. In this case the proposed formula does not make sense.

5. The strong form of p-adic length scale hypothesis allows only prime values for k. This would allow Mersenne prime M_{89} (intermediate gauge boson mass scale) for the lower energy range and $k = 83$ and $k = 79$ for the upper energy range. A rough estimate is obtained by assuming that the the two energy ranges correspond to $k_1 = 89$ and $k_2 = 79$.

6. The expression for τ reads as $\tau = (g_{tt})^{1/2}t$. $\Delta\tau/\tau$ is given by

$$\begin{aligned}&\tfrac{\Delta\tau}{\tau} \simeq (g_{tt})^{-1/2}\tfrac{\Delta g_{tt}}{2} \simeq R^2\Delta\omega^2 = x[(k_2p_2)^{-1/2} - (k_1p_1)^{-1/2}] \simeq x(k_2p_2)^{-1/2}\\ &= x2^{-79/2}79^{-1/2} \quad .\end{aligned}$$

Using the experimental value for $\Delta\tau/\tau$ one obtains $x \simeq .45$. $x = 1/2$ is an attractive guess.

4.8.3 Is gravitational constant really constant?

The most convincing TGD based model for the p-adic coupling constant evolution identified hitherto [C5] predicts that gravitational coupling constant is proportional to the square of p-adic length scale: $G \propto L_p^2$. Together with p-adic length scale hypothesis this would predict that gravitational coupling strength can have values differing from its standard value by a power of 2. $p = M_{127}$ would characterize the space-time sheet mediating ordinary gravitational interactions. In the following possible indications for the variation of G is discussed.

The case of Bullet cluster

The studies of the Bullet cluster [37, 38], provide the best evidence to date for the existence of dark matter. Bullet cluster [36] consists of two colliding clusters of galaxies (strictly speaking, the term refers to the smaller one of the two clusters). The major components of the cluster pair, stars, gas and the putative dark matter, behave differently during collision, allowing them to be studied separately.

The stars of the galaxies, observable in visible light, were not greatly affected by the collision, and most passed right through, gravitationally slowed but not otherwise altered. The hot gas of the two colliding components, seen in X-rays, represents about 90 per cent of the mass of the ordinary matter in the cluster pair. The gases interact electromagnetically, so that the velocity change for the gases of clusters is larger than for the stars of clusters. The dominating dark matter component was detected indirectly by its gravitational lensing. The observation that the lensing is strongest in two separated regions near the visible galaxies, confirms with the assumption that most of the mass in the cluster pair is in the form of collisionless dark matter.

Particularly compelling results were inferred from the Chandra observations of the bullet cluster. Those authors report that the cluster is undergoing a high-velocity [around 4500 km/s] merger, evident from the spatial distribution of the hot, X-ray emitting gas, but this gas lags behind the sub-cluster galaxies. Furthermore, the dark matter clump, revealed by the weak-lensing map, is coincident with the collisionless galaxies, but lies ahead of the collisional gas.

Later came the work of Glennys Farrar, Rachel Rosen, and Volker Springler [39] suggesting that the situation might not be as simple as this (for a popular article see [40]). The velocity of the bullet of dark matter is higher than it should be in the cold dark matter scenario (CDM). The proposal is that dark matter has its own additional attractive interaction of finite range, "fifth force". Since the finite range of the force is not actually significant in the situation considered, the model is mathematically equivalent with a model assuming that dark gravitational coupling strength. A good fit is obtained by assuming that the net effective gravitational force is by a factor 2 stronger than gravitational force.

The hypothesis is claimed to solve also some other problems of the cold dark matter scenario (CDM). The number of dwarf galaxies around ordinary galaxies is considerably smaller than predicted by CDM. The strong binding of dark matter in dwarfs would make them more compact and this in turn would mean that the binding of visible matter is weaker so that ordinary galaxies would have ripped this matter off and dwarfs would be more difficult to detect. CDM also predicts less galaxy clusters and stronger attraction for dark matter could resolve the problem.

TGD predicts that gravitational constant is proportional to the square of p-adic length scale: $G \propto L_p^2 \equiv L(k)^2$, $p \simeq 2^k$, k integer, in particular power of prime. Ordinary gravitational constant would correspond to $p = M_{127} = 2^{127}-1$, which is the largest Mersenne prime which is not completely super-astrophysical and corresponds to electron's p-adic length scale. One can however ask whether it might be possible to have situations in which the p-adic length scale assigned to the space-time sheets mediating gravitational interaction differs from M_{127}. $L(k)$ $k = 2^7 = 128$, would would correspond to $G \rightarrow 2G$. The growth of the gravitational coupling strength could be a transient phenomenon taking place only during the collision.

Shrinking kilogram

The definition of kilogram [51] is not the topics number one in coffee table discussions and definitely not so because it could lead to heated debates. The fact however is that even the behavior of standard kilogram can open up fascinating questions about the structure of space-time.

The 118-year old International Prototype Kilogram is an alloy with 90 per cent Platinum and 10 per cent Iridium by weight (gravitational mass). It is held in an environmentally monitored vault in the basement of the BIPMs House of Breteuil in Sevres on the outskirts of Paris. It has forty copies located around the world which are compared with Sevres copy with a period of 40 years.

The problem is that the Sevres kilogram seems to behave in a manner totally in-appropriate taking into account its high age if the behavior of its equal age copies around the world is taken as the norm [51, 52]. The unavoidable conclusion from the comparisons is that the weight of Sevres kilogram has been reduced by about 50 μg during 118 years which makes about

$$\frac{dlog(m)}{dt} = -4.2 \times 10^{-10}/year \quad .$$

for Sevres copy or relative increase of same amout for its copies.

Specialists have not been able to identify any convincing explanation for the strange phenomenon. For instance, there is condensation of matter from the air in the vault which increases the weight and there is periodic cleaning procedure which however should not cause the effect.

1. Could the non-conservation of gravitational energy explain the mystery?

The natural question is whether there could be some new physics mechanism involved. If the copies were much younger than the Sevres copy, one could consider the possibility that gravitational mass of all copies is gradually reduced. This is not the case. One can still however look what this could mean.

In TGD Equivalence Principle is not a basic law of nature and in the generic case gravitational energy is non-conserved whereas inertial energy is conserved (I will not go to the delicacies of zero energy ontology here). This occurs even in the case of stationary metrics such as Reissner-Nordström exterior metric and the metrics associated with stationary spherically symmetric star models imbedded as vacuum extremals as has been found.

The basic reason is that Schwartschild time t relates by a scaling and shift to Minkowski time m^0:

$$m^0 = \lambda t + h(r)$$

such that the shift depends on the distance r to the origin. The Minkowski shape of the 3-volume containing the gravitational energy changes with M^4 time but this does not explain the effect. The key observation is that the vacuum extremal of Kähler action is not an extremal of the curvature scalar (these correspond to asymptotic situations). What looks first really paradoxical is that one obtains a constant value of energy inside a fixed constant volume but a non-vanishing flow of energy to the volume. The explanation is that the system simply destroys the gravitational energy flowing inside it! The increase of gravitational binding energy compensating for the feed of gravitational energy gives a more familiar looking articulation for the non-conservation.

Amusingly, the predicted rate for the destruction of the inflowing gravitational energy is of same order of magnitude as in the case of kilogram. Note also that the relative rate is of order $1/a$, a the value of cosmic time of about 10^{10} years. The spherically symmetric star model also predicts a rate of same order.

This approach of course does not allow to understand the behavior of the kilogram since it predicts no change of gravitational mass inside volume and does not even apply in the recent situation since all kilograms are in same age. The co-incidence however suggests that the non-conservation of gravitational energy might be part of the mystery. The point is that if the inflow satisfies Equivalence Principle then the inertial mass of the system would slowly increase whereas gravitational mass would remain constant: this would hold true only in steady state.

2. Is the change of inertial mass in question?

It would seem that the reduction in weight should correspond to a reduction of the inertial mass in Sevres or its increase of its copies. What would distinguish between Sevres kilogram and its cousins? The only thing one can imagine is that the cousins are brought to Sevres periodically. The transfer process could increase the kilogram or stop its decrease.

Could it be that the inertial mass of every kilogram increases gradually until a steady state is achieved? When the system is transferred to another place the saturation situation is changed to a situation in which genuine transfer of inertial and gravitational mass begins again and leads to a more massive steady state. The very process of transferring the comparison masses to Sevres would cause their increase.

In TGD Universe the increase of the inertial (and gravitational) mass is due to the flow of matter from larger space-time sheets to the system. The additional mass would not enter in via the surface of the kilogram but like a Trojan horse from the interior and it would be thus impossible to control using present day technology. The flow would continue until a flow equilibrium would be reached with as much mass leaving the kilogram as entering it.

3. A connection with gravitation after all?

Why the in-flow of the inertial energy should be of same order of magnitude as that for the gravitational energy predicted by simple star models? Why Equivalence Principle should hold for the in-flow although it would not hold for the body itself? A possible explanation is in terms of the increasing gravitational binding energy which in a steady situation leaves gravitational energy constant although inertial energy could still increase.

This would however require rather large value of gravitational binding energy since one has

$$\Delta E_{gr} = \frac{\Delta M_I}{M} \ .$$

The Newtonian estimate for E_{gr}/M is of order GM/R, where $R \simeq .1$ m the size of the system. This is of order 10^{-26} and too small by 16 orders of magnitude.

TGD predicts that gravitational constant is proportional to p-adic length scale squared

$$G \propto L_p^2 \ .$$

Ordinary gravitation can be assigned to the Mersenne prime M_{127} associated with electron and thus to p-adic length scale of $L(127) \simeq 2.5 \times 10^{-14}$ meters. The open question has been whether the gravities corresponding to other p-adic length scales are realized or not.

This question together with the discrepancy encourages to ask whether the value of the p-adic prime could be larger inside massive bodies (analogous to black holes in many respects in TGD framework) and make gravitation strong? In the recent case the p-adic length scale should correspond to a length scale of order $10^8 L(127)$. $L(181) \simeq 3.2 \times 10^{-4}$ m (size of a large neuron by the way) would be a good candidate for the p-adic scale in question and considerably smaller than the size scale of order .1 meter defining the size of the kilogram.

This discrepancy brings in mind the strange finding of Tajmar and collaborators [48, 49, 50]. suggesting that rotating super-conductors generate a gravimagnetic field with a field strength by a factor of order 10^{20} larger than predicted by General Relativity. I have considered in this chapter a model of the finding based on dark matter. An alternative model could rely on the assumption that Newton's constant can in some situations correspond to p larger than M_{127}. In this case the p-adic length scale needed would be around $L(193) \simeq 2$ cm.

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Chapter 5

Cosmic Strings

5.1 Introduction

Cosmic strings belong to the basic extremals of the Kähler action. These cosmic strings have nothing to do with the cosmic strings of GUTS [50] but their string tension $T \simeq .52 \times 10^{-6}/G$ happens to be in the same range as that for the GUT strings and this makes them very interesting cosmologically. Indeed, string like objects play a fundamental role in TGD inspired cosmology and also provide TGD based models for the galaxy formation, galactic dark matter, and for the generation of the large voids. Therefore the study of the properties of cosmic strings deserves a separate chapter.

The progress in the understanding of the physics of cosmic strings has been slow due to the difficult interpretational problems.

1. The physical interpretation of cosmic strings depends strongly on the principle assumed to select the preferred extremals as generalized Bohr orbits. There are some objections against absolute minimization.

   Number theoretical compactification [E2, D3] leads to very precise predictions about the structure of preferred extremals of Kähler action and implied breakthrough in the understanding of quantum TGD. In particular, their M^4 projections allow a distribution of $M^2(x) \subset M^4$ in their tangent space. A stronger condition is that this distribution is integrable [B4, D3]. The construction of extremals of Kähler action had led years earlier to the notion of Hamilton-Jacobi coordinates, whose existence realizes this conjecture [D1] so that the notion seems to be on firm basis. As a consequence, preferred extremals have dual slicings to string world sheets Y^2 and partonic 2-surfaces X^2.

   This observation stimulated a development leading to the realization that modified Dirac operator $D_K = D_K(X^2) + D_K(Y^2)$ associated with Kähler action can code via the generalized eigen value spectrum of $D_K(X^2)$ the value of Kähler action as Dirac determinant. Noether charges for the modified Dirac action are conserved only if the first variation of D_K vanishes, which means that second variation of Kähler action vanishes at least for the deformations responsible for dynamical symmetries. This criterion selects the preferred extremals and the choice is nothing but a space-time correlate for quantum criticality, which has been the basic guiding principle of quantum TGD. Ironically, absolute minimization is something diametrically opposite to criticality.

2. Physical interpretation depends also strongly on what one means with Equivalence Principle. Also here the number theoretical compactification meant breakthrough. The application of Equivalence Principle in General Relativistic formulation to cosmic strings produced a lot paradoxes and bad theory. The realization that it is stringy variant of Equivalence Principle, which works in short length scales and that general relativistic form of Equivalence Principle makes sense only in long length scales, solved these interpretational problems.

5.1.1 Various strings

TGD predicts two basic types of strings.

1. The analogs of hadronic strings correspond to deformations of vacuum extremals carrying non-vanishing induced Kähler fields. p-Adic thermodynamics for super-symplectic quanta condensed on them with additivity of mass squared yields without further assumptions stringy mass formula. These strings are associated with various fractally scaled up variants of hadron physics.

2. Cosmic strings correspond to homologically non-trivial geodesic sphere of CP_2 (more generally to complex sub-manifolds of CP_2) and have a huge string tension. These strings are expected to have deformations with smaller string tension which look like magnetic flux tubes with finite thickness in M^4 degrees of freedom. The signature of these strings would be the homological non-triviality of the CP_2 projection of the transverse section of the string.

5.1.2 Equivalence Principle and cosmic strings

The motivation for TGD as a Poincare invariant theory of gravitation was that the notion of four-momentum is poorly defined in curved space-time since corresponding Noether currents do not exist. There however seems to be a fundamental obstacle against the existence of a Poincare invariant theory of gravitation related to the notions of inertial and gravitational energy.

1. The conservation laws of inertial energy and momentum assigned to the fundamental action would be exact in this kind of a theory. Gravitational four-momentum can be assigned to the curvature scalar as Noether currents and is thus completely well-defined unlike in GRT. Equivalence Principle requires that inertial and gravitational four-momenta are identical. This is satisfied if curvature scalar defines the fundamental action principle crucial for the definition of quantum TGD. Curvature scalar as a fundamental action is however non-physical and had to be replaced with so called Kähler action.

2. One can question Equivalence Principle because the conservation of gravitational four-momentum seems to fail in cosmological scales.

3. For the extremals of Kähler action the Noether currents associated with curvature scalar are well-defined but non-conserved. Also for vacuum extremals satisfying Einstein's equations gravitational four-momentum fails to be conserved and non-conservation becomes large for small values of cosmic time. This looks fine but the problem is whether the possible failure of Equivalence Principle is so serious that it leads to conflict with experimental facts. Especially bad failure occurs for cosmic strings like objects f$X^2 \times Y^2 \subset M^4 \times CP_2$ for which gravitational mass becomes negative if the CP_2 projection has genus $g > 1$.

The cause of interpretational problems looks now obvious. I tried to deduce the formulation of Equivalence Principle in the framework provided by General Relativity framework applying only in the long length cale limit rather than in string model context. There were several steps in the process of becoming aware of this.

1. First came the conviction that coset representation for super-symplectic and super Kac-Moody algebras provides extremely general formulation of Equivalence Principle in which inertial and gravitational four-momenta are replaced with Super Virasoro generators of two algebras whose differences annihilate physical states. This idea came for years before becoming aware of its importance and I simply forgot it.

2. Next came the realization of the fundamental role of number theoretical compactification providing a number theoretical interpretation of $M^4 \times CP_2$ and thus also of standard model quantum numbers. This lead to the identification of the preferred extremals of Kähler action and to the formulation of quantum TGD in terms of second quantized induced spinors fields. One of conclusion was that dimensional reduction for preferred extremals of Kähler action- if they have the properties required by theoretic compactification- leads to string model with string tension which is however not proportional to the inverse of Newton's constant but to L_p^2, p-adic length scale squared and thus gigantic. The connection between gravitational constant and L_p^2 comes from an old argument that I discovered about two decades ago and which allowed to predict the value of Kähler coupling strength by using as input electron mass and p-adic mass calculations. In this framework the role of Planck length as a fundamental length scale is taken by CP_2 size

so that Planck length scale loses its magic role as a length scale in which usual views about space-time geometry cease to hold true.

3. The next step was the realization that zero energy ontology allows to avoid the paradox implied in positive energy ontology by the fact that gravitational energy is not conserved but inertial energy identified as Noether charge is. Energy conservation is always in some length scale in zero energy ontology.

4. As a matter fact, there was still one step. I had to become fully aware that the identification of gravitational four-momentum in terms of Einstein tensor makes sense only in long length scales. This is of course trivial but for some reason I did not realize that this fact resolves the paradoxes associated with objects like cosmic strings.

To summarize, the understanding of Equivalence Principle in TGD context required quite many discoveries of mostly mathematical character: the understanding of the super-conformal symmetries of quantum TGD, the discovery of zero energy ontology, the identification of preferred extremals of Kähler action by requiring number theoretical compactification, and the discovery that dimensional reduction allows to formulate quantum in terms of slicing of space-time surface by stringy word sheets. As far as cosmic strings are considered, the new vision throws to paper basket the idea about negative gravitational mass of the cosmic string inducing antigravity like effects.

5.1.3 TGD based quantum model for astrophysical systems

A brief summary of TGD based quantum model of astrophysical systems is in order.

1. TGD based quantum model for astrophysical systems relies on the evidence that planetary orbits (also those of known exoplanets) correspond to Bohr orbits with a gigantic value of gravitational Planck constant $h_{gr} = GMm/v_0$ characterizing the gravitational interaction between masses M and m. Nottale [30] introduced originally this quantization rule and assigned it to hydrodynamics.

2. TGD inspired hypothesis is that quantization represents genuine quantum physics and is due to the fact that dark matter matter corresponds to a hierarchy whose levels are labeled by the values of Planck constant. Visible matter bound to dark matter would make this quantization visible. Putting it more precisely, the space-time sheets mediating various interactions (electro-weak, color, gravitational) between the two physical systems are characterized by their own Planck constant which can have arbitrarily large values. For gravitational interactions the value of this Planck constant is gigantic and depends on the systems involved. These space-time sheets could correspond to magnetic flux tubes which were originally cosmic strings and concrete representations for gravitonic strings of astrophysical size having wormhole contacts at their ends.

3. The implication is that astrophysical systems are analogous to atoms and molecules and thus correspond to quantum mechanical stationary states have constant size in the local M^4 coordinates (t, r_M, Ω) related to Robertson Walker coordinates via the formulas (a, r, Ω) by $(a^2 = t^2 - r_M^2, r = r_M/a)$. This means that their M^4 radius R_M remains constant whereas the coordinate radius R decreases as $1/a$ rather than being constant as for co-moving matter.

4. Astrophysical quantum systems can however participate in the cosmic expansion by discrete quantum jumps in which Planck constant increases. This means that the parameter v_0 appearing in the gravitational Planck constant $\hbar = GMm/v_0$ is reduced in a discrete manner so that the quantum scale of the system increases.

5. This applies also to gravitational self interactions for which one has $\hbar = GM^2/v_0$. During the final states of star the phase transitions reduce the value of Planck constant and the prediction is that collapse to neutron or super-nova should occur via phase transitions increasing v_0. Ideal black-hole state could be identified as a state for which the scaled up Planck length $l_P(\hbar) = \sqrt{\hbar G}$ equals to Schwartschild radius $2GM$. This gives $v_0 = 1/4$.

6. Planetary Bohr orbit model explains the finding by Masreliez [22] that planetary radii seem to decrease when express in terms of the cosmic radial coordinate $r = r_M/a$ [D8]. The prediction is that planetary systems should experience now and then a phase transition in which the size of the system increases by an integer n. The number theoretically favored values are ruler-and-compass integers expressible as products of distinct Fermat primes (four of them are known) and power of 2. The most favored changes of v_0 are as powers of 2. That inner and outer planets correspond to the values of v_0 differing by a factor of 1/5 is consistent with ruler and compass hypothesis.

5.1.4 Correlation between super-novae and cosmic strings

During year 2003 two important findings related to cosmic strings were made.

1. A correlation between supernovae and gamma ray bursts was observed.

2. Evidence that some unknown particles of mass $m \simeq 2m_e$ and decaying to gamma rays and/or electron positron pairs annihilating immediately serve as signatures of dark matter. These findings challenge the identification of cosmic strings and/or their decay products as dark matter, and also the idea that gamma ray bursts correspond to cosmic fire crackers formed by the decaying ends of cosmic strings. This forces the updating of the more than decade old rough vision about topologically condensed cosmic strings and about gamma ray bursts described in this chapter (old version is left essentially untouched in order to demonstrate how important the experimental input is for the evolution of ideas).

According to the updated model, cosmic strings transform in topological condensation to magnetic flux tubes about which they represent a limiting case. Primordial magnetic flux tubes forming ferro-magnet like structures become seeds for gravitational condensation leading to the formation of stars and galaxies. The TGD based model for the asymptotic state of a rotating star as dynamo [D3] leads to the identification of the predicted magnetic flux tube at the rotation axis of the star as Z^0 magnetic flux tube of primordial origin (flux tube carries also em field but could carry only Z^0 charge). Besides Z^0 magnetic flux tube structure also magnetic flux tube structure exists at different space-time sheet but is in general not parallel to the Z^0 magnetic structure. This structure cannot have primordial origin (the magnetic field of star can even flip its polarity).

The flow of matter along Z^0 magnetic (rotation) axis generates synchrotron radiation, which escapes as a precisely targeted beam along magnetic axis and leaves the star. The identification is as the rotating light beam associated with ordinary neutron stars. During the core collapse leading to the supernova this beam becomes gamma ray burst. The mechanism is very much analogous to the squeezing of the tooth paste from the tube.

TGD based models of nuclei [F8] and condensed matter [F9] suggests that the nuclei of dense condensed matter develop anomalous color and weak charges coupling to dark weak bosons having Compton length L_w of order atomic size. Also lighter copies of weak bosons can be important in living matter. This weak charge is vacuum screened above L_w and by dark particles below it. Dark neutrinos are good candidates for screening dark particles. The Z^0 charge unbalance caused by the ejection of screening dark neutrinos hinders the gravitational collapse. The strong radial compression amplifies the tooth paste effect in this kind of situation so that there are hopes to understand the observed incredibly high polarization of 80 ± 20 per cent [36].

TGD suggests the identification of particles of mass $m \simeq 2m_e$ accompanying dark matter as lepto-pions [F7] formed by color excited leptons, and topologically condensed at magnetic flux tubes having thickness of about lepto-pion Compton length. Lepto-pions would serve as signatures of dark matter whereas dark matter itself would correspond to the magnetic energy of topologically condensed cosmic strings transformed to magnetic flux tubes.

5.2 General vision about topological condensation of cosmic strings

In this section the basic properties of free cosmic strings are discussed and a general vision about topological condensation of cosmic strings is proposed. In the later sections the vision is developed at a more quantitative level.

5.2.1 Free cosmic strings

The free cosmic strings correspond to four-surfaces of type $X^2 \times S^2$, where S^2 is the homologically nontrivial geodesic sphere of CP_2 [Appendix] and X^2 is minimal surface in M^4_+. As a matter fact, any complex manifold $Y^2 \subset CP_2$ is possible. In this section, a co-moving cosmic string solution inside the light cone $M^4_+(m)$ associated with a given m point of M^4_+ will be constructed.

Recall that the line element of the light cone in co-moving coordinates inside the light cone is given by

$$ds^2 = da^2 - a^2(\frac{dr^2}{1+r^2} + r^2 d\Omega^2) \ . \tag{5.2.1}$$

Outside the light cone the line element is given

$$ds^2 = -da^2 - a^2(-\frac{dr^2}{1-r^2} + r^2 d\Omega^2) \ , \tag{5.2.2}$$

and is obtained from the line element inside the light cone by replacements $a \rightarrow ia$ and $r \rightarrow -ir$.

Simplest solutions

Using the coordinates ($a = \sqrt{(m^0)^2 - r_M^2}, ar = r_M$) for X^2 the orbit of the cosmic string is given by

$$\begin{aligned} \theta &= \frac{\pi}{2} \ , \\ \phi &= f(r) \ . \end{aligned} \tag{5.2.3}$$

Inside the light cone the line element of the induced metric of X^2 is given by

$$ds^2 = da^2 - a^2(\frac{1}{1+r^2} + r^2 f_{,r}^2)dr^2 \ . \tag{5.2.4}$$

The equations stating the minimal surface property of X^2 can be expressed as a differential conservation law for energy or equivalently for the component of the angular momentum in the direction orthogonal to the plane of the string. The conservation of the energy current T^α gives

$$\begin{aligned} T^\alpha_{,\alpha} &= 0 \ , \\ T^\alpha &= T g^{\alpha\beta} m^0_{,\beta} \sqrt{g} \ , \\ T &= \frac{1}{8\alpha_K R^2} \simeq .52 \times 10^{-6} \frac{1}{G} \ . \end{aligned} \tag{5.2.5}$$

The numerical estimate $TG \simeq .52 \times 10^{-6}$ for the string tension is upper bound and corresponds to a situation in which the entire area of S^2 contributes to the tension. It has been obtained using $\alpha_K/104$ and $R^2/G = 2.5 \times 10^7 G$ given by the most recent version of p-adic mass calculations (the earlier estimate was roughly by a factor 1/2 too small due to error in the calculation [C5, D3]). The string tension belongs to the range $TG \in [10^{-6} - 10^{-7}]$ predicted for GUT strings [50]. WMAP data give the upper bound $TG \in [10^{-6} - 10^{-7}]$, which does not however hold true in the recent case since criticality predicts adiabatic spectrum of perturbations as in the inflationary scenarios.

The non-vanishing components of energy current are given by

$$\begin{aligned} T^a &= TUa \ , \\ T^r &= -T\frac{r}{U} \ , \\ U &= \sqrt{1 + r^2(1+r^2) f_{,r}^2} \ . \end{aligned} \tag{5.2.6}$$

The equations of motion give

$$U = \frac{r}{\sqrt{r^2 - r_0^2}} \ , \tag{5.2.7}$$

or equivalently

$$\phi_{,r} = \frac{r_0}{r\sqrt{(r^2 - r_0^2)(1 + r^2)}} \ , \tag{5.2.8}$$

where r_0 is an integration constant to be determined later. Outside the light cone the solution has the form

$$\phi_{,r} = \frac{r_0}{\sqrt{r^2 + r_0^2} r \sqrt{1 - r^2}} \ . \tag{5.2.9}$$

In the region inside the light cone, where the conditions

$$r_0 << r << 1 \tag{5.2.10}$$

hold, the solution has the form

$$\begin{aligned} \phi(r) &\simeq \phi_0 + \frac{v}{r} \ , \\ v &= \frac{r_0}{\sqrt{1 + r_0^2}} \ , \end{aligned} \tag{5.2.11}$$

corresponding to the linearized equations of motion

$$f_{,rr} + \frac{2f_{,r}}{r} = 0 \ , \tag{5.2.12}$$

obtained most nicely from the angular momentum conservation condition.

Cosmic string is stationary in comoving coordinates

In co-moving coordinates (in general the co-moving coordinates of sub-light-cone M^4_+!) the string is stationary. In Minkowski coordinates string rotates with an angular velocity inversely proportional to the distance from the origin

$$\omega \simeq \frac{v}{r_M} \tag{5.2.13}$$

so that the orbital velocity of the string becomes essentially constant in this region. For very large values of r the orbital velocity of the string vanishes as $1/r$. Outside the light cone the variable r is in the role of time and for a given value of the time variable r strings are straight and one can regard the string as a rigidly rotating straight string in this region.

Inside the light cone, the solution becomes ill defined for the values of r smaller than the critical value r_0. Although the derivative $\phi_{,r}$ becomes infinite at this limit, the limiting value of ϕ is finite so that strings winds through a finite angle. The normal component T^r of the energy momentum current vanishes at $r = r_0$ identically, which means that no energy flows out at the end of the string. The coordinate variable r becomes however bad at $r = r_0$ (string resembles a circle at r_0) and this conclusion must be checked using ϕ as coordinate instead of r. The result is that the normal component of the energy current indeed vanishes.

Field equations are not however satisfied at the end of the string since the normal component of the angular momentum current (in z- direction) is non-vanishing at the boundary and given by

$$J^r = Tr^2a \ . \tag{5.2.14}$$

This means that the string loses angular momentum through its ends although the angular momentum density of the string is vanishing. The angular momentum lost at moment a is given by

$$J = \frac{Tr^2a^2}{2} = \frac{Tr_M^2}{2} \ . \tag{5.2.15}$$

This angular momentum is of the same order of magnitude as the angular momentum of a typical galaxy [18].

In M^4 coordinates singularity corresponds to a disk in the plane of string growing with a constant velocity, when the coordinate m^0 is positive

$$\begin{aligned} r_M &= vm^0 \ , \\ v &= \frac{r_0}{\sqrt{1+r_0^2}} \ . \end{aligned} \tag{5.2.16}$$

From the expression of the energy density of the string

$$\begin{aligned} T^a &= T\frac{ar}{\sqrt{r^2-r_0^2}} \ , \\ T &= \frac{1}{8\alpha_K R^2} \ , \end{aligned} \tag{5.2.17}$$

it is clear that energy density diverges at the singularity.

Energy of the cosmic string

As already noticed, the string tension is by a factor of order 10^{-6} smaller than the critical string tension $T_{cr} = 1/4G$ implying angle deficit of 2π in GRT so that there seems to be no conflict with General Relativity (unlike in the original scenario, in which the CP_2 radius was of order Planck length).

The energy of the string portion ranging from r_0 to r_1 is given by

$$E = T\sqrt{(r_1^2 - r_0^2)a} = T\sqrt{\delta r_M^2} \ . \tag{5.2.18}$$

It should be noticed that M^4 time development of the string can be regarded as a scaling: each point of the string moves to radial direction with a constant velocity v.

One can calculate the total change of the angle ϕ from the integral

$$\Delta\phi = \sqrt{\frac{r_0^2}{1+r_0^2}}\int_{r_0}^{\infty} dr\frac{1}{r\sqrt{(r^2-r_0^2)(1+r^2)}} \ . \tag{5.2.19}$$

The upper bound of this quantity is obtained at the limit $r_0 \to 0$ and equals to $\Delta\phi = \pi/2$.

5.2.2 TGD based model for cosmic strings

The model for cosmic strings has forced to question all cherished assumptions including positive energy ontology, Equivalence Principle, and positivity of gravitational mass. The final outcome turned out to be rather conservative. Zero energy ontology is unavoidable, Equivalence Principle holds true universally but its general relativistic formulation makes sense only in long length scales, and gravitational mass has definite sign for positive/negative energy states. As a matter fact, all problems were created by the failure to realize that the expression of gravitational energy in terms of Einstein's tensor does not hold true in short length scales and must be replaced with the stringy expression resulting naturally by dimensional reduction of quantum TGD to string model like theory [B4, C5, D3].

Zero energy ontology and cosmic strings

There are two kinds of cosmic strings: free and topological condensed ones and both are important in TGD inspired cosmology.

1. Free cosmic strings are not absolute minima of the Kähler action (the action has wrong sign). In the original identification of preferred extremals as absolute minima of Kähler action this was a problem. In the new formulation preferred extremals correspond to quantum criticality identified as the vanishing of the second variation of Kähler action at least for the deformations defining symmetries of Kähler action [B4, D3]. Criticality guarantees the conservation of the Noether charges assignable to the modified Dirac action. Ideal cosmic strings are excluded because they fail to satisfy the conditions characterizing the preferred extremal as a space-time surface containing regions with both Euclidian and Minkowskian signature of the induced metric with light-like 3-surface separating them identified as orbits of partonic 2-surfaces carrying elementary particle quantum numbers. The topological condensation of CP_2 type vacuum extremals representing fermons generates negative contribution to the action and reduces the string tension and leaves cosmic strings still free.

2. If the topologically condensate of fermions has net Kähler charges as the model for matter antimatter asymmetry suggests, the repulsive interaction of the particles tends to thicken the cosmic string by increasing the thickness of its infinitely thin M^4 projection so that Kähler magnetic flux tubes result. These flux tubes are ideal candidates for the carriers of dark matter with a large value of Planck constant. The criterion for the phase transition increasing $\hbar$ is indeed the presence of a sufficiently dense plasma implying that perturbation theory in terms of $Z^2\alpha_{em}$ (Z is the effective number of charges with interacting with each other without screening effects) fails for the standard value of Planck constant. The phase transition $\hbar_0 \rightarrow \hbar$ reduces the value of $\alpha_{em} = e^2/4\pi\hbar$ so that perturbation theory works. This phase transition scales up also the transversal size of the cosmic string. Similar criterion works also for other charges. The resulting phase is anyonic if the resulting 2-surfaces containing almost spherical portions connected by flux tubes to each other encloses the tip of the causal diamond (CD). The proposal is that dark matter resides on complex anyonic 2-surfaces surrounding the tips of CDs.

3. The topological condensation of cosmic strings generates wormhole contacts represented as pieces of CP_2 type vacuum extremals identified as bosons composed of fermion-antifermion pairs. Also this generates negative action and can make cosmic string a preferred extremal of Kähler action. The earliest picture was based on dynamical cancelation mechanism involving generation of strong Kähler electric fields in the condensation whose action compensated for Kähler magnetic action [16]. Also this mechanism might be at work. Cosmic strings could also form bound states by the formation graviton like flux tubes connecting them and having wormhole contacts at their ends so that again action is reduced.

4. One can argue that in long enough length and time scales Kähler action per volume must vanish so that the idealization of cosmology as a vacuum extremal becomes possible and there must be some mechanism compensating the positive action of the free cosmic strings. The general mechanism could be topological condensation of fermions and creation of bosons by topological condensation of cosmic strings to space-time sheets.

In this framework zero energy states correspond to cosmologies leading from big bang to big crunch separated by some time interval T of geometric time. Quantum jumps can gradually increase the value T and TGD inspired theory of consciousness suggests that the increase of T might relate to the shift for the contents of conscious experience towards geometric future. In particular, what is usually regarded as cosmology could have started from zero energy state with a small value of T.

Topological condensation of cosmic strings

In the original vision about topological condensation of cosmic strings I assumed that large voids represented by space-time sheets contain "big" cosmic string in their interior and galactic strings near their boundaries. The recent much simpler view is that there are just galactic strings which carry net fermion numbers (matter antimatter asymmetry). If they have also net em charge they have a repulsive interaction and tend to end up to the boundaries of the large void. Since this slows down the expansive motion of strings, the repulsive interaction energy increases and a phase transition increasing Planck constant and scaling up the size of the void occurs after which cosmic strings are again driven towards the boundary of the resulting larger void.

One cannot assume that the exterior metric of the galactic strings is the one predicted by assuming General Relativity in the exterior region. This would mean that metric decomposes as $g = g_2(X^2) + g_2(Y^2)$. $g(X^2)$ would be flat as also $g_2(Y^2)$ expect at the position of string. The resulting angle defect due to the replacement of plane Y^2 with cone would be large and give rise to lense effect of same magnitude as in the case of GUT cosmic strings. Lense effect has not been observed.

This suggests that General Relativity fails in the length scale of large void as far as the description of topologically condensed cosmic strings is considered. The constant velocity spectrum for distant stars of galaxies and the fact that galaxies are organized along strings suggests that these string generate in a good approximation Newtonian potential. This potential predicts constant velocity spectrum with a correct value velocity.

In the stationary situation one expects that the exterior metric of galactic string corresponds to a small deformation of vacuum extremal of Kähler action which is also extremal of the curvature scalar in the induced metric. This allows a solution ansatz which conforms with Newtonian intuitions and for which metric decomposes as $g = g_1 + g_3$, where g_1 corresponds to axis in the direction of string and g_3 remaining $1 + 2$ directions.

Dark energy is replaced with dark matter in TGD framework

The observed accelerating expansion of the Universe has forced to introduce the notion of cosmological constant in the GRT based cosmology. In TGD framework the situation is different.

1. The gigantic value of gravitational Planck constant implies that dark matter makes TGD Universe a macroscopic quantum system even in cosmological length scales. Astrophysical systems become stationary quantum systems which participate in cosmic expansion only via quantum phase transitions increasing the value of gravitational Planck constant.

2. Critical cosmologies, which are determined apart from a single parameter in TGD Universe, are natural during all quantum phase transitions, in particular the phase transition periods increasing the size of large voids and having interpretation in terms of an increase of gravitational Planck constant. Cosmic expansion is predicted to be accelerating during these periods. The mere criticality requires that besides ordinary matter there is a contribution $\Omega_\Lambda \simeq .74$ to the mass density besides visible matter and dark matter. In fact, also for the over-critical cosmologies expansion is accelerating.

3. In GRT framework the essential characteristic of dark energy is its negative pressure. In TGD framework critical and over-critical cosmologies have automatically effective negative pressure. This is essentially due to the constraint that Lorentz invariant vacuum extremal of Kähler action is in question. The mysterious negative pressure would be thus a signal about the representability of space-time as 4-surface in H and there is no need for any microscopic description in terms of exotic thermodynamics.

The values for the TGD counterpart of cosmological constant

One can introduce a parameter characterizing the contribution of dark mass to the mass density during critical periods and call it cosmological constant recalling however that the contribution does not correspond to dark energy. The value of this parameter is same as in the standard cosmology from mere criticality assumption.

What is new that p-adic fractality predicts that Λ scales as $1/L^2(k)$ as a function of the p-adic scale characterizing the space-time sheet implying a series of phase transitions reducing Λ. The order of magnitude for the recent value of the cosmological constant comes out correctly. The gravitational energy density assignable to the cosmological constant is identifiable as that associated with topologically condensed cosmic strings and magnetic flux tubes to which they are gradually transformed during cosmological evolution.

The naive expectation would be the density of cosmic strings would behave as $1/a^2$ as function of M^4_+ proper time. The vision about dark matter as a phase characterized by gigantic Planck constant however implies that large voids do not expand in continuous manner during cosmic evolution but in discrete quantum jumps increasing the value of the gravitational Planck constant and thus increasing the size of the large void as a quantum state. Since the set of preferred values of Planck constant is closed under multiplication by powers of 2, p-adic length scales L_p, $p \simeq 2^k$ form a preferred set of sizes scales for the large voids.

TGD cosmic strings are consistent with the fluctuations of CMB

GUT cosmic strings were excluded by the fluctuation spectrum of the CMB background [64]. In GRT framework these fluctuations can be classified to adiabatic density perturbations and isocurvature density perturbations. Adiabatic density perturbations correspond to overall scaling of various densities and do not affect the vanishing curvature scalar. For isocurvature density fluctuations the net energy density remains invariant. GUT cosmic strings predict isocurvature density perturbations while inflationary scenario predicts adiabatic density fluctuations.

In TGD framework inflation is replaced with quantum criticality of the phase transition period leading from the cosmic string dominated phase to matter dominated phase. Since curvature scalar vanishes during this period, the density perturbations are indeed adiabatic.

5.3 More detailed view about topological condensation of cosmic strings

The purpose of this section is to represent in more detail the calculations behind the vision discussed in the previous section. As already noticed, free cosmic strings as such cannot correspond to the absolute minima of the action since their action is large and positive.

5.3.1 Topological condensation of a positive energy cosmic string

It is however useful to build a model of exterior space-time of topologically condensed cosmic string as a solution of Einstein's equations. For a straight string this solution is flat except at the position of the string. What happens is that the 2-dimensional plane orthogonal to the string becomes a conical surface. The angular defect is given by

$$\Delta\phi = \frac{T}{T_{max}} \times 2\pi \ , \ T_{max} = \frac{1}{4G} \ . \tag{5.3.1}$$

Here the string tension T refers to the gravitational mass density of the string and this is not necessarily identical with the inertial mass density. Obviously $T_{max} = 1/4G$ represents an upper bound for the gravitational mass density of the string.

The metric can be written as

$$\begin{aligned} ds^2 &= dt^2 - dz^2 - \frac{d\rho^2}{k_1^2} - \rho^2 d\phi^2 \ , \\ k_1^2 &= 1 - 4GT \ . \end{aligned} \tag{5.3.2}$$

The imbeddings of this metric as an induced metric are easy to find. The simplest imbedding is obtained by considering a map $M^4 \rightarrow S^1$, where S^1 is a geodesic circle of CP_2. Denoting by Φ the angle coordinate of S^1, one has

$$\begin{aligned} \Phi &= k\rho \ , \\ 1 + R^2k^2 &= \frac{1}{k_1^2} \ . \end{aligned} \tag{5.3.3}$$

The geodesic lines associated with this metric are easy to find in Cartesian coordinates. In M^4 coordinates the geodesics are slightly curved, which is nothing but the lense effect [22]. To see what happens consider geodesic lines in the plane; cut from the plane a sector corresponding to the deficit angle and bend it to form a cone; after this operation project the geodesic lines on the cone to the plane again to see how the geodesics look like in M^4 coordinates. The observation of this bending is possible if the coordinates used by the observers are actually M^4 coordinates rather than space-time coordinates.

The predicted lense effect would serve as a signature for the presence of strings with this kind of exterior metric and the experimental absence of this effect suggests that this metric is not a proper choice for the exterior metric but should be replaced with a metric inspired by Newtonian intuition.

5.3.2 Exterior metrics of cosmic string as extremal of curvature scalar

Einstein action with induced metric in general gives also solutions for exterior metric which are not gravitational vacua. One might hope these solutions in the first approximation correspond to Newtonian expectations and give rise only to a small lense effect. One must of course keep in mind that Einstein's equations and their TGD variant hold true only in long length scales and their application in the scale of cosmic string might not be justified. Second point is that it is the inertial energy density of cosmic strings rather than the energy density associated with curvature scalar, which serves as the source term in TGD variant of the Einstein's equations.

The ansatz

A rather general ansatz implying radial induced gauge fields in the background space is given by the following expression in cylindrical coordinates for M^4_+

$$\begin{aligned} m^0 &= \Lambda t \ , \\ cos(\Theta) &= u(\rho) \ , \\ \Phi &= \omega t + k(\rho) + n\phi \ . \end{aligned} \tag{5.3.4}$$

The reason why this ansatz works is that the components of metric and thus also of curvature tensor depend only on ρ so that field equations reduce to two differential equations. One can get rid of the $g_{t\rho}$ component of the induced metric by assuming $m^0 = \Lambda t + h(\rho)$ as in case of Schwartschild metric.

The interesting components of the induced metric in the cylindrical coordinates are given by the expression

$$\begin{aligned} g_{tt} &= \Lambda^2 - \omega^2 A \ , \\ g_{\rho\rho} &= -1 - A\left[\partial_\rho k)^2 + (\partial_\rho u)^2 \frac{1}{(1-u^2)^2}\right] \ , \\ g_{\rho t} &= -\omega \partial_\rho k A \ , \\ g_{t\phi} &= -\omega n A \ , \\ g_{\rho\phi} &= -\partial_\rho k A \ , \\ A &= R^2\omega^2(1-u^2) \ , \\ \Lambda^2 - \omega^2 A(\infty) &= 1 \ . \end{aligned} \tag{5.3.5}$$

Note that the induced gauge fields are Abelian. Em and Z^0 fields are proportional to each other and classical color field is proportional to induced Kähler form and vanishes for vacuum extremals. This can be seen as a signature of color confinement.

Field equations as conservation laws

The conservation law for color charge corresponding to $\Phi \to \Phi + \epsilon$ gives the first differential equation:

$$\partial_\rho \left[(G^{\rho\rho}\partial_\rho k + \frac{G^{\rho\phi} n}{\rho} + G^{\rho t}\omega) sin^2(\Theta)\sqrt{g}\right] = 0 \ . \tag{5.3.6}$$

For $m^0+\Lambda t+h(\rho)$ energy conservation one gets rid of the $G^{\rho t}$ term. This equation can be integrated to give

$$(G^{\rho\rho}\partial_\rho k+\frac{G^{\rho\phi}n}{\rho})sin^2(\Theta)\sqrt{g}=C \ . \tag{5.3.7}$$

and states that the conserved radial flow of $U(1)$ color charge is non-vanishing. This current must flow along the string. Note that for $k=constant$ gives $C=0$.

The second equation can be chosen to correspond to the momentum conservation in say x-direction and would give

$$\partial_\rho\left[(G^{\rho\rho}+\frac{G^{\phi\rho}}{\rho})\sqrt{g}\right]-G^{\phi\phi}\rho\sqrt{g}=0 \ . \tag{5.3.8}$$

The resulting field equations are extremely non-linear ordinary differential equations for $\Theta(\rho)$ and $\Phi(\rho)=k(\rho)$ having a character of a hydrodynamical conservation law. For $n=0$ one obtains effectively Einstein equations with purely geometric source terms.

$$\begin{aligned}G^{\rho\rho} &= \frac{C}{sin^2(\Theta)\partial_\rho k\sqrt{g}} \ ,\\ G^{\phi\phi} &= \partial_\rho\left[\frac{C}{sin^2(\Theta)\partial_\rho k}\right]\frac{1}{\rho\sqrt{g}} \ .\end{aligned} \tag{5.3.9}$$

Linearization

The linearized expression of the Einstein tensor with respect to the deviation $h_{\alpha\beta}$ of the induced metric from flat metric should give a good approximation to the field equations and allow to decide whether the Newtonian picture holds true. The linearized Ricci tensor is given by

$$\begin{aligned}2R_{\alpha\beta} &= D_\gamma D_\beta h^\gamma{}_\alpha+D_\gamma D_\alpha h^\gamma{}_\beta-D_\alpha D_\beta h-D_\gamma D^\gamma h_{\alpha\beta} \ ,\\ R &= D_\alpha D_\beta h^{\alpha\beta}-D_\alpha D^\alpha h \ .\end{aligned} \tag{5.3.10}$$

The covariant derivatives are with respect to the flat M^4 metric.

Are field equations consistent with the Newtonian limit?

One can hope that the field equations are consistent with the Newtonian limit which implies $R_{tt}=g_{tt}R/2$ outside z-axis in the linear approximation. If this is true, the gravitational energy density of the exterior metric would remain vanishing in the linear approximation for the metric so that a minimal modification of the vacuum Einstein equations would be in question. That Newtonian limit makes sense could be due to the fact that Einstein tensor represents the action of a non-linear wave operator on metric. Hence metric should be expressible in terms of its sources and topologically condensed cosmic string defines such a source very naturally.

Newtonian limit corresponds to the approximation

$$g_{tt}-1=2\Phi_{gr} \ , \quad \nabla^2\Phi_{gr}=-4\pi\rho_{gr} \ . \tag{5.3.11}$$

For string tension $T=dM/dl$, which corresponds to the density of inertial mass, one has $\Phi_{gr}=2TGlog(\rho/\rho_0)$ as the 2-dimensional variant of Gauss law shows. This corresponds to the simplified ansatz

$$\begin{aligned}u &= u(\rho) \ , \ \Phi=\omega t+k(\rho) \ ,\\ A-A(\infty) &= 2\Phi_{gr}=4GT\times log(\frac{\rho}{\rho_0}) \ .\end{aligned} \tag{5.3.12}$$

This gives

$$\begin{aligned} u^2 &= u^2(\infty) - K \times log(\frac{\rho}{\rho_0}) \ , \\ K &= \frac{16GT}{R^2\omega^2} \ . \end{aligned} \quad (5.3.13)$$

The imbedding ceases to exist at certain critical radii corresponding to

$$\begin{aligned} \frac{\rho_{max}}{\rho_0} &= exp(\frac{u^2(\infty)}{K}) \ , \\ \frac{\rho_{min}}{\rho_0} &= exp(\frac{u^2(\infty)-1}{K}) \ , \\ \frac{\rho_{max}}{\rho_{min}} &= exp(\frac{1}{K}) \ , K = \frac{4GT}{R^2\omega^2} \ . \end{aligned} \quad (5.3.14)$$

This ansatz with suitably chosen $k_0(\rho)$ could be taken as the lowest order approximation to the solution and one can expand the solution as $X \equiv u^2 = X_0 + \epsilon X_1 + ...$ $k = k_0(\rho) + \epsilon_1 k_1 + ...$ and solve u_n and k_n by linearizing the field equations around $X = X_0 + ...\epsilon^n X_n$ and $k = k_0 + ...\epsilon^n k_n$ solving (X_{n+1}, k_{n+1}) from the linearized differential equations. One could also proceed by substituting to the right hand side n:th order approximation and linearized Einstein tensor to the left hand side using $n+1$:nt order approximation. Note that the ansatz makes sense also for negative gravitational energy.

The angle defect (or surplus) is given by

$$\Delta\Phi(\rho) = \frac{\sqrt{\rho^2 + R^2u^2n^2}}{\int_0^\rho \sqrt{g_{\rho\rho}}d\rho} \times 2\pi \ . \quad (5.3.15)$$

For small values of n the effect is expected to be small.

5.3.3 Geodesic motion in the exterior metric of cosmic string

Writing the geodesic equations explicitly one finds that the conservation of energy and angular momentum give the conditions

$$\begin{aligned} \frac{dt}{ds} &= E \ , \\ \rho^2k^2\frac{d\phi}{ds} &= L \ . \end{aligned} \quad (5.3.16)$$

In the radial direction one obtains the equation of motion

$$\frac{d^2u}{ds^2} = \frac{u}{1-u^2} \times (\frac{du}{ds})^2 + \frac{L^2}{\rho_0^2}\frac{1-u^2}{u^3} \ . \quad (5.3.17)$$

The cosmic string induces besides ordinary centrifugal acceleration a radial repulsive acceleration

$$g = \frac{u}{1-u^2} \times (\frac{du}{ds})^2 \ . \quad (5.3.18)$$

The geodesic lines lead to the boundary of the cylindrical region. A possible interpretation is that this acceleration drives galactic cosmic strings with reduced string tension to the boundary of the large void.

The exterior solution does not represent co-moving matter which conforms with the idea that gravitational space-time sheets correspond to gigantic values of Planck constants implying that even astrophysical objects correspond to stationary quantum states following cosmic expansion only in average sense by quantum jumps leading to a reduction of Planck constant and rapid expansion of the space-time sheet. Classical picture would suggests that these jumps occur when the matter has ended up sufficiently near to the boundary of the large void.

Note that if one completes the space-time sheet by gluing "above" it second cosmic string with positive time orientation and positive gravitational mass the geodesic lines could turn around at the boundary so that the accelerated expansion of the matter would transform to compression.

It is easy to see that simple imbeddings of almost everywhere flat metric do not exist so that the density of gravitational energy in the exterior region is unavoidable. The condition $g_{\rho\rho} = 1$ could be satisfied by assuming $m^0 = t + h(\rho)$ and choosing h properly. This generates however also $g_{t\rho}$ component to the induced metric and to compensate it one should have $\Phi = n\phi + \omega t + k(\rho)$ with k chosen properly. This however generates $g_{t\phi} \neq 0$ which cannot be canceled and would mean that the solution is rotating.

One obtains also vacuum extremals representing solutions for which gauge charges and angular momentum are non-vanishing by a very simple deformation $\Phi \rightarrow \Phi + \omega t$ of the proposed ansatz. Interestingly, non-vanishing gauge charges are necessarily accompanied by angular momentum and vice versa.

5.3.4 Matter distribution around cosmic string

The distribution of stars in the vicinity of cosmic string can be modeled using kinetic model for the evolution of the distribution of stars. Assuming that stars have some average mass M and that the situation is non-relativistic the kinetic equation for the distribution of stars reads

$$\frac{dn}{dt} = \nabla \cdot (D\nabla n + \bar{w}n) \ . \tag{5.3.19}$$

The second term is the divergence of the current consisting of diffusion term and drift term caused by the Kähler force.

The drift velocity $\bar{w}$ is related to the Kähler force F_K

$$\bar{w} = b\bar{F}_K \ , \tag{5.3.20}$$

where b is the mobility of the star. Assuming that one can associate a well defined temperature parameter to the star distribution the mobility is related to the diffusion constant D by the Einstein relation $D = bT$. Kähler force is expressible in terms of Kähler gauge potential

$$\bar{F}_K = \nabla Q\Phi \ . \tag{5.3.21}$$

Here $\Phi = kT_sG\omega ln(\rho/\rho_0)$ is the gauge potential of the Kähler electric field. T_s denotes the string tension:

$$T_s \simeq .52 \ \times 10^{-6} \times \frac{\epsilon}{G} \ .$$

The lower bound for ϵ is about 10^{-7} from the previous considerations. Q is the average Kähler charge of the star: $Q \simeq \epsilon M\sqrt{G}$,

An order of magnitude estimate for diffusion constant is given by $D \simeq \langle v\rangle/n\sigma$, where $\langle v\rangle = \sqrt{(T/M)}$ is the average thermal velocity of star and σ is the collision cross section for collisions with other stars.

The equilibrium distribution corresponds to the cancelation of diffusion and drift currents

$$\frac{dn}{dr} \simeq -\frac{M\sqrt{G}\omega}{T}\partial_r\Phi n \ . \tag{5.3.22}$$

In isothermal case one obtains for the distribution of stars the following expression

$$
\begin{aligned}
n(\rho) &= n_0 exp(-\frac{M\sqrt{G}\Phi_K\omega}{T}) = n_0(\frac{r}{r_0})^{\alpha} \ , \\
\alpha &= \frac{M\sqrt{G}T_sG\omega}{T} \ ,
\end{aligned}
\tag{5.3.23}
$$

so that a power law behavior results. Unfortunately, concerning the value of the temperature parameter there is nothing interesting to say.

The second alternative is based on the adiabaticity assumption

$$
\frac{T}{T_0} = (\frac{n}{n_0})^{1-\gamma} \ , \tag{5.3.24}
$$

where γ denotes adiabatic constant. In this case one obtains

$$
\begin{aligned}
n(r) &= n_0(Aln(\frac{r}{r_0}))^{\frac{1}{(1-\gamma)}} \ , \\
A &= (1-\gamma)M\sqrt{G}T_s\frac{G}{T_0} \ .
\end{aligned}
\tag{5.3.25}
$$

for the distribution of stars.

5.3.5 Quantization of the cosmic recession velocity

The statistical analysis of the observational data about red shift of quasars [17] shows that the distribution of emission line red shifts of quasars have a periodicity, which can be explained most nicely by assuming that the recession velocity v calculated from red shift is quantized so that one has, using the standard relation between the recession velocity and distance of the emitting object,

$$
v = H_0(r_0 + nR) \ . \tag{5.3.26}
$$

Here H_0 denotes the present value of Hubble constant. The order of magnitude for the parameter R is $R \simeq 10^8$ ly.

There is also a problem of the association between galaxies and quasars. There are indications that galaxies and quasars form correlated pairs but that the red shift of the quasar is much larger than the red shift of the galaxy [20]. In case that the two systems are actually different physical systems, this implies that the red shift of the quasar member is of non-cosmological origin.

Various explanations for these effects have been proposed. For example, the idea that Universe is multiply connected has been put forward [17]. According to this explanation the emission lines with different red shifts correspond to images of single object: the light emitted from the object can travel several times "around the world" before being detected and the distance to the observe is thus quantized: $r = r_0 + nL$, where L is the size of the non-simply connected Universe. Observations require that L is of the order of $L \simeq 10^8 - 10^9\ ly$.

The TGD based explanation for the phenomenon is similar in spirit to this explanation (see Fig. 5.3.5). The original model for the phenomenon turned out to be inconsistent with the revised view about cosmic strings. The model however allows an obvious modification.

Original model for the quantization of red shifts

The original model was based on the idea is that null geodesic lines around the topologically condensed "big" strings ("big" meant that the parameter $K = \omega^2R^2$ is not too far from unity) do not leave the 3-space surrounding "big" string in the center of large void of radius of order 10^8 ly and carrying strong Kähler electric field canceling its magnetic action: for the simplest geodesic the projection to the plane orthogonal to the string is just circle. Galaxies tend to be situated near the boundaries of the 3-space surrounding big string and the light emitted from quasar can travel several times around the string before being detected.

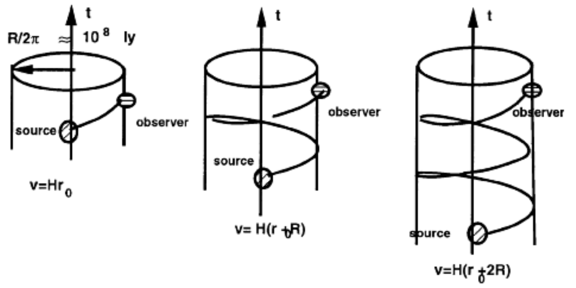

Figure 5.1: Quantization of the cosmic recession velocity.

A simplified situation is obtained, when the distance R of the emitting quasar and observer from the string is same ($R \simeq 10^8\ ly$) and when the distance along string direction is L. In this case the projection of the light like geodesic on plane is circle and the motion in z-direction is along straight line. The distance traveled by light before its detection is given by the expression

$$r = \sqrt{L^2 + (r_0 + n2\pi R)^2} \ . \quad (5.3.27)$$

If observer and source are in same plane one obtains the previous formula for the quantized recession velocity. The size of the parameter R, which is fixed by the hypothesis that big void regions correspond to cosmic strings is indeed in accordance with the observational constraints.

It is not at all obvious that the orbit of photon can indeed be confined inside the outer critical radius ρ_+ associated with the string having $\omega R \sim 1$: the Kähler charge cannot obviously be all that matters since photons do not couple to it. For "big" strings however $\omega R \sim 1$ holds true. This is indeed the case: the physical reason is the extremely strong gravitational field caused by the big string. To see this consider the equations of motion for an orbit with circular projection in the plane orthogonal to the string. Orbit is characterized by energy conservation condition, momentum conservation condition in the direction of string, masslessness condition and the equation of motion in radial direction (essentially Kepler law)

$$\begin{aligned} \frac{dt}{ds} &= E \ , \\ \frac{dz}{ds} &= p \ , \\ E^2 g_{tt} - p^2 - \rho^2\omega_0^2 &= 0 \ , \\ \rho\omega_0^2 &= \frac{\partial_\rho g_{tt} E^2}{2} \ , \end{aligned} \quad (5.3.28)$$

The last equation forces the photon to a circular orbit if some additional consistency conditions are satisfied and obviously requires Kähler charged string. The expression for the time component of the metric is given by

$$\begin{aligned} g_{tt} &= 1 - R^2\omega^2(1-u^2) \ , \\ u &= cos(\Theta) = kln(\frac{\rho}{\rho_0}) \ , \\ k &= \frac{1}{ln(\frac{\rho_+}{\rho_0})} \ . \end{aligned} \quad (5.3.29)$$

Here $u = cos\Theta$ denotes the coordinate variable of the geodesic sphere S^2 as a function of the radial coordinate approaching value $u = -1$ at the boundary of the cylindrical region surrounding big string.

These conditions boil down to the following condition fixing the value for the radius ρ of the circular orbit

$$cos(\Theta) = \frac{1}{\sqrt{K}}\sqrt{\frac{1-\frac{p^2}{E^2}-K}{1-\frac{Kk^2}{\omega_0^2\rho^2}}} \quad . \tag{5.3.30}$$

This equation has real solutions provided the argument of the square root term is positive. In addition the condition $|cos\Theta| \leq 1$ must hold true.

If the longitudinal momentum of the photon vanishes, one has

$$cos(\Theta) = \frac{1}{\sqrt{K}}\sqrt{\frac{1-K}{1-\frac{Kk^2}{E^2}}} \quad . \tag{5.3.31}$$

In the approximation $\frac{Kk^2}{E^2} \simeq 0$ this gives the bounds $1/2 < K < 1$. This condition is not consistent with the assumption that $K = R^2\omega^2$ is a small parameter given by

$$K = \frac{\epsilon}{2\alpha_K k} \quad .$$

The small value of K is consistent with $p/E \simeq 1$ so that most of photons momentum is in the direction of string. The result means that the original model based on "big" strings in the center of the large void and explaining the observations must be given up.

Modified model for the quantization of red shifts

The modification of the previous model is obvious and much analogous to the topological model for the quantization. If closed galactic strings and torus like space-time sheets containing them and winding around the boundary of the large void are closed and are able to confine photons inside them and thus acting as cosmic wave guides, the photons from a distant star can rotate several times along these space-time sheets and same quantization of the red shift would result also now.

If the proposed explanation for the quantized red shift is correct, one can in principle observe the time development of single object from quasar to galaxy by a series of images, the time difference between two successive images being of the order of 10^8 ly. These images are observed on the same line of sight, when the light comes from a distant object.

5.4 Cosmic evolution and cosmic strings

In this section a general vision about cosmic evolution based on zero energy ontology is discussed.

5.4.1 Cosmic strings and generation of structures

p-Adic fractality and simple quantitative observations lead to the hypothesis that cosmic strings are responsible for the evolution of astrophysical structures in a very wide length scale range. Large voids with size of order 10^8 light years can be seen as structures containing near their boundaries long cosmic strings at around which galaxies are organized linear structures like pearls in string. The original model contained big string in the center of void but it might well be possible to do without it. Galaxies would correspond to similar string like structure with smaller size and linked around the supra-galactic strings. This indeed conforms with the finding that galaxies tend to be grouped along linear structures. Simple quantitative estimates show that even stars and planets could be seen as structures formed around cosmic strings of appropriate size. Thus Universe could be seen as fractal cosmic necklace consisting of cosmic strings linked like pearls around longer cosmic strings linked like...

The observed quantization of the cosmic recession velocity [17] supports the proposed view. The space-time sheet of large void containing galactic cosmic strings is closed structure. The photons from a distance astrophysical experience radial outwards acceleration and are drifted to the boundaries of the void but they cannot escape this space-time sheet. Hence these photons can be detected after having traversed several times around the closed loop and the red shift is proportional to the number of traversals. In case of larger void the order of magnitude for the quantization is predicted correctly.

5.4.2 Generation of ordinary matter via TGD counterpart of Hawking radiation?

Cosmic strings can reduce their inertial masses by the analog of Hawking radiation involving the generation of fermion particle-antiparticle pairs, whose negative energy member remains inside string and annihilates there and positive energy member is radiated away. This mechanism can generate ordinary matter during initial stages of cosmic evolution and its temporal mirror image could give rise to a process analogous to the flow of ordinary matter to a black-hole during the final stages of the cosmic evolution. Highly tangled strings indeed within volume whose radius corresponds to black-hole radius indeed define a very general TGD based microscopic model of a black-hole. This "Hawking radiation" could generate at least part of the visible matter. The splitting of cosmic strings followed by a "burning" of the string ends provides a second manner to generate visible matter.

5.4.3 How single cosmic string could reduce its Kähler string tension?

The string tension of cosmic strings is due to Kähler action and has microscopic interpretation in terms of the mass of wormhole contacts having boson interpretation and fermions and super-symplectic bosons which correspond to topologically condensed CP_2 type vacuum extremals. The model of hadrons suggests that super-symplectic bosons could dominate the mass of cosmic string. If one accepts the general formula for the string tension in terms of Kähler coupling strength and quantum classical correspondence, one must conclude that the total contribution of matter to string tension equals to that of Kähler action.

One can imagine several mechanisms for how cosmic string could reduce its string tension. The topological condensation of CP_2 type vacuum extremals generates negative Kähler action so that string tension is reduced. The fact that Kähler action for the infinitely thin cosmic strings depends only on Kähler coupling strength suggests that the cosmic string transforms somehow in the process so that Kähler magnetic field flux remains constant but magnetic energy is reduced. This happens if the cosmic string develops finite transversal size in M^4 degrees of freedom since energy for magnetic flux tubes behaves as $1/S$, S the transversal thickness.

TGD predicts what I have used to call super-symplectic bosons and also their super-partners carrying having fermionic quantum numbers of right handed neutrino [D3]. These bosons have no electro-weak interactions and define a particular candidate for dark matter. Super-symplectic boson corresponds to single wormhole throat just like fermions and string like hadronic space-time sheets containing super-symplectic bosons and their super-partners connected by join along boundaries bonds to partonic space-time sheets have a key role in the recent model of hadrons. Also the model of black-hole as a gigantic hadron like entity relies on them. Two kinds of black-holes, "fermionic" and "bosonic" corresponding to strings and pairs of strings suggest themselves.

5.4.4 Zero energy ontology and cosmic strings

The combination of zero energy ontology with the cosmic evolution inspires concrete ideas about what the localization of contents of consciousness experience around narrow time interval identified as moment of subjective time could mean.

Zero energy ontology and cosmic evolution

Zero energy ontology means that all matter is creatable from vacuum as zero energy states which can be decomposed to positive and negative energy states whose space-time correlates correspond to partonic 2-surfaces in geometric past and future. This suggests strongly a picture about cosmic evolution beginning with TGD counterpart of Big Bang and ending with that of Big Crunch. It is however more appropriate to speak about "a silent whisper amplified to a big bang" since the amount of gravitational energy of cosmic strings in co-moving volume approaches zero at the limit of initial singularity.

This picture means genuine temporal non-locality and correlations over time interval T characterizing the distance between Bang and Crunch. It is however quite possible that T increases quantum jump by quantum jump and has been very small in past. The gradual shifting of the future end of zero energy state to the geometric future might relate directly to the arrow of subjective time. The usual identification of subjective time with geometric time can be understood if the arrow of subjective time corresponds to the gradual shift of the space-time volume from which the contents of conscious experience are to geometric future. TGD of course predicts a fractal hierarchy of cosmologies within cosmologies. Even elementary particle reactions have interpretation in terms of zero energy states identifiable as kind of mini-cosmologies.

If the main contribution to the contents of consciousness comes from the upper end of the zero energy state, and if T increases quantum jumps by quantum jump, this correlation could be understood and biological life cycle might have interpretation in terms of cosmology in human time scale at some level of dark matter hierarchy. Interestingly, the apparent increase of order suggests that the crunch phase might be experienced as a kind of Ω point. We could live all the subjective time at the Ω point which shifts to the geometric future quantum jump by quantum jump.

In the case of cosmic strings zero energy ontology would mean that cosmic strings are created in pairs of positive and negative energy cosmic strings. The mechanism could be non-local in the sense that the strings need not form tightly correlated pairs. An analogy with TGD based description of particle reaction would allow positive energy fermions from the geometric past and negative energy fermions from geometric future to meet somewhere in between. Bosons would correspond to tightly correlated pairs of positive and negative space-time sheets connected by wormhole contacts.

If the mechanism of generation of strings is local, "bosonic" strings formed by pairs of positive and negative inertial energy cosmic strings connected by connected by wormhole contacts would appear near the bang and crunch so that the density of inertial energy would vanish at this limit. With respect to geometric time single sub-cosmology would correspond to kind of vacuum polarization event for inertial energy. Locality assumption is however not necessary but would be consistent with the fact that Robertson Walker cosmology for which inertial mass density vanishes works so well.

The new view about second law

Quantum classical correspondence suggests negative and positive energy strings (in the sense of zero energy ontology) tend to dissipate backwards in opposite directions of the geometric time in their geometric degrees of freedom. Time reversed dissipation of negative energy states looks from the point of view of systems consisting of positive energy matter self-organization and even self assembly. The matter at the space-time sheet containing strings in turn consists of positive energy matter and negative energy antimatter and also here same competition would prevail.

This tension suggests a general manner to understand the paradoxical aspects of the cosmic and biological evolution.

1. The first paradox is that the initial state of cosmic evolution seems to correspond to a maximally entropic state. Entropy growth would be naturally due to the emergence of matter inside cosmic strings giving them large p-adic entropy proportional to mass squared [C5, D3]. As strings decay to ordinary matter and transform to magnetic flux tubes the entropy related to translation degrees of freedom increases.

2. The dissipative evolution of matter at space-time sheets with positive time orientation would obey second law and evolution of space-time sheets with negative time orientation its geometric time reversal. Second law would hold true in the standard sense as long as one can neglect the interaction with negative energy antimatter and strings.

3. The presence of the cosmic strings with negative energy and time orientation could explain why gravitational interaction leads to a self-assembly of systems in cosmic time scales. The formation of supernovae, black holes and the possible eventual concentration of positive energy matter at the negative energy cosmic strings could reflect the self assembly aspect due to the presence of negative energy strings. An analog of biological self assembly identified as the geometric time reversal for ordinary entropy generating evolution would be in question.

4. In the standard physics framework the emergence of life requires extreme fine tuning of the parameters playing the role of constants of Nature and the initial state of the Universe should

be fixed with extreme accuracy in order to predict correctly the emergence of life. In the proposed framework situation is different. The competition between dissipations occurring in reverse time directions means that the analog of homeostasis fundamental for the functioning of living matter is realized at the level of cosmic evolution. The signalling in both directions of geometric time makes the system essentially four-dimensional with feedback loops realized as geometric time loops so that the evolution of the system would be comparable to the carving of a four-dimensional statue rather than approach to chaos.

5.5 Cosmic string model for galaxies and other astrophysical objects

The new view about the relationship between gravitational and inertial energy forces to modify the original model based of galaxy based on split cosmic strings. Splitting, although possible, might not be needed since Hawking radiation might replace it as a basic mechanism generating visible matter. By p-adic fractality the mechanism generalizes and provides a universal mechanism for the generation of astrophysical structures and universe can be seen as fractal necklace containing coiled pairs of cosmic strings linked around larger structures of similar kind linked...

5.5.1 Cosmic strings and the organization of galaxies into linear structures

Astronomical observations suggest that galaxies form linear structures [22]. This inspired the original TGD based model of galaxies as decay products of split cosmic strings forming kind of cosmic fire crackers. The required order of magnitude for the string tension was of order $10^{-6}/G$ the same as the string tension of the cosmic strings predicted by TGD (so that CP_2 radius would reflect itself directly in the galactic dynamics!). The model suggested also a solution of galactic dark matter problem since the net mass of a ball containing string is expected to depend linearly on the radius of the ball as indeed found.

One problem of this model was that galactic strings ought be in the plane of the galaxy. The galactic jets which one might expect to be parallel to the strings are however orthogonal to the galactic plane which suggests that visible matter condensed on certain points of a long string roughly orthogonal to the galactic plane.

The new view about the relationship between inertial and gravitational energy and the necessity of cosmological constant forces to modify this scenario.

1. The observation that galaxies are organized in linear structures can be understood if the basic structures cosmic strings with string tension determined by Kähler action and winding in a spaghetti like manner along the boundaries of large voids. Part of ordinary matter would results as a Hawking radiation from these strings but the very fact these strings are mostly invisible suggests that the matter emitted by them remains in the vicinity of strings. Visible jets orthogonal to the galactic plane usually interpreted in terms of black hole emissions could correspond to the emission of Hawking radiation from these structures. Galaxies are concentrations of visible matter around these strings and they are roughly orthogonal to the plane of galaxy.

2. The generation of positive and negative energy matter with zero net energy from vacuum does not contribute to the inertial energy in time scales longer than the scale of causal diamond (CD) involved. This has occurred already during string dominated critical period during which the density of gravitational mass behaves as $\rho \propto 1/a^2$ as a function of the light cone proper time and the mass per co-moving volume is proportional to a. The fractality of TGD inspired cosmology suggests that the creation pairs of positive and negative energy cosmic strings giving rise to cosmologies inside cosmologies has occurred also later in smaller length scales. In particular, galaxies and even smaller structures could be seen as cosmologies within cosmologies. Pairs of cosmic strings and magnetic flux tubes are not visible and are thus excellent candidates for the dark matter. The non-conservation of inertial and gravitational energy identified locally as energy associated with positive energy part of the local zero energy state supports this view.

   If the initial inertial and gravitational mass per unit length of these objects is same as that for a free string, the order of magnitude for the gravitational energy density of dark matter per volume is predicted correctly if the length L of string inside sphere R is proportional to its radius: $L \propto R$. Galaxies could be strongly knotted relatively short cosmic strings linked around the long cosmic strings like pearls in a necklace. Their shortness would mean that they do not contribute significantly to the mass of the void.

3. p-Adic fractality suggests that even smaller astrophysical structures might involve strings linked with larger strings linked with...., the cosmic necklace would be a fractal necklace. In the case of Sun a string of length $L \sim 10^{11}$ m, which is not far from the distance $AU = 1.5 \times 10^{11}$ m between Earth and Sun, would be needed whereas the radius of Sun is $\sim 7 \times 10^8$ meters. Thus the magnetic flux tubes resulting form these strings could wind around solar system and bind the entire system into single coherent magnetic structure. For Earth one would have $L \sim 3 \times 10^5$ m, which is smaller than the radius $R = 6.4 \times 10^6$ m of Earth. What makes this interesting is that quite recently it has been announced that Earth contains a previously unidentified core region with size of 3×10^5 m [21]. This picture suggest a universal mechanism for the evolution of the solar system replacing the existing Newtonian model based on the amplification of gravitational perturbations.

5.5.2 Cosmic strings and dark matter problem

Consider now the idea that the presence of cosmic strings might solve the dark matter puzzle [23]. The presence of the dark matter is indicated by the velocity spectrum of the distant stars (at distance of few tens of kilo-parsecs from the center of the galaxy), which according to the recent observations [16, 28] approaches to a constant depending on the galaxy in question and having the general order of magnitude $V \simeq 10^{-3}$.

One can estimate the velocity V of a distant star in galactic plane from Kepler law (the spherically symmetric model for galaxy suggests that this argument indeed applies)

$$\frac{V^2}{R} = \frac{GM(R)}{R^2} , \tag{5.5.1}$$

where $M(R)$ denotes the mass inside a sphere of radius R. Since the mass of the cosmic string dominates the mass inside a sphere of radius R one gets the following very rough estimate for the effective gravitational mass inside the sphere of radius R

$$M(R) \simeq n2TR , \tag{5.5.2}$$

where $n > 1$ accounts for the fact that straight string is not in question. From the known velocity V one obtains for the string tension the estimate

$$T \sim \frac{V^2}{4nG} \sim \frac{10^{-6}}{4nG} \sim v_D T_{free} . \tag{5.5.3}$$

This estimate is of the same order of magnitude as the lower bound of string tension obtained from the Jeans criterion. The result is also consistent with the assumption that, due to their gravitational binding to strings, stars rotate with the same velocity as strings.

Recall that an upper bound for the string tension of the TGD cosmic string is given by

$$T = \frac{1}{8\alpha_K R^2} \simeq .52 \times 10^{-6} \frac{1}{\hbar_0 G} .$$

This is roughly twice the required tension for $n = 1$ so that TGD is consistent with the experimental input. The effective string tension of the co-moving string also increases for $r \rightarrow r_0$ (see the general description of cosmic string solution) and diverges at $r = 0$. Furthermore, since the cosmic string is not straight there appears additional factor n making $M(R)$ larger than the simple estimate above.

On basis of these observations one has a strong temptation to think that the still existing cosmic strings, possibly thickened to magnetic flux tubes, correspond to galactic and extragalactic dark matter. At this stage one must leave open whether the naive argument leads to a correct form for the velocity spectrum of stars. Whether or not true this prediction would have nice features in that it would relate the velocity spectrum directly to the size and age of the galaxy since the velocity v determines the recent size of the visible galaxy (if it corresponds to the recent distance of the string end from the center of galaxy): the older the galaxy with given size the smaller the rotational velocity v. Elliptic galaxies are older than spiral galaxies: rotational velocities for the elliptic galaxies are indeed smaller than for spiral galaxies [28]. Furthermore, the rotational velocities increase with the size of the galaxy, when the age of the galaxy is kept constant: also this feature is in qualitative accordance with observed facts [16, 28].

An interesting question is whether one could explain the angular momentum of galaxies in terms of the tidal forces acting between the galaxies [29] at the opposite ends of a string (having length of order 10^5 light years. The idea is following. For free cosmic string there is a flux of angular momentum of order Tar^2 (using Robertson-Walker coordinates (a, r))) through the end of the string, which produces a correct order of magnitude for the galactic angular momentum at time a given by $J \sim Ta^2r^2 = Tr_M^2$, $r_M \sim 10^5\ ly$.

5.5.3 Estimate for the velocity parameters

The first task is to fix the value of the velocity parameter, to be denoted by V, appearing in the general solution describing one arm of the split cosmic string. In the region, where linearized equations of motion hold the orbital velocity V of the cosmic string is constant.

The radius of the singular region associated with cosmic string increases with some velocity v_D identifiable as the velocity with which the size of a typical galaxy (defined for example as the distance of spiral arm L from the center of galaxy) is about $L \simeq 10^4 - 10^5$ light years [24, 26]. The condition $vT < L$, where $T \simeq 10^9 - 10^{10}$ years is the typical age of the galaxy, gives the estimate

$$v_D \quad < \quad 10^{-5} \ , \tag{5.5.4}$$

for the velocity v_D using the velocity of light as unit.

One can relate the velocity v_D to the string tension if one accepts the assumption that the relative motion of the string ends results from the shortening of strings, which in turn results from the decay of the string ends to elementary particles (some of them possibly exotics). A rough estimate for the velocity of the shortening of the string [22] is based on the observation that the velocity

$$v \quad \simeq \quad TG \sim 10^{-6} \tag{5.5.5}$$

seems to set the time scale for the various dynamical processes leading to the decay of strings [22]: for example, the shortening of loop with radius L via gravitational radiation as well as the shortening of the string connecting the monopole pair takes place with this velocity [22]. This velocity is considerably smaller than the typical velocity $V \simeq 10^{-3}$ [16, 28] of the distant stars moving in the galactic plane, which in turn can be understood using Kepler law.

The idea that the spiral arms of the spiral galaxy correspond to cosmic strings seems to be in accordance with the observational facts. In case of Milky Way [26] the distance of spiral arms is about $L = 10^4 - 10^5$ light years from the center of the galaxy so that the order of magnitude for the velocity v_D is $v_D \sim 10^{-6} - 10^{-5}$. Furthermore, spiral arms are known to recede from the center of the Milky Way [26].

The model suggests also an explanation for the observed bar like structure connecting the ends of the spiral arms of the spiral galaxies. The gravitational field is most intense near the string end so that the density of the ordinary matter is expected to be largest near the end of the string. On the other hand, the orbit of the string end is straight line so that "bar" like structure might be formed [24], when the ends of the spiral arms recede from each other.

It should be stressed that the visible form of galaxies is not so closely related with the form of strings contrary to the original expectations (we used the term "spiral string"). This is clear from the observation that the total change of angle ϕ is smaller than $\pi/2$, which means that simplest cosmic strings are really not "spiral" like. Of course, this result holds for free strings and it might be that condensation in fact creates spiral structure somehow. A more conventional explanation is the generation of density waves with spiral structure [18] and the presence of strings might have something to do with this phenomenon.

5.5.4 Galaxies as split cosmic strings?

It is not clear whether the Hawking radiation from a coiled pair of cosmic strings is able to explain galactic visible matter. The reason is that the cosmic strings responsible for linear structures formed by galaxies are not visible along their entire length. One might argue that same applies also the knotted and linked galactic cosmic string pairs. If this is the case, the dark matter problem becomes visible matter problem. A possible solution of the problem is based on split cosmic strings with splitting possibly resulting in the collision of galactic strings with the long supra-galactic strings.

This scenario has indeed some attractive features (see Fig. 5.5.4).

1. The ends of the split cosmic string create strong gravitational fields and serve as seeds for the galaxy formation. Lense effect [22] is predicted to be a signature of the string pairs. The fact that spiral galaxies have in general two arms, has a nice topological explanation.

2. One ends up to a rather simple scenario for the evolution of the galaxy.

   (a) The splitting occurs most probably during the string dominated phase for $t < L \sim 10^4\sqrt{G}$ (L is essentially CP_2 radius) and results most naturally from the collision of two strings.

   (b) The split strings begin to decay by emitting particles from their ends. The decay leads to a shortening of the split strings with constant velocity v so that the ends of the split strings recede from each other. This velocity can be identified with the velocity parameter $v \sim TG$ associated with the motion of the spiral arms. A correct size for the visible part of the galaxy is predicted.

   (c) Decaying cosmic string ends provide a model for the 'central engines' associated with the galactic nuclei [46]. The energy production by string decay turns out to be of same order of magnitude as the energy production in quasars assuming that the energy is produced in a narrow jet parallel to the string (momentum conservation favors this option). This was proposed as an explanation for the visible jets associated with the active galaxies as resulting from the interaction of the decay products with the ordinary matter. The fact that these jets are orthogonal to the galactic plane suggests Hawking radiation from supra-galactic string stimulated by the collision as an alternative explanation.

   (d) Co-moving cosmic strings happen to rotate with the same velocity as distant stars (relative to the center of galaxy) are found to rotate. The gravitational binding of stars by the average gravitational field created by cosmic strings would explain the rotational velocity spectrum.

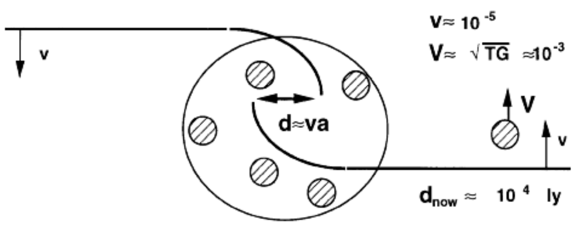

Figure 5.2: String model for galaxies.

In the following the model will be discussed in more detail to see whether it really works. The value for the velocity parameter v will be derived, Jeans criterion for the formation of the structures around a split cosmic string will be discussed, a simple toy model for a galaxy using spherically symmetric mass distribution will be constructed and the possibility that cosmic strings might provide a solution to the galactic dark matter problem will be studied.

Jeans criterion for the galaxy formation

It is not obvious that Jeans criterion for the generation of structures by gravitational interaction can be applied to galaxy formation in the recent situation differing so dramatically from Newtonian framework. One can however check what Jeans criterion would give in the case of split cosmic strings [22].

1. The size L of the density fluctuation leading to the formation of a structure satisfies the inequality

$$l_J < L < l_H \ , \tag{5.5.6}$$

where the Jeans length l_J is given by [22]

$$l_J \simeq 10 v_s t \ , \tag{5.5.7}$$

where v_s denotes the velocity of sound. Notice that the formation of structures is not possible at the radiation dominated era since Jeans length is larger than horizon: $l_H \simeq t < l_J \simeq 10t$ since the velocity of sound is of order 1.

2. When radiation and matter decouple from each other (corresponding to the value of about $a_{dec} = 10^8$ light years [21]), the formation of galaxies becomes possible due to the lowering of the pressure, which leads also to the lowering of the sound velocity v_s from $v_s \simeq 1$ to $v_s \simeq 10^{-5}$ (thermal velocity of hydrogen). Jeans length shortens by a factor 10^{-5} and the formation of structures becomes possible.

In accordance with the idea that the split strings act as seeds for the galaxy formation, one can identify Jeans length as the minimal distance between the ends of the split string, which leads to a formation of galaxy

$$v_D a_{dec} > l_J \ . \tag{5.5.8}$$

Using the values for a_{dec} and l_J one obtains lower bounds for the velocity v_D between the ends of the galactic string and for the string tension of the galactic strings (accepting the proposed relationship between v_D and string tension)

$$\begin{aligned} v_D &> 10^{-6} \ , \\ T &> \frac{10^{-6}}{G} \ . \end{aligned} \tag{5.5.9}$$

One obtains also a lower bound for the recent size L_{now} of the galactic nuclei assuming that the decay of galactic strings continues with velocity v_D

$$L_{now} > 10^4 \ ly \ . \tag{5.5.10}$$

These numbers are in accordance with the estimate obtained for the string tension of a typical galactic strings and with what is known about recent sizes of the galaxies [24].

Spherically symmetric model

The imbeddability requirement plays central role in TGD inspired cosmology and the galaxy model based on spherically symmetric mass ($M(r) = kr$) distribution is of some interest. This model could be regarded as a large length scale idealization of galaxy mass distribution. In case that galactic dark matter consists of the exotic decay products of the cosmic string the model might be even reasonably realistic. The line element for an energy momentum tensor characterized by energy density $\rho(r)$ and pressure $p(r)$ is given by the expression $ds^2 = A(r)dt^2 - B(r)dr^2 - r^2d\Omega^2$ and to find an imbedding for this metric one can use the general imbedding ansatz introduced, when discussing the imbedding of Reissner- Nordström metric.

Under rather general assumptions about the mass density the time component of the metric for a spherically symmetric mass distribution $M(r)$ (the mass inside the sphere of radius r) is given by the expression $g_{tt} = 1 - 2GM(r)/r$. In present case one would obtain $g_{tt} = constant$ so that some of the underlying assumptions must fail. The following form leads to a correct gravitational force

$$g_{tt} = 1 + 2Gkln(\frac{r}{r_0}) \ . \tag{5.5.11}$$

The gravitational force in the Newtonian limit is $2Gk/r = 2GM(r)/r^2$ and implies that Kepler law to be used later to derive velocity distribution of distant stars is indeed applicable.

The general expression for the metric component g_{tt} in terms of the imbedding ($m^0 = \lambda t, \Theta = \Theta(r), \Phi = \omega t + f(r)$)

$$g_{tt} = \lambda^2 - R^2\omega^2 sin^2(\Theta) \ , \tag{5.5.12}$$

which gives

$$sin^2(\Theta) = \lambda^2 - 1 - \frac{2Gk}{R^2\omega^2} ln(\frac{r}{r_0}) \ . \tag{5.5.13}$$

Imbedding fails for two critical radii r_{in} ($sin^2|(\Theta) = 1$) and r_{out} ($sin^2(\Theta) = 0$)

$$\begin{aligned} ln(\frac{r_{in}}{r_0}) &= \frac{(\lambda^2 - 1 - R^2\omega^2)}{2Gk} \ , \\ ln(\frac{r_{out}}{r_0}) &= \frac{(\lambda^2 - 1)}{2Gk} \ . \end{aligned} \tag{5.5.14}$$

An interesting question is whether one could relate the inner critical radii to the existence of the galactic nucleus having diameter of the order of 2 parsecs (.65 light years).

5.5.5 Cylindrically symmetric model for the galactic dark matter

TGD allows also a model of the dark matter based on cylindrical symmetry. In this case the dark matter would correspond to the mass of a cosmic string orthogonal to the galactic plane and traversing through the galactic nucleus. The string tension would the one predicted by TGD. In the directions orthogonal to the plane of galaxy the motion would be free motion so that the orbits would be helical, and this should make it possible to test the model. In this kind of situation general theory of relativity would predict only an angle deficit giving rise to a lens effect. TGD predicts a Newtonian $1/\rho$ potential in a good approximation.

Spiral galaxies are accompanied by jets orthogonal to the galactic plane and a good guess is that they are associated with the cosmic strings. The two models need not exclude each other. The vision about astrophysical structures as pearls of a fractal necklace would suggest that the visible matter has resulted in the decay of cosmic strings originally linked around the cosmic string going through the galactic plane and creating $M(R) \propto R$ for the density of the visible matter in the galactic bulge. The finding that galaxies are organized along linear structures [22] fits nicely with this picture.

5.6 Cosmic strings and energy production in quasars

One of the basic mysteries of astrophysics are so called 'central engines' in the centers of the galaxies [46]. These engines are very massive, have very small size of at most few light hours, their luminosity fluctuates in hour time scale, their electromagnetic spectrum is non-thermal and they are often accompanied by two jets in opposite directions. One should also understand why some galaxies are active (have a pair of jets) and others are not. A mysterious property of jets is their microstructure: main jets with length of order 10^6 light years are accompanied by short jets with length of order one light year and with directions parallel to the long jets.

In the standard model the central engine is a galactic black hole but the mechanism of the jet production is not well understood. In the following it is shown that decaying cosmic string ends provide a good candidate for the central engine. Note that in the standard picture jets are orthogonal to galactic plane whereas in the proposed model jets are parallel to the galactic plane. One could consider also the possibility that galaxies are formed in the splitting of cosmic strings orthogonal to galactic plane but this option will not be discussed here.

5.6.1 Basic properties of the decaying cosmic strings

The rate for the shortening of a split galactic cosmic string can be deduced by an order of magnitude argument

$$\begin{aligned} v &\sim kTG \ , \\ T &\simeq \frac{2\times 10^{-7}}{G} \ . \end{aligned} \tag{5.6.1}$$

T is the string tension of the cosmic string. k is some numerical constant not too far from unity. The numerical study of the *ordinary* cosmic strings [22] gives support for this order of magnitude estimate.

Taking the age of the Universe to be $a \sim 10^{11}$ years and assuming that the cosmic string is split in early phase of cosmology, the length of the portion of the decayed string is of the order

$$L \sim kTGa \simeq 2\times 10^4 k \ \text{light years} \ , \tag{5.6.2}$$

which is of the same order of magnitude as the typical size of the visible part of the galaxy.

An estimate for the rate of the energy production by single cosmic string is given by

$$P \sim Tv = kT^2G \sim \frac{4\times 10^{-14}k}{G} \sim 10^{47}k \times m(proton)/sec \ . \tag{5.6.3}$$

The energy production in quasars is roughly 10^{14} times larger than the energy production in Sun, which is about 10^{25} W: this gives $P \sim 10^{49} m_p/sec$. In order to have same order of magnitude one should have

$$k \sim 25 \ . \tag{5.6.4}$$

The required value of k looks suspiciously large and suggests that the energy flux from the decaying cosmic string could well be a jet directed to a narrow cone, which would increase the observed effective energy flux.

5.6.2 Decaying cosmic string ends as a central engine

It seems that the decaying cosmic string could explain elegantly the basic properties of the central engines. There are two alternative scenarios to be considered.

I) Galaxies are formed around the ends created in the splitting of a very long cosmic string.

II) Galaxies are formed by a decay of a piece of cosmic string. The decay of a finite piece of cosmic might explain the existence of some stellar objects accompanied by jet like structures.

In both cases the rate of the string decay gives a correct upper bound for the recent size of the visible part of the galaxies. Consider now the explanation of basic characteristics of active galaxies.

1. Visible jets are created by the energy beams

   The rate of the energy production in the decay of a cosmic string is few per cent about the estimated energy production in quasars assuming spherical symmetry. A correct rate for the observed energy flux from quasars is obtained if the energy from the decay of the string is liberated in a jet. Since two string ends are involved, the visible two-jet structure is an automatic consequence. The jets emerging from the active galactic nuclei are created by the interaction of the primary jets with the ordinary matter.

2. Quasars.

   Quasars differ from the ordinary galaxies only in that the energy jet from the cosmic string decay meets Earth. This explains the non-thermal nature of the spectrum and the absence of the atomic lines for the most intensive quasars (they are masked by the primary radiation). The rapid variations (a time scale of an hour) in the luminosity can be understood as resulting from the motion of the cosmic string inducing changes in the direction of the jet. Also the similarity between active and inactive galaxies is an automatic consequence.

3. Active-inactive distinction.

   For the option I possible explanation is that the galactic black hole has absorbed all matter around the galaxy and the jets coming from the decay of the cosmic strings have nothing with which to interact. It could however happen that the two jets interact with matter in very distant regions creating two tightly correlated jets but apparently originating from very distant sources. It could also occur that string ends are inside a galactic black hole for inactive galaxies so that the decay products remain inside the black hole and no visible jets are created. For the option II inactive galaxies without any jets, one can also consider the possibility that the piece of cosmic string has already decayed completely.

4. Dark matter halo.

   There are two alternative explanations for the velocity spectrum of the distant stars around the galaxy. The first, purely TGD based, explanation is that distant stars are gravitationally bound to the rotating cosmic string. Cosmic string indeed rotates with a correct velocity and, being Kähler charged, creates a genuine gravitational field unlike neutral cosmic string. The standard explanation is based on the assumption that galaxy is surrounded by a dark matter halo.

   An interesting possibility is that a halo of dark matter could result from the decay of the cosmic strings, perhaps in the form of ordinary and exotic neutrino like matter predicted by TGD. The decay could produce also part of the visible matter around the galactic nucleus. The jet model suggests that most of the decay products of the cosmic string escape the visible region of the galaxy but massive and Kähler charged particles with a proper sign of charge could remain bound to the cosmic string. Dark variants of ordinary elementary particles, in particular dark neutrinos, suffer classical Z^0 force below appropriate p-adic length scale. Clearly, Kähler force favors the generation of matter antimatter asymmetry. The average density in the halo would however be perhaps too small to explain the velocity spectrum.

5. Production mechanism for ultrahigh energy cosmic rays.

   The decay of the cosmic string should also give rise to ultrahigh energy cosmic rays. This production mechanism would provide an alternative for the production mechanisms based on the acceleration of the charged particles [it is difficult to conceive how any acceleration mechanism could lead to the generation of ultra high energy cosmic rays].

5.6.3 How to understand the micro-jet structure?

The long jets with length of roughly 10^6 light years have microstructure consisting of micro-jets with length of order one light year. This feature could be regarded as a shortcoming of the model. A possible TGD based explanation is based on lense effect on the gravitational field of the split cosmic string (scenario I).

In option I, a lense effect, caused by the strong gravitational field of the cosmic string itself, and creating multiple images could be involved. Since charged cosmic string is in question, the situation is more complicated than for the ordinary cosmic string. For instance, photon could rotate several times around the cosmic string before leaving the galactic region. The disappearance of the effect in distant regions (of length of order light year) could be understood if the energy jet were on the wrong side of the string at large distances or the distance between the jet and cosmic string would become so large that photons would not anymore circulate around the string.

5.6.4 Gamma-ray bursts and cosmic strings

Gamma ray bursters [31] are now quite generally believed to have a cosmological origin. The energy flux from the gamma ray bursters (assuming spherical symmetry and cosmological origin and distance of order 10^8 ly) is about 10^{16} times the energy flux from Sun and by a factor of 10^2 larger than the total energy flux from the decaying cosmic string. The order of magnitude is same as for the energy flux of quasars. Typically the energy is produced in pulses lasting for a few seconds but also long lasting bursts consisting of a train of smaller pulses with a duration of order second are detected. It seems that the system emitting pulses is in some sense near criticality. The distribution of the gamma ray bursters is isotropic.

An interesting possibility is that decaying cosmic strings might explain also this phenomenon. The string would produce a continuous stream of energy, which fails slightly to meet Earth. Small perturbations causing the string end to oscillate (random oscillation of the direction of a flicker is a good analogy) imply that the beam of energy can meet the Earth at each period of oscillation and cause a sequence of pulses. A unique maximum intensity is predicted.

The shape of the pulse is predicted to reflect only the time development of the direction of the cosmic string rather than the actual intensity distribution of the pulse and this should make it possible to distinguish between TGD based and other explanations for the bursts. For instance, the typical bi-modality of the pulse could reflect directly to a perturbation taking string direction from the equilibrium position and bringing it back. The asymmetry of this perturbation caused by dissipative effects should explain the asymmetry of the two intensity peaks. The observed hardness-brightness correlation could be understood as following from the cosmic red shift and cosmic time dilatation increasing the observed duration of the pulse.

From the estimate that there are

$$\frac{dN}{dt} \sim 10^{-6}\ year^{-1}\ galaxy^{-1}$$

bursts per galaxy per year and taking the average duration t_P of the pulse to be

$$t_P \sim 1\ sec\ ,$$

one obtains a *very* rough estimate for the probability that a given galaxy acts as a gamma ray burster at a given moment as

$$P \sim t_P \times \frac{dN}{dt} \sim 10^{-13}.$$

One can estimate the solid angle Ω of the cone to which the energy of the decaying cosmic string is emitted: the probability P for galaxy being a burster, is simply the product of the probability $p(A)$ that galaxy is active multiplied with the probability $\Omega/(4\pi)$ that Earth happens to be in the solid angle Omega

$$P = \frac{p(A)\Omega}{4\pi} \sim 10^{-13}\ ,$$

which gives

$$\Omega \sim \frac{4\pi P}{p(A)} \sim \frac{10^{-12}}{p(A)}\ .$$

To proceed further an estimate for the probability of being active galaxy is needed. The value of Ω had better to be rather small since the oscillations in the direction of the cosmic string leading to fluctuations in the intensity of beam must be of the order of Ω and too large fluctuations are not expected (cosmic string is quite a heavy object!).

5.7 The light particles associated with dark matter and the correlation between gamma ray bursts and supernovae

Both the model for dark matter identified as cosmic strings or their decay products and the model for gamma ray bursts identified as beams resulting in the fire cracker like decay of cosmic strings were constructed more than decade ago. During year 2003 came several astonishing observations, which at first seemed to be in a dramatic conflict with both the model of the dark matter and the model of gamma ray bursts.

It however turned out that these findings allow to relate, modify, and generalize as many as five models sketched at that time as the first applications of TGD. The subjects modeled were following:
i) The final state of a rotating star predicting flux tube like magnetic field along the symmetry axis [D3],
ii) Dark matter identified as cosmic strings or their decay products,
iii) Sunspots identified as the throats of magnetic flux tubes feeding magnetic flux to larger space-time sheet and behaving effectively as magnetic monopoles [D6]),
iv) Gamma ray bursts explained as cosmic firecrackers resulting from the decay of split cosmic strings to elementary particles,
v) The anomalous e^+e^- pairs produced in the collisions of heavy nuclei at energy near the Coulomb wall as decay products of lepto-pions consisting of color excited leptons [F7].

5.7.1 Correlations between gamma ray bursts and supernovae

The established correlation between gamma ray bursts and supernovae is certainly the cosmological discovery of the year 2003 [32, 33].

1. The first indications for supernova gamma ray burst connection came 1998 when a supernova was seen few days after the gamma ray burst in the same region of sky. In this case the intensity of the burst was however by four orders of magnitude weaker than for the typical gamma ray bursts so that the idea about the correlation was not taken seriously. On 29 March, observers recorded a burst christened as GRB030329. On 6 April, theorists at the Technion Institute of Technology in Israel and CERN in Geneva predicted that there would be signs of a supernova in the visible light and infrared spectra on 8 April [32]. On cue, two days later, observers picked up the telltale spectrum of a type Ic supernova in the same region of sky, triggered as the collapsing star lost hydrogen from its surface. It has now become clear that a large class of gamma ray bursts correlate with supernovae of type Ib and Ic [34], and that they could thus be powered by the mere core collapse leading to supernova. Recall that supernovae of type II involve hydrogen lines unlike those of type I. Supernovae of type Ib shows Helium lines, and Ic shows neither hydrogen nor helium but intermediate mass elements instead. Supernovae of type Ib and Ic are thought to result as core collapse of massive stars.

2. One of the most enigmatic findings were the "mystery spots" accompanying supernova SN1987A at a distance of few light weeks at the symmetry axis at opposite sides of the supernova [35] Their luminosity was nearly 5 per cent of the maximal one. SN1987A was also accompanied by an expanding axi-symmetric remnant surrounded by three concentric rings.

3. The latest finding [36] is that the radiation associated with the gamma ray bursts is maximally polarized. The polarization degree is the incredible 80 ± 20 per cent, which tells that it must be generated in an extremely strong magnetic field rather than in a simple explosion. The magnetic field must have a strong component parallel to the eye sight direction.

Do topologically condensed cosmic strings become co-moving magnetic flux tubes serving as seeds for the formation of stars and galaxies

According to the model for the formation of stars and galaxies proposed already fifteen years ago, topologically condensed pieces of cosmic strings perhaps resulting in the collision of long possibly knotted cosmic strings would serve as seeds making possible formation of lumps of matter forming later stars. The assumption that the pieces of cosmic strings result in the collision of cosmic strings leading to the splitting of them to pieces with some fractal length distribution perhaps concentrated around p-adic length scales would explain why the mass $M(R)$ of galactic dark matter inside a sphere of radius R is proportional to the radius: $M(R) \propto R$.

1. Topologically condensed cosmic strings as co-stretching magnetic flux tubes

I considered already 15 years ago a model for topological condensation of cosmic strings assuming that strong radial Kähler electric fields are generated to compensate the large positive magnetic action. Cosmic strings are actually a special case of magnetic flux tube solutions of field equations. This leads to a revised vision for what happens for topologically condensed cosmic strings. This model does not exclude the presence of the radial electric fields due to the charging of the cosmic strings.

Cosmic strings, which are in the ideal situation string like objects of type $X^2 \times Y^2$, X^2 string like object in M^4_+ and Y^2 geodesic sphere of CP_2 or a piece of it, generate an M^4_+ projection which increases in thickness so that the solution becomes increasingly thicker magnetic flux tube. In the topological condensation the open ends of the string disappear and thus no decay to elementary particles can occur. Thus the topological condensation would stabilize the cosmic strings against decay.

1. The simplest assumption is that the topologically condensed piece of a magnetic flux tube of finite length co-stretches with the expanding universe so that its length increases as $L \propto a$, a light cone proper time.

2. The requirement that magnetic flux is conserved and quantized implies $B \propto 1/S$, S the transverse area of the flux tube. The condition that magnetic energy is conserved, implies $S \propto L \propto a$ and $B \propto 1/a$. This of course applies both to the magnetic and Z^0 magnetic flux tubes.

The assumption that topologically condensed pieces of cosmic strings remain co-stretching forever is questionable, and it might be that when the thickness of the flux tube reaches a critical value corresponding to a Compton length of say pion or lepto-pion, expansion stops, and the flux tube freezes to a very long hadronic or lepto-hadronic (color) magnetic flux tube (a Kähler field giving rise to em or Z^0 field gives also rise to a classical color field).

"Wormhole magnetic fields" consist of pairs of magnetic flux tubes represented by space-time sheets with opposite time orientations and thus having opposite energies. These structures have zero energy and I have proposed that they play a key role in the physics of living matter. In particular, they could be generated by intentional action by first generating a p-adic variant of the wormhole magnetic field representing the intention to generate wormhole magnetic field, and then transforming it to its real counterpart in quantum jump. One cannot exclude the possibility that cosmic strings could also be generated as zero energy pairs of cosmic strings with opposite time orientation. This would make possible to intentionally create universe from nothing. This is actually the only possibility if one poses the boundary condition that no quantum numbers flow out of the future light cone at its boundary.

2. Stars and galaxies as gravitational condensates around fragments of cosmic strings

The gravitational condensation of matter around short parallel flux tubes topologically condensed at larger space-time sheets is a natural mechanism for generating structures like galaxies and stars. The pieces of magnetic flux tubes would form expanding ferro-magnet like structure in the self-consistent magnetic field defined by the by the return flux flowing at the space-time sheet at which strings have suffered topological condensation. The contribution of the magnetic flux tubes to the total mass of the star can be small and the ordinary matter can be seen as decay products of cosmic strings as in the earlier model. Similar mechanism with different initial length of topologically condensed cosmic strings and resulting in fragmentation in the collision of say two long cosmic strings could give rise to the birth of galactic nuclei.

According to the TGD based model of primordial critical cosmology, the transition from string dominated to radiation dominated cosmology should have occurred at $a_0 \sim 10^{-10}$ s, and one could argue that the topological condensation of the magnetic flux tubes should have started at this time. With this assumption the recent thickness of the magnetic flux tubes would be $d = (a/a_0)^{1/2} \times 10^4\sqrt{G} \sim 10^{-16}$ m for $a \sim 10^{11}$ years. This corresponds to a hadronic length scale. Quite generally, this would suggest that at light cone proper time a the fragments of long cosmic strings, which have survived the decay to elementary particles, have typical length $L \sim a$.

From the recent length of about light month associated with super nova SN1987A (identifying the mysterious light spots as ends of the flux tube), one can deduce that the length L_0 of the cosmic strings at a_0 would have been $L_0 \simeq 10^{-14}$ m, roughly the Compton length of pion. The corresponding magnetic field would be about 10^{16} Tesla and extremely strong. Fields of similar magnitude have been proposed to result in the core collapse of supernovae [38]. It however seems that the flux tubes of the primordial magnetic fields cannot explain the highly polarized synchrotron radiation but that the temporary extremely strong Z^0 magnetic field induced by the core collapse are responsible for the polarization.

Magnetic and Z^0 magnetic flux tubes as templates for the formation of material structures is an idea borrowed from TGD inspired theory of consciousness and of bio-systems as macroscopic quantum systems [TGDconsc]. The TGD based quantum model for bio-matter assumes that the magnetic flux tubes of Earth serve as templates for the formation of bio-matter, and also define what I have called magnetic bodies controlling pre-biotic and biotic evolution [L5]. Also the idea that magnetic flux tubes act as wave guides and make precisely targeted communications possible originates from TGD inspired theory of consciousness [K1]. Thus magnetic flux tube structures could serve as templates for and even guide the evolution of matter in all length and time scales: this is certainly in spirit with the fractality of TGD Universe.

A mechanism producing gamma ray burst and polarized synchrotron radiation

The dynamo model for the final state of a rotating star leads to a model for gamma ray bursts consistent with ultrahigh polarization of the synchrotron radiation. The model is consistent with the standard model for the radiation beams from neutron stars.

1. Generalizing the dynamo model for the final state of rotating star

TGD based dynamo model for the final state of rotating star predicts that the rotation axis star contains extremely strong magnetic or Z^0 magnetic field. The field along the axis can also be helical and B_ϕ would naturally result from the rotation of the matter. While attempting to interpret the dynamo model I proposed that the axial field might somehow relate to a cosmic string. This might be indeed the case.

What I did not realize 15 years ago that many-sheeted space-time allows both magnetic and Z^0 magnetic dynamo fields and their symmetry axes of the fields need not coincide.

1. The atomic nuclei of even ordinary condensed matter can carry anomalous weak charges due to the presence of color bonds between nucleons having at their ends exotic quarks with mass of order electron mass and carrying also weak charges [F8, F9]. If some color bonds become charged they have also net weak charges. The Z^0 repulsion due to the weak bosons with Compton length of order atomic radius can explain the low compressibility of condensed matter and give rise to the repulsive term in van der Waals equation. Weak repulsion due to exotic weak bosons is expected to become important in the extremely dense phase of matter inside star.

2. There are good justifications for the assumption that Z^0 magnetic axis is parallel to the rotation axes- Z^0 magnetic field having neutron number as its source receives a large varying contribution dictated by the flow dynamics of the star. Hence Z^0 magnetic field is expected to be very strong, at least in the situations in which currents of different dark matter particle species do not cancel each other. In particular, the ejection of dark neutrinos during the formation of supernova is expected to generate a strong Z^0 charge due to the anomalous Z^0 charges of nuclei. This induces both Z^0 electric field and Z^0 magnetic fields. Since rotation and Z^0 magnetic fields are so strongly coupled, the Z^0 magnetic and rotation axes should coincide.

3. The fact that the rotation axis of the star is rather stable is consistent with the primordial origin of the Z^0 magnetic field and suggests that Z^0 magnetic field as the primordial cause of the rotation.

4. Magnetic axis need not coincide with the rotation axis. The direction of the magnetic field of the star can be reversed (this is happening just now in case of Sun). This suggests that magnetic field does not have primordial origin and reflects the dynamics of the star.

5. TGD based variant for charged particle currents frozen to the magnetic field lines (assumed to have infinity conductivity in magnetohydrodynamics) are non-dissipative supra currents flowing along magnetic flux tubes of the magnetic and Z^0 magnetic fields. These currents in turn

generate magnetic and/or Z^0 magnetic fields with field lines circulating around the rotation axes and thus make the magnetic field along symmetry axis helical.

6. Both in the case of magnetic or Z^0 magnetic field, the charged particles topologically condensed at the super-conducting flux tubes could be also spin polarized and amplify the field further.

In many-sheeted space-time topologically condensed magnetic flux tubes must feed their fluxes to larger space-time sheets so that a many-sheeted variant of the dipole field would result. The return fluxes would flow at larger space-time sheet and correspond to thicker flux tubes with weaker intensity of the magnetic flux. The regions, where the flux would be transferred between space-time sheets could correspond to join along boundaries bonds or wormhole contacts. In the latter case they would look like magnetic charges. As the in case of the sunspots, a fractal structure containing flux tubes inside flux tubes is expected [D6].

The mysterious light spots associated with SN1987A [35] could correspond to join along boundaries bonds or the throats of the magnetic flux tubes of or primordial Z^0 magnetic flux tubes.

3. Synchrotron radiation in strong Z^0 magnetic field as a mechanism generating strong polarization

Usually the degree of polarization for the radiation from supernovae is around few per cent [40]. The polarization associated with gamma ray burst GRB021206 is however incredibly high 80 ± 20 per cent and maximal polarization of the radiation [36]. This requires extremely strong Z^0 magnetic field. The helical Z^0 magnetic field along the rotation axis can have flux quanta of astrophysical size and is ideal for accelerating dark charges flowing along the rotation axis and for producing dark photon synchrotron radiation leaking out in the direction of the rotating magnetic axis and transforming to ordinary photons by a mechanism analogous to decoherence of laser beams [F9, J6]. Gamma ray bursts could be seen as a particular case of this radiation resulting when an especially strong dark current (say dark electron current) flows along the rotational axis in an exceptionally strong dynamically generated Z^0 magnetic field, and induces a beam of synchrotron radiation along the rotating magnetic axis.

The radiation is linearly polarized with the polarization direction and intensity defined by the vector

$$\overline{n} \times (\overline{n} \times \overline{B}^Z) = \overline{B}^Z - B_z^Z cos(\theta)\overline{n} \ ,$$

where $\overline{n}$ is the direction of the observer in the direction of the axial magnetic flux tubes and characterized by the angle θ. The direction of polarization is constant during the observation period if the symmetry axis associated with B^Z coincides with the rotation axis. It is essential that magnetic and Z^0 magnetic fields are not parallel and reside at different space-time sheets. The intensity is proportional to the square of the polarization factor given by

$$(B^Z)^2 \times \left(1 - cos^2(\alpha)cos^2(\theta)\right) \quad , \quad cos(\alpha) \equiv \frac{B_z^Z}{B^Z} \ .$$

If the Z^0 magnetic field has only z-component, the intensity is proportional to $(B^Z)^2 sin^2(\theta)$ and at minimum.

4. Radial compression as a mechanism producing strong Z^0 magnetic field

A sudden compression in radial directions orthogonal to the rotation axis at the core collapse could be seen as a process analogous to the squeezing of the tooth paste tube. A strong non-dissipative supra current along the axis of magnetic field is induced because this is the route of the lowest resistance. This current in turn generates a strong magnetic field component B_ϕ^Z, and the charges accelerated in the axial direction in this field emit synchrotron radiation with a direction of polarization tangential to the magnetic field component B_ϕ^Z. If all nuclei possess anomalous Z^0 charges, the matter flow along rotation axis can generate very strong Z^0 magnetic field so that there are good hopes of explaining the anomalously high value of polarization of the synchrotron radiation.

The three expanding ring like structures associated with SN1987A [26] could be identified as being due to dark Z^0 currents rotating around the strong axial Z^0 magnetic field. Even the identification as torus like flux quanta of Z^0 magnetic field induced by the very strong Z^0 current along the z-axis is possible. This kind of Z^0 magnetic dark currents rotating around axial Z^0 magnetic field could be even responsible for the rings associated with planets like Saturnus and even with the ring current associated with Earth. This picture conforms with the model for the formation of solar system in which macroscopically quantum coherent dark matter serves as a template around which ordinary matter is condensed [D6, J6] as also with the explanation of tritium beta decay anomaly assuming that Earth's orbit is surrounded by dark neutrino belt [F8].

It is known that spherical and even axial symmetry is broken in case of SN1987A and this is consistent with the fact that magnetic and Z^0 magnetic axis are not parallel. Let L be the line of sight orthogonal to the plane S of sky, and R the projection of the ring to S. Let z-axis correspond to L and x- and y-axis to the directions of the minor and major axis of R. Denote by E_z and E_y the projections of ejecta to S and xz-plane. From the figure 2 of [37] one can deduce that the plane of the ring forms an angle of 44 degrees with respect L. The symmetry axes of E_y resp. E_z forms an angle of 45 degrees resp. 15 degrees with respect to x-axis. From this one can conclude the polar and azimuthal angles of the symmetry axis of ejecta are $\theta = 45.4$ degrees and $\phi = 9$ degrees. A good guess is that this axis corresponds to the rotation axis and axis of Z^0 magnetic field tilted by 45.4 degrees with respect to the line of sight parallel to the magnetic axis. Mystery spots are known to be located at this axis too [37] so that they could indeed correspond to sunspot like throats at which Z^0 magnetic flux is transferred between space-time sheets.

Magnetic flux tubes as wave guides

Magnetic flux tubes are ideal wave guides forcing the confined radiation to propagate in a precisely targeted manner along them. Topological light rays (MEs) accompany magnetic flux tubes involved and have interpretation as space-time correlates for a radiation propagating in the waveguide defined by the magnetic flux tube. They are accompanied by coherent light generated by light like vacuum currents associated with then. Topological light rays would couple to Alfwen waves representing transversal oscillations of the magnetic flux tubes propagating also with light velocity.

The wave guide function of magnetic flux tubes suggests a generalization and modification of the model of gamma ray bursts. Gamma ray bursts would be generated by the synchrotron radiation generated in the acceleration of charges when they move along rotation axis with dynamically generated component B^Z_ϕ. Part of the resulting radiation would end up to a rotating magnetic flux tube bundle in the direction of the rotating magnetic axis. The initial channelling at the magnetic flux tubes would force synchrotron radiation to propagate to distant parts of the universe in a precisely targeted manner. This mechanism would explain the observed universal properties for the gamma ray bursts [42] difficult to understand in the models involving mergers, say collisions of white dwarf binaries [34]. As already noticed, the model is consistent with the existing model for the ordinary radiation arriving from supernovae and thought of as involving a beam rotating with the supernova.

Gamma ray bursts as dark photons

In [D6] a model for dark graviton with a large value of Planck constant is developed. This yields also a model for the de-coherence of dark graviton and for what happens in the detection of dark gravitational radiation. The model applies also to dark gauge bosons.

1. The basic new element is that dark bosons are associated with topological light rays which are N-sheeted multiple coverings of M^4. The energy absorbed in the detection of a dark boson would be N-fold whereas the frequency for detections is expected to be $1/N$ times lower so that in average sense dark bosons would behave like normal ones. The events in which dark gravitons with large N are detected would be interpreted as noise. Same could apply to other dark bosons. Dark matter would be only apparently dark.

2. The propagation of of dark boson can be regarded as a sequential de-coherence in which pieces with smaller value of Planck constant and thus smaller energy are split off from the original dark boson. Frequency is not altered in this process.

   Gamma ray bursts could correspond to dark photons with very large value of N so that strongly targeted and very intense beam of ordinary photons results in the de-coherence process.

Gamma ray bursts as collective transitions of cosmic strings identified as scale up hadrons

According to the TGD based model [F4], hadrons consists of two kinds of matter. Valence quark space-time sheets have fused to single structure by color bonds, the "Pomeron" of the physics before

QCD. This structure is in turn connected by bonds (possibly carrying the color of sea quarks) to string like hadronic space-time sheet characterized by Mersenne prime M_{107} and containing super-symplectic bosons giving the dominating contribution to the mass of light baryons.

The black-hole like characteristics of the hadronic space-time sheet, which conform with the experimental findings at RHIC, plus the general vision about the formation of neutron stars and quark stars via the fusion of hadronic space-time sheets encourage a generalization to a model for the microscopic structure of black-holes as highly tangled strings inside black-hole horizon. Black-hole would be kind of scaled up hadron.

The Mersenne primes characterizing the hadronic space-time sheet in the hierarchy extending from cosmic strings to hadrons would belong to the set $\{M_n|vertn = 2,3,5,7,13,17,19,31,61,89,107\}$. The quarks contained by cosmic string would be labeled by rather small p-adic primes. Cosmic strings would give rise to primordial black-holes decaying to ordinary matter and magnetic flux tubes with a lower string tension. Gamma ray bursts could result in collective quantum transitions of cosmic strings involving several steps with end products of final state at each step characterized by a smaller Mersenne prime. For gamma ray bursts produced by super-novae the value of Mersenne prime would be probably $k = 107$.

Note that ordinary hadrons need not define the lowest level of the hierarchy since also M_{127} copy of hadron physics appears in the TGD based model of nucleus. If Gaussian Mersennes are allowed then much more levels are possible: in particular, in length scale range especially relevant for living systems.

Gamma ray bursts and quantum phase transitions in the scale of string like object

The model of hadrons behind hadronic mass calculations leads to the vision that super-symplectic bosons are responsible for the most of hadronic mass [F4, F5]. This in turn leads to a microscopic model for neutron stars, quark stars, and black-holes as highly entangled hadronic strings resulting in the fusion of hadronic strings. Also cosmic strings would contain super-symplectic matter and separate from environment by black hole horizon.

All these objects would be macroscopic quantum systems and their quantum transitions could generate dark gamma rays, dark gravitons, and other dark particles decaying to ordinary particles in de-coherence phase transition.

A model for dark graviton emission assignable to the gravitational quantum transition of astrophysical objects characterized by gigantic gravitational Planck constant is discussed in [D3]. Dark gravitons would correspond to pulses of ordinary gravitons resulting in de-coherence rather than continuous flow of gravitons. These pulses might be dismissed as noise in measurement philosophy based on standard quantum mechanics.

5.7.2 Lepto-pions as a signature dark matter?

The identification of cosmic strings as the ultimate source of both visible and dark matter does not exclude the possibility that a considerable portion of topologically condensed cosmic strings have decayed to some light particles. In particular, this could be the situation in the galactic nuclei. On the other hand, if some fraction of cosmic strings evolve to magnetic flux tubes, these flux tubes identifiable as dominant part of the dark matter can carry phases of some exotic particles serving as signatures of the dark matter. Quite recent experimental findings [43] suggest that these exotic particles could be lepto-hadrons predicted by TGD [F7].

Two anomalies

The idea that lepto-hadrons might have something to do with the dark matter has popped up now and then during the last decade but for some reason I have not taken it seriously. Situation changed towards the end of the year 2003. There exist now detailed maps of the dark matter in the center of galaxy and it has been found that the density of dark matter correlates strongly with the intensity of monochromatic photons with energy equal to the rest mass of electron [43].

The only explanation for the radiation is that some yet unidentified particle of mass very nearly equal to $2m_e$ decays to an electron positron pair or directly to gamma pair. Electron and positron are almost at rest and this implies a high rate for the annihilation to a pair of gamma rays. A natural identification for the particle in question would be as a lepto-pion. By their low mass lepto-pions, just like ordinary pions, would be produced in high abundance, in lepto-hadronic strong reactions and therefore the intensity of the monochromatic photons resulting in their decays would serve as a measure for the density of the lepto-hadronic matter. Also the presence of lepto-pionic condensates can be considered. Lepto-pions decay directly to both gamma pairs and electron-positron pairs. Indeed, galaxy is for long time known to be a source of positrons and there is no generally accepted mechanism producing them [43].

The second anomaly was the microwave interstellar medium emission observed by WMAP used to map the anistropy of cosmic microwave spectrum [39]. Unfortunately, the anomaly reached my attention for more than 4 years later. Anomalous lines at frequencies $f = 23; 33, 41, 61, 94$ GHz have been observed. In good approximation they correspond to harmonics of single frequency of f= 10 GHz. For the cyclotron transitions of electron the required magnetic field would be about 0.36 Tesla. The identification would be in terms of cyclotron transitions of dark electrons or of their Cooper pairs residing at magnetic flux tubes of galactic magnetic fields and characterized by so large value of Planck constant that cyclotron energy is above thermal energy. The emitted cyclotron radiation would decay into bunches of ordinary photons with same frequency but much smaller energy.

Lepto-hadron as explanation of gamma ray anomaly?

In the chapter [F7] I have discussed the TGD based explanation for the anomalous production of electron positron pairs in the collisions of heavy nuclei at energies corresponding to the height of Coulomb wall. The effect was observed for more than fifteen years ago [60] but after string model revolution has been forgotten by theorists like many other anomalies of particle physics. The hypothesis is that so called lepto-pions are produced in the strong, non-orthogonal, and rapidly varying electric and magnetic fields of the colliding nuclei. Lepto-hadrons are color bound states of colored excitations of leptons predicted by TGD defining an asymptotically non-free QCD. Actually an entire hierarchy of non-asymptotically free QCD:s are allowed in TGD Universe.

These findings force to take seriously either the identification
a) of the dark matter as lepto-hadrons or
b) of lepto-pions as a signature of dark matter, which itself would be basically magnetic energy associated the with cosmic strings transformed to magnetic flux tubes in topological condensation. Of course, leptopions could correspond to only a small fraction of dark matter and one can quite well imagined that they are created in strong interactions of leptobaryons.

In fact, lepto-pions are not the only possibility. The TGD based model for tetra-neutrons [61] [F8] is based on the hypothesis that mesons made of scaled down versions of quarks corresponding to Mersenne prime M_{127} (ordinary quarks correspond to $k = 107$) and having masses around one MeV could correspond to the color electric flux tubes binding the neutrons to form a tetra-neutron. The same force would be also relevant for the understanding of alpha particles.

Why lepto-hadrons cannot directly correspond to dark matter?

The identification of lepto-hadrons as dark matter raises several questions leading to the conclusion that lepto-pions are most probably only a signature of dark matter.

1. Why the ratio of the lepto-hadronic mass density to the mass density of the ordinary hadrons would be so high, of order 7? Could an entire hierarchy of asymptotically non-free QCDs be responsible for the dark matter so that lepto-hadrons would explain only a small portion of the dark matter? Is even the hierarchy of QCD:s enough?

2. Under what conditions one can regard lepto-hadronic matter as a dark matter? Could short life-times of lepto-hadrons make them effectively dark matter in the sense that there would be no stable enough atom like structures consisting of say charged lepto-baryons bound electromagnetically to the ordinary nuclei or electrons? But what would be the mechanism producing lepto-hadrons in this case (nuclear collisions produce lepto-pions only under very special conditions)?

3. What would be the role of the many-sheeted space-time: could lepto-hadrons and atomic nuclei reside at different space-time sheets so that lepto-baryons could be long-lived? Could dark

matter quite generally correspond to the matter at different space-time sheets and thus serve as a direct signature of the many-sheeted space-time topology? Magnetic flux tubes are excellent candidates for the space-time sheets accommodate the dark matter but there are good reasons to believe that magnetic energy is considerably higher than the energy of particles condensed on magnetic flux tubes so that magnetic energy is the best candidate for dark matter.

These objections suggest that lepto-pions serve only as a signature of dark matter. The recent vision about dark matter suggests that all particles can appear as dark variants and reside at magnetic flux tubes and leptopions could be only particular kind of dark matter. Of course, dark matter itself could correspond also to the magnetic energy of the magnetic flux tubes and cosmic strings.

Lepto-pions topologically condensed on magnetic flux tubes as a signature of dark matter?

Lepto-pions and other leptohadrons producing copiously lepto-pions could reside at magnetic of Z^0 magnetic flux tubes of thickness of order Compton length of lepto-pion. These strings could be seen as kind of very long lepto-hadronic strings. Also long hadronic flux tubes carrying coherent states of ordinary pions are possible and Z^0 flux tubes beaming the gamma ray bursts could correspond to them.

One could identify the lepto-hadronic magnetic flux tubes as structures generated later in the cosmic evolution, when the magnetic flux of hadronic flux tubes flow to larger space-time sheets. The transversal length scales of the flux tubes would be in ratio m_e/m_p and the magnetic field would be by a factor of about 10^{-6} weaker, about 10^{10} Tesla whereas the magnetic field of supernovae are around 10^9 Tesla. If the thickness of the magnetic flux tube at the moment of the annihilation of lepto-pion is of the order of Compton length of electron, one obtains an estimate for its thickness at the moment when the transition to the radiation dominated phase occurred.

If the strength of the magnetic field is of order $eB \sim m_e^2 \sim 10^9$ Tesla, the cyclotron frequency would be of same order as electron mass $eB/m_e \sim m_e$ and in gamma ray region. For $eB \sim m_p^2$ the field strength would be 10^{15} Tesla and cyclotron energy would be of order proton mass. Harmonics of this line might serve as a signature for the strength of the magnetic field. The monochromatic gamma lines at electron mass could also result in cyclotron transitions of electrons if the magnetic field at magnetic flux tubes that $eB = m_e^2$ holds true in high precision.

One can imagine two mechanisms of lepto-pion production.

1. The magnetic and Z^0 magnetic fields associated with the magnetic flux tubes give rise to classical color fields, which suggest that one could regard the flux tubes as macroscopic color magnetic and possibly also color electric flux tubes carrying lepto-hadrons, which produce copiously lepto-pions in their reactions.

2. In heavy ion collisions lepto-pion production is caused by the presence of the rapidly varying non-orthogonal electric and magnetic fields of colliding nuclei, whose "instanton density" $E \cdot B$ is non-vanishing (this means that the magnetic flux tube has higher than 2-dimensional CP_2 projection). The amplitude for lepto-pion production as a decay of the coherent state is proportional to the Fourier component of the "instanton density". The mechanism could be at work also now if magnetic flux tubes carry strong charges and generate radial electric fields. Lepto-pions would serve as signature for rapid changes of the magnetic and electric fields induced by rapid deformations of the magnetic flux tubes.

Solar X-ray halo and scaled up QCDs at magnetic flux tubes

Quite recently New Scientist told about an explanation proposed by Kostantin Zioukas and his colleagues [45] for the X-ray halo of Sun in terms of axions, one of the many candidates for the dark matter [67]. The X-ray halo of Sun was detected at 1940. The halo extends from the surface of Sun (free path for photons increases at the surface). The X-ray intensity decays exponentially and extends several solar radii from the surface. The energy range of X-rays is $3-15$ keV. The origin of the X-ray halo has remained a mystery.

The axions in the required mass range are predicted by certain higher-dimensional theories [45]. The axions would be produced in the solar core and because of their extremely long lifetime they would propagate to the surface of Sun and some fraction of non-relativistic axions would remain bound in the solar gravitational field where they would decay. The estimated mean distance of the proposed axion population from the solar surface is about 6.2 solar radii. Zioukas and his colleagues are able to deduce the value of the coupling constant $g_{A\gamma\gamma}$ characterizing the rate of axion decay and the interaction cross section of axion with matter from the fact that the X-ray luminosity must be proportional to $g^4_{A\gamma\gamma}$. The resulting lifetime of the axion is about 10^{21} s to be compared with the lifetime of ordinary pion about 10^{-16} s.

TGD suggests an alternative explanation based on a non-asymptotically free exotic QCD at a magnetic flux tube corresponding to a p-adic length scale $L(k)$ for which the scaled down value of pion mass corresponds to mass of about 3 keV. Assuming that pion corresponds to $k = 107$ ($k = 109$ is the second candidate) this gives $2^{(k-107)/2} \sim m_{\pi(107)}/m_{\pi(k)}$. The lower limit for the energy spectrum would favor the p-adic length scale $L(139)$ giving $m_{\pi(139)} \simeq 2.2$ keV. The lifetime of lepto-pion would be scaled up by a factor 2^{16} so that one would have $\tau \sim 10^{-11}$ s. One cannot exclude the presence of several scaled up QCDs with $k = 139, 137$ and $k = 131$ being the most favored ones in the energy range of about 3 octaves spanned by the X-ray spectrum.

In the recent case the intensity of the X-ray halo from a given spherical volume V of the halo defining the pixel is determined by the density $dn(\pi)/dl$ of the exotic pions per unit length of the magnetic flux tube and the length $l(V)$ of the magnetic flux tube inside the volume, which is expected behave as $l(V) \sim V^{1/3}$. A rough estimate is

$$I(V) \sim \frac{dn(\pi)}{dl} \times l(V) \times \Gamma \times \langle E(\pi)\rangle \Delta\Omega \ ,$$

where $\Delta\Omega = A/4\pi R^2$ is the solid angle defined spanned by the active detection area A of the measuring instrument at a given point of the magnetic flux tube and R is the distance of Earth from Sun. In principle this allows to estimate the density of exotic pions per unit length of the magnetic flux tube.

The exponential decay of the intensity with distance from the surface of the Sun would suggest that magnetic flux tubes might be regarded as threads extending from the solar surface and returning back to it, and that the probability of a path of given length decreases exponentially with its length. If the probability for the appearance of a thread of given length is proportional to the Boltzman weight $exp(-E_B/T)$, where E_B is magnetic energy of the thread and T is temperature parameter, this indeed holds true.

The intensity of the magnetic field at the flux tubes can be estimated from the nominal value $B_E = .5 \times 10^{-4}$ Tesla of the Earth's magnetic field at the space-time sheet $k = 169$. By scaling one would obtain $B = 2^{169-139} B_E = 5 \times 10^4$ Tesla. The field is extremely strong and could be perhaps assigned to remnants of primordial cosmic strings. Note that also Z^0 magnetic field could be in question in which case dark matter coupling to scaled down copies of electro-weak bosons would be in question [F6, F9].

Do the length scale ratios for astrophysical objects reflect Compton length ratios of elementary particles?

The ratio for the size $L_l \sim 10^5$ light years of a galactic nucleus to the distance $L_h \sim 1$ light month between the light spots of super nova gives an estimate for the ratio of the lengths of the lepto-hadronic and hadronic magnetic flux tubes. This would predict $L_l/L_h \sim 10^6$ and that the ratio of transverse thicknesses $d_l/d_h = 10^3$, which is the ratio of lepto-pion Compton length scale scale to proton Compton length. This would suggests that the length scale hierarchy for astrophysical objects could represent a scaled up version of the p-adic length scale hierarchy associated with elementary particles.

Frequency cutoff for zero point frequencies as a test for many-sheeted space-time?

For a quantum system mode lable in terms of harmonic oscillators (say photon field) the frequency spectrum in the thermal equilibrium obeys Planck distribution. Besides this the system exhibits zero point fluctuations whose energy density is given by $\rho_0(f) = 8\pi^2 f^3$ ($\hbar = c = 1$) in the 3-dimensional case. Zero point fluctuations appear in many models of physical phenomena such as X-ray scattering in solids, Lamb shift, Casimir effect, and the interpretation of the Aharonov Bohm effect (for references see [46]).

The zero point fluctuations are predicted to appear also in electronic systems, and the experimentally measured spectral density of the current noise measured by Koch [47] in Josephson junctions provides a direct support for this prediction. The fluctuations have been observed up to the frequency of $f = .6$ THz which corresponds to a microwave wavelength of .5 mm.

It has been proposed by Beck and Mackey [46] that if these fluctuations are associated with the vacuum energy, the total vacuum energy density associated with these fluctuations cannot exceed the recently measured dark energy density of the Universe: this leads to a cutoff frequency of $f_c = (1.69 \pm .05)$ THz for the measured frequency spectrum.

In TGD framework dark matter is ordinary matter at larger space-time sheets. First of all, the finite size of the space-time sheet poses an IR cutoff. p-Adic length scale hierarchy suggests that that there is also UV cutoff that corresponds to the next p-adic length scale in the hierarchy. Hence the frequencies above the UV cutoff would correspond to oscillations at smaller space-time sheets. The interpretation would be in terms of de-coherence.

Thus a given space-time sheet would contain half octave of frequencies between the frequency cutoffs $f_{low}(k) = c/L(k) \propto 2^{-k/2}$ and $f_{up}(k) = c/L(k+1)$. Cutoff frequencies would come as half octaves for k integer as predicted by the most general form of the p-adic length scale hypothesis. The stronger form of the hypothesis favors prime values of k. Note that for $k = 179$ (prime) the predicted cutoff frequency would be $f_c(179) \simeq 1.74$ THz, which happens consistent with the prediction of [46] deduced from the estimate for the dark matter density. This need not be an accident. According to the TGD based model explaining the finding that neutrino mass depends on the environment, neutrinos can condense on several space-time sheets and neutrinos in dense matter travel along $k = 179$ space-time sheet [F3].

The problem is that the spectral density would be same at every space-time sheet. One might however hope that the shift of the spectrum from a space-time sheet to another one manifests itself as some kind of structure at half-integer octaves of a basic frequency. By using a suitable arrangement one might be even able to eliminate some space-time sheet so that a gap would result. An interesting question is how the measurement instrument could be constructed to detect only the frequencies associated with a space-time sheet corresponding to a fixed value of k.

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Chapter 6

TGD and Cosmology

6.1 Introduction

TGD inspired cosmology in its recent form relies on an ontology differing dramatically from that of GRT based cosmologies. Zero energy ontology states that all physical states have vanishing net quantum numbers so that all matter is creatable from vacuum. The hierarchy of dark matter identified as macroscopic quantum phases labeled by arbitrarily large values of Planck constant is second aspect of the new ontology. The values of the gravitational Planck constant assignable to space-time sheets mediating gravitational interaction are gigantic. This implies that TGD inspired late cosmology might decompose into stationary phases corresponding to stationary quantum states in cosmological scales and critical cosmologies corresponding to quantum transitions changing the value of the gravitational Planck constant and inducing an accelerated cosmic expansion.

6.1.1 Zero energy cosmology

Robertson-Walker cosmologies correspond to vacua with respect to inertial energy and in fact with respect to all quantum numbers. They are not vacua with respect to gravitational charges defined as Noether charges associated with the curvature scalar. Also more general imbeddings of Einstein's equations are typically vacuum extremals with respect to Noether charges assignable to Kähler action since otherwise one ends up with conflict between imbeddability and dynamics. This suggests that physical states have vanishing net quantum numbers quite generally. The construction of quantum theory [C1, D3] indeed leads naturally to zero energy ontology stating that everything is creatable from vacuum.

Zero energy states decompose into positive and negative energy parts having identification as initial and final states of particle reaction in time scales of perception longer than the geometro-temporal separation T of positive and negative energy parts of the state. If the time scale of perception is smaller than T, the usual positive energy ontology applies.

In zero energy ontology inertial four-momentum is a quantity depending on the temporal time scale T used and in time scales longer than T the contribution of zero energy states with parameter $T_1 < T$ to four-momentum vanishes. This scale dependence alone implies that it does not make sense to speak about conservation of inertial four-momentum in cosmological scales. Hence it would be in principle possible to identify inertial and gravitational four-momenta and achieve strong form of Equivalence Principle. It however seems that this is not the correct approach to follow.

Negative energy virtual gravitons represented by topological quanta having negative time orientation and hence also negative energy. The absorption of negative energy gravitons by photons could explain the gradual red-shifting of the microwave background radiation. Negative energy virtual gravitons give also rise to a negative gravitational potential energy. Quite generally, negative energy virtual bosons build up the negative interaction potential energy. An important constraint to TGD inspired cosmology is the requirement that Hagedorn temperature $T_H \sim 1/R$, where R is CP_2 size, is the limiting temperature of radiation dominated phase.

6.1.2 Dark matter hierarchy and hierarchy of Planck constants

The idea about hierarchy of Planck constants relying on generalization of the imbedding space was inspired both by empirical input (Bohr quantization of planetary orbits) and by the mathematics of hyper-finite factors of type II_1 combined with the quantum classical correspondence.

Quantum classical correspondence suggests that Jones inclusions [18] have space-time correlates [C6, A9]. There is a canonical hierarchy of Jones inclusions labeled by finite subgroups of SU(2)[17] This leads to a generalization of the imbedding space obtained by gluing an infinite number of copies of H regarded as singular bundles over $H/G_a \times G_b$, where $G_a \times G_b$ is a subgroup of $SU(2) \times SU(2) \subset SL(2,C)\times SU(3)$. Gluing occurs along a factor for which the group is same. The generalized imbedding space has clearly a book like structure with pages of books intersecting along 4-D sub-manifold $M^2\times S^2$, S^2 a geodesic sphere of CP_2 characterizing the choice of quantization axies. Entire configuration space is union over "books" corresponding to various choices of this sub-manifold.

The groups in question define in a natural manner the direction of quantization axes for for various isometry charges and this hierarchy seems to be an essential element of quantum measurement theory. Ordinary Planck constant, as opposed to Planck constants $\hbar_a = n_a\hbar_0$ and $\hbar_b = n_b\hbar_0$ appearing in the commutation relations of symmetry algebras assignable to M^4 and CP_2, is naturally quantized as $\hbar = (n_a/n_b)\hbar_0$, where n_i is the order of maximal cyclic subgroup of G_i. The hierarchy of Planck constants is interpreted in terms of dark matter hierarchy [A9]. What is also important is that $(n_a/n_b)^2$ appear as a scaling factor of M^4 metric so that Kähler action via its dependence on induced metric codes for radiative corrections coming in powers of ordinary Planck constant: therefore quantum criticality and vanishing of radiative corrections to functional integral over WCW does not mean vanishing of radiative corrections.

G_a would correspond directly to the observed symmetries of visible matter induced by the underlying dark matter [A9]. For instance, in living matter molecules with 5- and 6-cycles could directly reflect the fact that free electron pairs associated with these cycles correspond to $n_a = 5$ and $n_a = 6$ dark matter possibly responsible for anomalous conductivity of DNA [A9, J1] and recently reported strange properties of graphene [75]. Also the tedrahedral and icosahedral symmetries of water molecule clusters could have similar interpretation [70, F9].

A further fascinating possibility is that the observed indications for Bohr orbit quantization of planetary orbits [30] could have interpretation in terms of gigantic Planck constant for underlying dark matter [D6] so that macroscopic and -temporal quantum coherence would be possible in astrophysical length scales manifesting itself in many manners: say as preferred directions of quantization axis (perhaps related to the CMB anomaly) or as anomalously low dissipation rates.

Since the gravitational Planck constant is proportional to the product of the gravitational masses of interacting systems, it must be assigned to the field body of the two systems and characterizes the interaction between systems rather than systems themselves. This observation applies quite generally and each field body of the system (em, weak, color, gravitational) is characterized by its own Planck constant.

In the gravitational case the order of G_a is gigantic and at least GM_1m/v_0, $v_0 = 2^{-11}$ the favored value. The natural interpretation is as a discrete rotational symmetry of the gravitational field body of the system having both gravimagnetic and gravi-electric parts. The subgroups of G_a for which order is a divisor of the order of G_a define broken symmetries at the lower levels of dark matter hierarchy, in particular symmetries of visible matter.

The number theoretically simple ruler-and-compass integers having as factors only first powers of Fermat primes and power of 2 would define a physically preferred sub-hierarchy of quantum criticality for which subsequent levels would correspond to powers of 2: a connection with p-adic length scale hypothesis suggests itself. Ruler and compass hypothesis implies that besides p-adic length scales also their 3- and 5- multiples should be important.

A crucially important implication of dark matter hierarchy is macroscopic quantum coherence in astrophysical scales. This means that astrophysical systems tend to retain their M^4 size during cosmic expansion and change their size only during quantum jumps increasing the value of Planck constant. Cosmological quantum states can be modeled in terms of stationary Robertson-Walker cosmologies, which are extremals of curvature scalar. These cosmologies are determined apart from single parameter and string dominated having infinite horizon size.

Quantum phase transitions between stationary cosmologies are modelable in terms of quantum critical cosmologies which are also determined apart from single parameter. They correspond to accelerated cosmic expansion having interpretation in terms of increase of quantum scale due to the increases of gravitational Planck constant.

6.1.3 Quantum criticality and quantum phase transitions

TGD Universe is quantum counterpart of a statistical system at a critical temperature. As a consequence, topological condensate is expected to possess hierarchical, fractal like structure containing topologically condensed 3-surfaces with all possible sizes. Both Kähler magnetized and Kähler electric 3-surfaces ought to be important and string like objects indeed provide a good example of Kähler magnetic structures important in TGD inspired cosmology. In particular space-time is expected to be many-sheeted even at cosmological scales and ordinary cosmology must be replaced with many-sheeted cosmology. The possible presence of vapor phase consisting of free cosmic strings and possibly also elementary particles is second crucial aspects of TGD inspired cosmology.

Quantum criticality of TGD Universe supports the view that many-sheeted cosmology is in some sense critical, at least during quantum phase transitions. Criticality in turn suggests fractality. Phase transitions, in particular the topological phase transitions giving rise to new space-time sheets, are (quantum) critical phenomena involving no scales. If the curvature of the 3-space does not vanish, it defines scale: hence the flatness of the cosmic time=constant section of the cosmology implied by the criticality is consistent with the scale invariance of the critical phenomena. This motivates the assumption that the new space-time sheets created in topological phase transitions are in good approximation modelable as critical Robertson-Walker cosmologies for some period of time at least. It turns out that the critical cosmologies are naturally assignable to phase transitions and quantum criticality.

6.1.4 Critical and over-critical cosmologies are highly unique

Any one-dimensional sub-manifold of CP_2 allows global imbeddings of subcritical cosmologies whereas for a given 2-dimensional Lagrange manifold of CP_2 critical and overcritical cosmologies allow only one-parameter family of partial imbeddings.

The infinite size of the horizon for the imbeddable critical cosmologies is in accordance with the presence of arbitrarily long range fluctuations at criticality and guarantees the average isotropy of the cosmology. Imbedding is possible for some critical duration of time. The parameter labeling these cosmologies is a scale factor characterizing the duration of the critical period. These cosmologies have the same optical properties as inflationary cosmologies but exponential expansion is replaced with logarithmic one.

Cosmic expansion is accelerated for critical cosmologies. This gives good hopes of avoiding the introduction of cosmological constant and exotic forms of matter such as quintessence. Critical cosmologies might be completely universal and assignable to any quantum phase transitions in proper length scale. Dark matter hierarchy realized in terms of gigantic values of gravitational Planck constant predicts that even astrophysical systems are macroscopic quantum systems at the level of dark matter. This means that their M^4 size remains constant during cosmic expansion and can change only in quantum jump increasing the value of Planck constant. Critical cosmologies would be assigned to this kind of phase transitions occurring for large voids [D4].

Critical cosmology can be regarded as a 'Silent Whisper amplified to Bang' rather than 'Big Bang' and transformed to hyperbolic cosmology before its imbedding fails. Split strings decay to elementary particles in this transition and give rise to seeds of galaxies. In some later stage the hyperbolic cosmology can decompose to disjoint 3-surfaces. Thus each sub-cosmology is analogous to biological growth process leading eventually to biological death.

Critical and stationary cosmologies for which gravitational charges are conserved can be used as a building blocks of a fractal cosmology containing cosmologies containing ... cosmologies. p-Adic length scale hypothesis allows a quantitative formulation of the fractality [D6]. Fractal cosmology predicts cosmos to have essentially same optical properties as inflationary scenario but avoids the prediction of unknown vacuum energy density. Fractal cosmology explains the paradoxical result that the observed density of the matter is much lower than the critical density associated with the largest space-time sheet of the fractal cosmology. Also the observation that some astrophysical objects seem to be older than the Universe, finds a nice explanation.

The key difference between inflationary and quantum critical cosmologies relates to the interpretation of the fluctuations of the microwave background. In the inflationary option fluctuations are amplified to long length scale fluctuations during inflationary expansion. In quantum critical cosmology the fluctuations be assigned to the quantum critical period accompanying macroscopic quantum fluctuations of the dark matter appearing in very long length scales during the phase transition so that no inflationary expansion is needed. Sub-critical cosmology is predicted after the inflationary period.

6.1.5 Equivalence Principle in TGD framework

The motivation for TGD as a Poincare invariant theory of gravitation was that the notion of four-momentum is poorly defined in curved space-time since corresponding Noether currents do not exist. A lot of cognitive noise was caused by my attempt to deduce the formulation of Equivalence Principle in the framework provided by General Relativity framework applying only in the long length cale limit rather than in string model context. There were several steps in the process of becoming aware of this.

1. First came the conviction that coset representation for super-symplectic and super Kac-Moody algebras provides extremely general formulation of Equivalence Principle in which inertial and gravitational four-momenta are replaced with Super Virasoro generators of two algebras whose differences annihilate physical states. This idea came for years before becoming aware of its importance and I simply forgot it.

2. Next came the realization of the fundamental role of number theoretical compactification providing a number theoretical interpretation of $M^4 \times CP_2$ and thus also of standard model quantum numbers. This lead to the identification of the preferred extremals of Kähler action and to the formulation of quantum TGD in terms of second quantized induced spinors fields. One of conclusion was that dimensional reduction for preferred extremals of Kähler action- if they have the properties required by theoretic compactification- leads to string model with string tension which is however not proportional to the inverse of Newton's constant but to L_p^2, p-adic length scale squared and thus gigantic. The connection between gravitational constant and L_p^2 comes from an old argument that I discovered about two decades ago and which allowed to predict the value of Kähler coupling strength by using as input electron mass and p-adic mass calculations. In this framework the role of Planck length as a fundamental length scale is taken by CP_2 size so that Planck length scale loses its magic role as a length scale in which usual views about space-time geometry cease to hold true.

3. The next step was the realization that zero energy ontology allows to avoid the paradox implied in positive energy ontology by the fact that gravitational energy is not conserved but inertial energy identified as Noether charge is. Energy conservation is always in some length scale in zero energy ontology.

4. As a matter fact, there was still one step. I had to become fully aware that the identification of gravitational four-momentum in terms of Einstein tensor makes sense only in long length scales. This is of course trivial but for some reason I did not realize that this fact resolves the paradoxes associated with objects like cosmic strings.

To summarize, the understanding of Equivalence Principle in TGD context required quite many discoveries of mostly mathematical character: the understanding of the super-conformal symmetries of quantum TGD, the discovery of zero energy ontology, the identification of preferred extremals of Kähler action by requiring number theoretical compactification, and the discovery that dimensional reduction allows to formulate quantum in terms of slicing of space-time surface by stringy word sheets. As far as cosmic strings are considered, the new vision throws to paper basket the idea about negative gravitational mass of the cosmic string inducing antigravity like effects.

6.1.6 Cosmic strings as basic building blocks of TGD inspired cosmology

Cosmic strings are the basic building blocks of TGD inspired cosmology and all structures including large voids, galaxies, stars, and even planets can be seen as pearls in a cosmic fractal necklaces consisting of cosmic strings containing smaller cosmic strings linked around them containing... During cosmological evolution the cosmic strings are transformed to magnetic flux tubes with smaller Kähler string tension and these structures are also key players in TGD inspired quantum biology.

Cosmic strings are of form $X^2 \times Y^2 \subset M^4 \times CP_2$, where X^2 corresponds to string orbit and Y^2 is a complex sub-manifold of CP_2. The gravitational mass of cosmic string is $M_{gr} = (1-g)/4G$, where g is the genus of Y^2. For $g=1$ the mass vanishes. When Y^2 corresponds to homologically trivial geodesic sphere of CP_2 the presence of Kähler magnetic field is however expected to generate inertial mass which also gives rise to gravitational mass visible as asymptotic behavior of the metric of space-time sheet at which the cosmic string has suffered topological condensation. The corresponding string tension is in the same range that for GUT strings and explains the constant velocity spectrum of distant stars around galaxies.

For $g>1$ the gravitational mass is negative. This inspires a model for large voids as space-time regions containing $g>1$ cosmic string with negative gravitational energy and repelling the galactic $g=0$ cosmic strings to the boundaries of the large void.

These voids would participate cosmic expansion only in average sense. During stationary periods the quantum states would be modelable using stationary cosmologies and during phase transitions increasing gravitational Planck constant and thus size of the large void they critical cosmologies would be the appropriate description. The acceleration of cosmic expansion predicted by critical cosmologies can be naturally assigned with these periods. Classically the quantum phase transition would be induced when galactic strings are driven to the boundary of the large void by the antigravity of big cosmic strings with negative gravitational energy. The large values of Planck constant are crucial for understanding of living matter so that gravitation would play fundamental role also in the evolution of life and intelligence.

6.1.7 Topics of the chapter

In the following this scenario is described in detail.

1. Basic ingredients of TGD inspired cosmology are introduced. The consequences of the imbeddability requirement are analyzed. The basic properties of cosmic strings are summarized and simple model for vapor phase as consisting of critical density of cosmic strings are introduced. Additional topics are thermodynamical aspects of cosmology, in particular the new view about second law and the consequences of Hagedorn temperature. Non-conservation of gravitational momentum is considered.

2. The evolution of the fractal cosmology is described in more detail.

3. TGD inspired cosmology is compared to inflationary scenario: in particular, the TGD based explanation for the recently observed flatness of 3-space and a possible solution to the Hubble constant controversy are discussed.

   e) Certain problems of the cosmology such as the questions why some stars seem to be older than the Universe, the claimed time dependence of the fine structure constant, the generation of matter antimatter asymmetry, and the problem of the fermion families, are discussed.

4. Simulating Big Bang in laboratory is the title of the last section. The motivation comes from the observation that critical cosmology could serve as a universal model for phase transitions.

6.2 Basic ingredients of TGD inspired cosmology

In this section the general principles and ingredients of the TGD inspired cosmology are discussed briefly.

6.2.1 Many-sheeted space-time defines a hierarchy of smoothed out space-times

The notion of quantum average space-time obtained by smoothing out details below the scale of resolution was inspired by renormalization philosophy and for long time I regarded it as a fictive concept. The rough idea was that quantum average effective space-times correspond to the absolute minima of the Kähler action associated with the maxima of the Kähler function. Therefore the dynamics of the quantum average effective space-time is fixed and the stationarity requirement for the effective action should only select some physically preferred maxima of the Kähler function. The topologically trivial space time of classical GRT cannot directly correspond to the topologically highly nontrivial TGD space-time but should be obtained only as an idealized, length scale dependent and essentially macroscopic concept. This allows the possibility that also the dynamics of the effective smoothed out space-times is determined by the effective action.

The space-time in length scale L is obtained by smoothing out all topological details (particles) and by describing their presence using various densities such as energy momentum tensor $T^{\alpha\beta}_{\#}$ and Yang Mills current densities $J^{\alpha}_{a\#}$ serving as sources of classical electro-weak and color gauge fields (see Fig. 6.2.1). It is important to notice that the smoothing out procedure eliminates elementary particle type boundary components in all length scales: this suggests that the size of a typical elementary particle boundary component sets lower limit for the scale, where the smoothing out procedure applies.

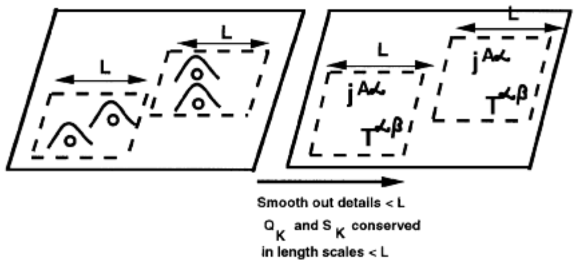

Figure 6.1: Intuitive definition of length scale dependent space-time

During development of the many-sheeted space-time concept it has become obvious that the notions of classical space-time and of smoothing out of details are not only activities of a theoretician, but that the many-sheeted space-time itself can be said to perform renormalization theory.

1. In TGD framework classical space-time is much more than a fiction produced by the stationary phase approximation. The localization in the so called zero modes, which corresponds to state function reduction in TGD, which occurs in each quantum jump (the delicacies due to macro-temporal quantum coherence will not be discussed here) means that the superposition of space-time surfaces in the final state of quantum jump, consists of space-time surfaces equivalent from the point of view of observer.

2. The notion of many-sheeted space-time predicts a hierarchy of space-time sheets labeled by p-adic primes $p \simeq 2^k$, k integer with primes and prime powers being in preferred role. The space-time sheets at a given level of hierarchy play a role of particles topologically condensed at larger space-time sheets. Hence the physics at larger space-time sheets is quite concretely a smoothed out version of the physics at smaller space-time sheets. Many-sheeted space-time itself performs renormalization group theory, and p-adic primes characterizing the sizes of the space-time sheets correspond to the fixed points of the renormalization group evolution.

3. There are good reasons to expect that the absolute minimum value for the Kähler action vanishes for large enough space-time sheets, and that space-time sheets result as small deformations of the vacuum extremals at the long length scale limit. The equations derived from Einstein-Hilbert action for the induced metric can be posed as an additional constraint on stationary vacuum extremals for which the gravitational four momentum current is conserved. It must be however emphasized that the structure of Einstein tensor as a source of the wave equation for the metric is enough to guarantee that gravitational masses make themselves visible in the asymptotic behavior of the metric.

An important difference to the standard view is that energy momentum tensor is defined by the Einstein tensor (plus possible contribution of metri

4. rather than vice versa. Since the dynamics of the induced EYM fields is dictated by the absolute minimization of Kähler action, EYM equations cannot in general be satisfied without the introduction of particle currents. This conforms with the view that Einstein's equations relate to a statistical description of matter in terms of both particle densities and classical fields. The imbeddability to $H = M^4_+ \times CP_2$ means a rich spectrum of predictions not made by GRT. TGD inspired cosmology and TGD based model for the final state of the star are good examples of these predictions, and are consistent with experimental facts.

5. Quantum measurement theory with a finite measurement resolution formulated in terms of Jones inclusions replacing effectively complex numbers as coefficient field of Hilbert space with non-commutative von Neumann algebra is the most recent formulation for the finite measurement resolution and leads to the rather fascinating vision about quantum TGD [C6, A9]. This formulation should have also a counterpart at space-time level and combined with number theoretical vision it leads to the emergence of discretization at space-time level realized in terms of number theoretical braids.

6. Dark matter hierarchy whose levels are labeled by the values of Planck constant brings in an additional complication [A9, D3]. Planck constant actually labels the "field bodies" mediating various interactions and gravitational field bodies have a gigantic value of Planck constant.

   The realization of this hierarchy at the level of imbedding space means the replacement of the imbedding space with a book like structure whose pages are copies of imbedding space endowed with a finite and singular bundle projection corresponding to the group $Z_{n_a} \times Z_{n_b} \subset SO(3) \times SU(3)$. These groups act as discrete symmetries of field bodies.

   The choice of these discrete subgroups realizes the choice of angular momentum and color quantization axes at the level of imbedding space and thus realizes quantum classical correspondence. Any two pages of this book with 8-D pages intersect along common at most 4-D sub-manifold and the partonic 2-surfaces in the intersection can regarded as quantum critical systems in the sense that they correspond to a critical point of a quantum phase transition in general changing the value of Planck constant. Field bodies are four-surfaces mediating interactions between four-surfaces at different pages of this book.

   The value of Planck constant makes itself visible in the scaling of M^4 part of the metric of H appearing in Kähler action. The scaling factor of M^4 metric m_{kl} equals to $(\hbar/\hbar_0)^2 = (n_a/n_b)^2$ as is clear from the fact that the Laplacian part of Schrödinger equation is at same time proportional to the contravariant metric and to $1/\hbar^2$. This means that radiative corrections are coded by the nonlinear dependence of the Kähler action on the induced metric. This means that all radiative corrections assignable to functional integral defined by exponent of Kähler function can vanish for preferred values of Kähler coupling strength. Number theoretic arguments require this.

6.2.2 Robertson-Walker cosmologies

Robertson-Walker cosmologies are the basic building block of standard cosmologies and sub-critical R-W cosmologies have a very natural place in TGD framework as Lorentz invariant cosmologies. Inflationary cosmologies are replaced with critical cosmologies being parameterized by a single parameter telling the duration of the critical cosmology. Over-critical cosmologies are also possible and have the same form as critical cosmologies and finite duration.

Why Robertson-Walker cosmologies?

Robertson Walker cosmology, which is a vacuum extremal of the Kähler action, is a reasonable idealization only in the length scales, where the density of the Kähler charge vanishes. Since (visible) matter and antimatter carry Kähler charges of opposite sign this means that Kähler charge density vanishes in length scales, where matter-antimatter asymmetry disappears on the average. This length scale is certainly very large in present day cosmology: in the proposed model for cosmology its present value is of the order of 10^8 light years: the size of the observed regions containing visible matter predominantly on their boundaries [22]. That only matter is observed could be understood if it resides dominantly outside cosmic strings and antimatter inside cosmic strings.

Robertson Walker cosmology is expected to apply in the description of the condensate locally at each condensate level and it is assumed that the GRT based criteria for the formation of "structures" apply. In particular, the Jeans criterion stating that density fluctuations with size between Jeans length and horizon size can lead to the development of the "structures" will be applied.

Imbeddability requirement for RW cosmologies

Standard Robertson-Walker cosmology is characterized by the line element [21]

$$ds^2 = f(a)da^2 - a^2(\frac{dr^2}{1-kr^2} + r^2 d\Omega^2) \ , \tag{6.2.1}$$

where the values $k = 0, \pm 1$ of k are possible.

The line element of the light cone is given by the expression

$$ds^2 = da^2 - a^2(\frac{dr^2}{1+r^2} + r^2 d\Omega^2) \ . \tag{6.2.2}$$

Here the variables a and r are defined in terms of standard Minkowksi coordinates as

$$\begin{aligned} a &= \sqrt{(m^0)^2 - r_M^2} \ , \\ r_M &= ar \ . \end{aligned} \tag{6.2.3}$$

Light cone clearly corresponds to mass density zero cosmology with $k = -1$ and this makes the case $k = -1$ is rather special as far imbeddings are considered since any Lorentz invariant map $M^4_+ \rightarrow CP_2$ defines imbedding

$$s^k = f^k(a) \ . \tag{6.2.4}$$

Here f^k are arbitrary functions of a.

$k = -1$ requirement guarantees imbeddability if the matter density is positive as is easy to see. The matter density is given by the expression

$$\rho = \frac{3}{8\pi G a^2}(\frac{1}{g_{aa}} + k) \ . \tag{6.2.5}$$

A typical imbedding of $k = -1$ cosmology is given by

$$\begin{aligned} \phi &= f(a) \ , \\ g_{aa} &= 1 - \frac{R^2}{4}(\partial_a f)^2 \ . \end{aligned} \tag{6.2.6}$$

where ϕ can be chosen to be the angular coordinate associated with a geodesic sphere of CP_2 (any one-dimensional sub-manifold of CP_2 works equally well). The square root term is always positive by the positivity of the mass density and the imbedding is indeed well defined. Since g_{aa} is smaller than one, the matter density is necessarily positive.

Critical and over-critical cosmologies

TGD allows the imbeddings of a one-parameter family of critical over-critical cosmologies. Critical cosmologies are however not inflationary in the sense that they would involve the presence of scalar fields. Exponential expansion is replaced with a logarithmic one so that the cosmologies are in this sense exact opposites of each other. Critical cosmology has been used hitherto as a possible model for the very early cosmology. What is remarkable that this cosmology becomes vacuum at the moment of 'Big Bang' since mass density behaves as $1/a^2$ as function of the light cone proper time. Instead of 'Big Bang' one could talk about 'Small Whisper amplified to bang' gradually. This is consistent with the idea that space-time sheet begins as a vacuum space-time sheet for some moment of cosmic time.

As an imbedded 4-surface this cosmology would correspond to a deformed future light cone having its tip inside the future light cone. The interpretation of the tip as a seed of a phase transition is possible. The imbedding makes sense up to some moment of cosmic time after which the cosmology becomes necessarily hyperbolic. At later time hyperbolic cosmology stops expanding and decomposes to disjoint 3-surfaces behaving as particle like objects co-moving at larger cosmological space-time sheet. These 3-surfaces topologically condense on larger space-time sheets representing new critical cosmologies.

Consider now in more detail the imbeddings of the critical and overcritical cosmologies. For $k = 0, 1$ the imbeddability requirement fixes the cosmology almost uniquely. To see this, consider as an example of $k = 0/1$ imbedding the map from the light cone to S^2, where S^2 is a geodesic sphere of CP_2 with a vanishing Kähler form (any Lagrage manifold of CP_2 would do instead of S^2). In the standard coordinates (Θ, Φ) for S^2 and Robertson-Walker coordinates (a, r, θ, ϕ) for future light cone (, which can be regarded as empty hyperbolic cosmology), the imbedding is given as

$$\begin{aligned} sin(\Theta) &= \frac{a}{a_1} \ , \\ (\partial_r \Phi)^2 &= \frac{1}{K_0}\left[\frac{1}{1-kr^2} - \frac{1}{1+r^2}\right] \ , \\ K_0 &= \frac{R^2}{4a_1^2} \ , \ \ k = 0, 1 \ , \end{aligned} \tag{6.2.7}$$

when Robertson-Walker coordinates are used for both the future light cone and space-time surface.

The differential equation for Φ can be written as

$$\partial_r \Phi = \pm\sqrt{\frac{1}{K_0}\left[\frac{1}{1-kr^2} - \frac{1}{1+r^2}\right]} \ . \tag{6.2.8}$$

For $k = 0$ case the solution exists for all values of r. For $k = 1$ the solution extends only to $r = 1$, which corresponds to a 4-surface $r_M = m^0/\sqrt{2}$ identifiable as a ball expanding with the velocity $v = c/\sqrt{2}$. For $r \rightarrow 1$ Φ approaches constant Φ_0 as $\Phi - \Phi_0 \propto \sqrt{1-r}$. The space-time sheets corresponding to the two signs in the previous equation can be glued together at $r = 1$ to obtain sphere S^3.

The expression of the induced metric follows from the line element of future light cone

$$ds^2 = da^2 - a^2\left(\frac{dr^2}{1-kr^2} + r^2 d\Omega^2\right) \ . \tag{6.2.9}$$

The imbeddability requirement fixes almost uniquely the dependence of the S^2 coordinates a and r and the g_{aa} component of the metric is given by the same expression for both $k = 0$ and $k = 1$.

$$\begin{aligned} g_{aa} &= 1 - K \ , \\ K &\equiv K_0 \frac{1}{(1-u^2)} \ , \\ u &\equiv \frac{a}{a_1} \ . \end{aligned} \tag{6.2.10}$$

The imbedding fails for $a \geq a_1$. For $a_1 \gg R$ the cosmology is essentially flat up to immediate vicinity of $a = a_1$. Energy density and "pressure" follow from the general equation of Einstein tensor and are given by the expressions

$$\begin{aligned}
\rho &= \frac{3}{8\pi G a^2}(\frac{1}{g_{aa}} + k) \ , \quad k = 0, \pm 1 \ , \\
\frac{1}{g_{aa}} &= \frac{1}{1-K} \ , \\
p &= -(\rho + \frac{a\partial_a \rho}{3}) = -\frac{\rho}{3} + \frac{2}{3} K_0 u^2 \frac{1}{(1-K)(1-u^2)^2}\rho_{cr} \ , \\
u &\equiv \frac{a}{a_1} \ .
\end{aligned} \tag{6.2.11}$$

Here the subscript 'cr' refers to $k = 0$ case. Since the time component g_{aa} of the metric approaches constant for very small values of the cosmic time, there are no horizons associated with this metric. This is clear from the formula

$$r(a) = \int_0^a \sqrt{g_{aa}} \frac{da}{a}$$

for the horizon radius.

The mass density associated with these cosmologies behaves as $\rho \propto 1/a^2$ for very small values of the M^4_+ proper time. The mass in a co-moving volume is proportional to $a/(1-K)$ and goes to zero at the limit $a \to 0$. Thus, instead of Big Bang one has 'Silent Whisper' gradually amplifying to Big Bang. The imbedding fails at the limit $a \to a_1$. At this limit energy density becomes infinite. This cosmology can be regarded as a cosmology for which co-moving strings ($\rho \propto 1/a^2$) dominate the mass density as is clear also from the fact that the "pressure" becomes negative at big bang ($p \to -\rho/3$) reflecting the presence of the string tension. The natural interpretation is that cosmic strings condense on the space-time sheet which is originally empty.

The facts that the imbedding fails and gravitational energy density diverges for $a = a_1$ necessitates a transition to a hyperbolic cosmology. For instance, a transition to radiation or matter dominated hyperbolic cosmology can occur at the limit $\theta \to \pi/2$. At this limit $\phi(r)$ must transform to a function $\phi(a)$. The fact, that vacuum extremals of Kähler action are in question, allows large flexibility for the modeling of what happens in this transition. Quantum criticality and p-adic fractality suggest the presence of an entire fractal hierarchy of space-time sheets representing critical cosmologies created at certain values of cosmic time and having as their light cone projection sub-light cone with its tip at some a=constant hyperboloid.

More general imbeddings of critical and over-critical cosmologies as vacuum extremals

In order to obtain imbeddings as more general vacuum extremals, one must pose the condition guaranteing the vanishing of corresponding the induced Kähler form (see the Appendix of this book). Using coordinates $(r, u = cos(\Theta), \Psi, \Phi)$ for CP_2 the surfaces in question can be expressed as

$$\begin{aligned}
r &= \sqrt{\frac{X}{1-X}} \ , \\
X &= D|k+u| \ , \\
u &\equiv cos(\Theta) \ , \quad D = \frac{r_0^2}{1+r_0^2} \times \frac{1}{C} \ , \quad C = |k + cos(\Theta_0)| \ .
\end{aligned} \tag{6.2.12}$$

Here C and D are integration constants.

These imbeddings generalize to imbeddings to $M^4 \times Y^2$, where Y^2 belongs to a family of Lagrange manifolds described in the Appendix of this book with induced metric

$$\begin{aligned}
ds^2_{eff} &= \frac{R^2}{4}[s^{eff}_{\Theta\Theta}d\Theta^2 + s^{eff}_{\Phi\Phi}d\Phi^2] \ , \\
s^{eff}_{\Theta\Theta} &= X \times \left[\frac{(1-u^2)}{(k+u)^2} \times \frac{1}{1-X} + 1 - X\right] \ , \\
s^{eff}_{\Phi\Phi} &= X \times \left[(1-X)(k+u)^2 + 1 - u^2\right] \ .
\end{aligned} \tag{6.2.13}$$

For $k \neq 1$ $u = \pm 1$ corresponds in general to circle rather than single point as is clear from the fact that $s^{eff}_{\Phi\Phi}$ is non-vanishing at $u = \pm 1$ so that u and Φ parameterize a piece of cylinder. The generalization of the previous imbedding is as

$$sin(\Theta) = ka \quad \rightarrow \quad \sqrt{s^{eff}_{\Phi\Phi}} = ka \ . \tag{6.2.14}$$

For Φ the expression is as in the previous case and determined by the requirement that g_{rr} corresponds to $k = 0, 1$.

The time component of the metric can be expressed as

$$g_{aa} = 1 - \frac{R^2k^2}{4}\frac{s^{eff}_{\Theta\Theta}}{\frac{d\sqrt{s^{eff}_{\Phi\Phi}}}{d\Theta}} \tag{6.2.15}$$

In this case the $1/(1-k^2a^2)$ singularity of the density of gravitational mass at $\Theta = \pi/2$ is shifted to the maximum of $s^{eff}_{\Phi\Phi}$ as function of Θ defining the maximal value a_{max} of a for which the imbedding exists at all. Already for $a_0 < a_{max}$ the vanishing of g_{aa} implies the non-physicality of the imbedding since gravitational mass density becomes infinite.

The geometric properties of critical cosmology change radically in the transition to the radiation dominated cosmology: before the transition the CP_2 projection of the critical cosmology is two-dimensional. After the transition it is one-dimensional. Also the isometry group of the cosmology changes from $SO(3)\times E^3$ to $SO(3,1)$ in the transition. One could say that critical cosmology represents Galilean Universe whereas hyperbolic cosmology represents Lorentzian Universe.

String dominated cosmology

A particularly interesting cosmology is string dominated cosmology with very nearly critical mass density. Assuming that strings are co-moving the mass density of this cosmology is proportional to $1/a^2$ instead of the $1/a^3$ behavior characteristic to the standard matter dominated cosmology. The line element of this metric is very simple: the time component of the metric is simply constant smaller than 1:

$$g_{aa} = K < 1 \ . \tag{6.2.16}$$

The Hubble constant for this cosmology is given by

$$H = \frac{1}{\sqrt{K}a} \ , \tag{6.2.17}$$

and the so called acceleration parameter [21] k_0 proportional to the second derivative $\ddot{a}$ therefore vanishes. Mass density and pressure are given by the expression

$$\rho = \frac{3}{8\pi GKa^2}(1-K) = -3p \ . \tag{6.2.18}$$

What makes this cosmology so interesting is the absence of the horizons. The comparison with the critical cosmology shows that these two cosmologies resemble each other very closely and both could be used as a model for the very early cosmology.

Stationary cosmology

An interesting candidate for the asymptotic cosmology is stationary cosmology for which gravitational four-momentum currents (and also gravitational color currents) are conserved. This cosmology extremizes the Einstein-Hilbert action with cosmological term given by $\int(kR+\lambda)\sqrt{g}d^4x+\lambda$ and is obtained as a sub-manifold $X^4\subset M^4_+\times S^1$, where S^1 is the geodesic circle of CP_2 (note that imbedding is now unique apart from isometries by variational principle).

For a vanishing cosmological constant, field equations reduce to the conservation law for the isometry associated with S^1 and read

$$\partial_a(G^{aa}\partial_a\phi\sqrt{g}) = 0 \ , \tag{6.2.19}$$

where ϕ denotes the angle coordinate associated with S^1. From this one finds for the relevant component of the metric the expression

$$\begin{aligned} g_{aa} &= \frac{(1-2x)}{(1-x)} \ , \\ x &= (\frac{C}{a})^{2/3} \ . \end{aligned} \tag{6.2.20}$$

The mass density and "pressure" of this cosmology are given by the expressions

$$\begin{aligned} \rho &= \frac{3}{8\pi Ga^2}\frac{x}{(1-2x)} \ , \\ p &= -(\rho+\frac{a\partial_a\rho}{3}) = -\frac{\rho}{9}\left[3-\frac{2}{(1-2x)}\right] \ . \end{aligned} \tag{6.2.21}$$

The asymptotic behavior of the energy density is $\rho\propto a^{-8/3}$. "Pressure" becomes negative indicating that this cosmology is dominated by the string like objects, whose string tension gives negative contribution to to the "pressure". Also this cosmology is horizon free as are all string dominated cosmologies: this is of crucial importance in TGD inspired cosmology.

It should be noticed that energy density for this cosmology becomes infinite for $x=(C/a)^{2/3}=1/2$ implying that this cosmology doesn't make sense at very early times so that the non-conservation of gravitational energy is necessary during the early stages of the cosmology.

Stationary cosmologies could define space-time correlates for macroscopic quantum states in cosmological length scales predicted by the hypothesis for the values of gravitational Planck constant [D3]. Together with critical cosmologies serving as space-time correlates for cosmic quantum jumps increasing gravitational Planck constant they could define basic building blocks for late cosmologies in TGD Universe.

Non-conservation of gravitational energy in RW cosmologies

In RW cosmology the gravitational energy in a given co-moving sphere of radius r in local light cone coordinates (a,r,θ,ϕ) is given by

$$E = \int\rho g^{aa}\partial_a m^0\sqrt{g}dV \ . \tag{6.2.22}$$

The rate characterizing the non-conservation of gravitational energy is determined by the parameter X defined as

$$X \equiv \frac{(dE/da)_{vap}}{E} = \frac{(dE/da+\int|g^{rr}|p\partial_r m^0\sqrt{g}d\Omega)}{E} \ , \tag{6.2.23}$$

where p denotes the pressure and $d\Omega$ denotes angular integration over a sphere with radius r. The latter term subtracts the energy flow through the boundary of the sphere.

The generation of the pairs of positive and negative (inertial) energy space-time sheets leads to a non-conservation of gravitational energy. The generation of pairs of positive and negative energy cosmic strings would be involved with the generation of a critical sub-cosmology. "Fermionic" pairs would have time-like separation and "bosonic" pairs would consist of parallel stringy space-time sheets connected by wormhole contacts.

For RW cosmology with subcritical mass density the calculation gives

$$X = \frac{\partial_a(\rho a^3/\sqrt{g_{aa}})}{(\rho a^3/\sqrt{g_{aa}})} + \frac{3pg_{aa}}{\rho a} \quad . \tag{6.2.24}$$

This formula applies to any infinitesimal volume. The rate doesn't depend on the details of the imbedding (recall that practically any one-dimensional sub-manifold of CP_2 defines a huge family of subcritical cosmologies). Apart from the numerical factors, the rate behaves as $1/a$ in the most physically interesting RW cosmologies. In the radiation dominated and matter dominated cosmologies one has $X = -1/a$ and $X = -1/2a$ respectively so that gravitational energy decreases in radiation and matter dominated cosmologies. For the string dominated cosmology with $k = -1$ having $g_{aa} = K$ one has $X = 2/a$ so that gravitational energy increases: this might be due to the generation of dark matter due to pairs of cosmic strings with vanishing net inertial energy.

For the cosmology with exactly critical mass density Lorentz invariance is broken and the contribution of the rate from 3-volume depends on the position of the co-moving volume. Taking the limit of infinitesimal volume one obtains for the parameter X the expression

$$\begin{aligned} X &= X_1 + X_2 \ , \\ X_1 &= \frac{\partial_a(\rho a^3/\sqrt{g_{aa}})}{(\rho a^3/\sqrt{g_{aa}})} \ , \\ X_2 &= \frac{pg_{aa}}{\rho a} \times \frac{3+2r^2}{(1+r^2)^{3/2}} \quad . \end{aligned} \tag{6.2.25}$$

Here r refers to the position of the infinitesimal volume. Simple calculation gives

$$\begin{aligned} & X = X_1 + X_2 \ , \\ & X_1 = \frac{1}{a}\left[1 + 3K_0u^2\frac{1}{1-K}\right] \ , \\ & X_2 = -\frac{1}{3a}\left[1 - K - \frac{2K_0u^2}{(1-u^2)^2}\right] \times \frac{3+2r^2}{(1+r^2)^{3/2}} \ , \\ & \qquad K = \frac{K_0}{1-u^2} \ , \quad u = \frac{a}{a_0} \ , \quad K_0 = \frac{R^2}{4a_0^2} \quad . \end{aligned} \tag{6.2.26}$$

The positive density term X_1 corresponds to increase of gravitational energy which is gradually amplified whereas pressure term ($p < 0$) corresponds to a decrease of gravitational energy changing however its sign at the limit $a \to a_0$.

The interpretation might be in terms of creation of pairs of positive and negative energy particles contributing nothing to the inertial energy but increasing gravitational energy. Also pairs of positive energy gravitons and negative anti-gravitons are involved. The contributions of all particle species are determined by thermal arguments so that gravitons should not play any special role as thought originally.

Pressure term is negligible at the limit $r \to \infty$ so that topological condensation occurs all the time at this limit. For $a \to 0, r \to 0$ one has $X > 0 \to 0$ so that condensation starts from zero at $r = 0$. For $a \to 0, r \to \infty$ one has $X = 1/a$ which means that topological condensation is present already at the limit $a \to 0$.

Both the existence of the finite limiting temperature and of the critical mass density imply separately finite energy per co-moving volume for the condensate at the very early stages of the cosmic evolution. In fact, the mere requirement that the energy per co-moving volume in the vapor phase remains finite and non-vanishing at the limit $a \rightarrow 0$ implies string dominance as the following argument shows.

Assuming that the mass density of the condensate behaves as $\rho \propto 1/a^{2(1+\alpha)}$ one finds from the expression

$$\rho \propto \frac{(\frac{1}{g_{aa}} - 1)}{a^2} \ ,$$

that the time component of the metric behaves as $g_{aa} \propto a^{\alpha}$. Unless the condition $\alpha < 1/3$ is satisfied or equivalently the condition

$$\rho \ < \ \frac{k}{a^{2+2/3}} \qquad (6.2.27)$$

is satisfied, gravitational energy density is reduced. In fact, the limiting behavior corresponds to the stationary cosmology, which is not imbeddable for the small values of the cosmic time. For stationary cosmology gravitational energy density is conserved which suggests that the reduction of the density of cosmic strings is solely due to the cosmic expansion.

6.2.3 Cosmic strings and cosmology

The model for cosmic strings has forced to question all cherished assumptions including positive energy ontology, Equivalence Principle, and positivity of gravitational mass. The final outcome turned out to be rather conservative. Zero energy ontology is unavoidable, Equivalence Principle holds true universally but its general relativistic formulation makes sense only in long length scales, and gravitational mass has definite sign for positive/negative energy states. As a matter fact, all problems were created by the failure to realize that the expression of gravitational energy in terms of Einstein's tensor does not hold true in short length scales and must be replaced with the stringy expression resulting naturally by dimensional reduction of quantum TGD to string model like theory [B4, C5, D3].

Zero energy ontology and cosmic strings

There are two kinds of cosmic strings: free and topological condensed ones and both are important in TGD inspired cosmology.

1. Free cosmic strings are not absolute minima of the Kähler action (the action has wrong sign). In the original identification of preferred extremals as absolute minima of Kähler action this was a problem. In the new formulation preferred extremals correspond to quantum criticality identified as the vanishing of the second variation of Kähler action at least for the deformations defining symmetries of Kähler action [B4, D3]. Criticality guarantees the conservation of the Noether charges assignable to the modified Dirac action. Ideal cosmic strings are excluded because they fail to satisfy the conditions characterizing the preferred extremal as a space-time surface containing regions with both Euclidian and Minkowskian signature of the induced metric with light-like 3-surface separating them identified as orbits of partonic 2-surfaces carrying elementary particle quantum numbers. The topological condensation of CP_2 type vacuum extremals representing fermons generates negative contribution to the action and reduces the string tension and leaves cosmic strings still free.

2. If the topologically condensate of fermions has net Kähler charges as the model for matter antimatter asymmetry suggests, the repulsive interaction of the particles tends to thicken the cosmic string by increasing the thickness of its infinitely thin M^4 projection so that Kähler magnetic flux tubes result. These flux tubes are ideal candidates for the carriers of dark matter with a large value of Planck constant. The criterion for the phase transition increasing $\hbar$ is indeed the presence of a sufficiently dense plasma implying that perturbation theory in terms of $Z^2\alpha_{em}$ (Z is the effective number of charges with interacting with each other without screening effects) fails for the standard value of Planck constant. The phase transition $\hbar_0 \rightarrow \hbar$ reduces the value of $\alpha_{em} = e^2/4\pi\hbar$ so that perturbation theory works. This phase transition scales up

also the transversal size of the cosmic string. Similar criterion works also for other charges. The resulting phase is anyonic if the resulting 2-surfaces containing almost spherical portions connected by flux tubes to each other encloses the tip of the causal diamond (CD). The proposal is that dark matter resides on complex anyonic 2-surfaces surrounding the tips of CDs.

3. The topological condensation of cosmic strings generates wormhole contacts represented as pieces of CP_2 type vacuum extremals identified as bosons composed of fermion-antifermion pairs. Also this generates negative action and can make cosmic string a preferred extremal of Kähler action. The earliest picture was based on dynamical cancelation mechanism involving generation of strong Kähler electric fields in the condensation whose action compensated for Kähler magnetic action [16]. Also this mechanism might be at work. Cosmic strings could also form bound states by the formation graviton like flux tubes connecting them and having wormhole contacts at their ends so that again action is reduced.

4. One can argue that in long enough length and time scales Kähler action per volume must vanish so that the idealization of cosmology as a vacuum extremal becomes possible and there must be some mechanism compensating the positive action of the free cosmic strings. The general mechanism could be topological condensation of fermions and creation of bosons by topological condensation of cosmic strings to space-time sheets.

In this framework zero energy states correspond to cosmologies leading from big bang to big crunch separated by some time interval T of geometric time. Quantum jumps can gradually increase the value T and TGD inspired theory of consciousness suggests that the increase of T might relate to the shift for the contents of conscious experience towards geometric future. In particular, what is usually regarded as cosmology could have started from zero energy state with a small value of T.

Topological condensation of cosmic strings

In the original vision about topological condensation of cosmic strings I assumed that large voids represented by space-time sheets contain "big" cosmic string in their interior and galactic strings near their boundaries. The recent much simpler view is that there are just galactic strings which carry net fermion numbers (matter antimatter asymmetry). If they have also net em charge they have a repulsive interaction and tend to end up to the boundaries of the large void. Since this slows down the expansive motion of strings, the repulsive interaction energy increases and a phase transition increasing Planck constant and scaling up the size of the void occurs after which cosmic strings are again driven towards the boundary of the resulting larger void.

One cannot assume that the exterior metric of the galactic strings is the one predicted by assuming General Relativity in the exterior region. This would mean that metric decomposes as $g = g_2(X^2) + g_2(Y^2)$. $g(X^2)$ would be flat as also $g_2(Y^2)$ expect at the position of string. The resulting angle defect due to the replacement of plane Y^2 with cone would be large and give rise to lense effect of same magnitude as in the case of GUT cosmic strings. Lense effect has not been observed.

This suggests that General Relativity fails in the length scale of large void as far as the description of topologically condensed cosmic strings is considered. The constant velocity spectrum for distant stars of galaxies and the fact that galaxies are organized along strings suggests that these string generate in a good approximation Newtonian potential. This potential predicts constant velocity spectrum with a correct value velocity.

In the stationary situation one expects that the exterior metric of galactic string corresponds to a small deformation of vacuum extremal of Kähler action which is also extremal of the curvature scalar in the induced metric. This allows a solution ansatz which conforms with Newtonian intuitions and for which metric decomposes as $g = g_1 + g_3$, where g_1 corresponds to axis in the direction of string and g_3 remaining $1 + 2$ directions.

Dark energy is replaced with dark matter in TGD framework

The observed accelerating expansion of the Universe has forced to introduce the notion of cosmological constant in the GRT based cosmology. In TGD framework the situation is different.

1. The gigantic value of gravitational Planck constant implies that dark matter makes TGD Universe a macroscopic quantum system even in cosmological length scales. Astrophysical systems

become stationary quantum systems which participate in cosmic expansion only via quantum phase transitions increasing the value of gravitational Planck constant.

2. Critical cosmologies, which are determined apart from a single parameter in TGD Universe, are natural during all quantum phase transitions, in particular the phase transition periods increasing the size of large voids and having interpretation in terms of an increase of gravitational Planck constant. Cosmic expansion is predicted to be accelerating during these periods. The mere criticality requires that besides ordinary matter there is a contribution $\Omega_\Lambda \simeq .74$ to the mass density besides visible matter and dark matter. In fact, also for the over-critical cosmologies expansion is accelerating.

3. In GRT framework the essential characteristic of dark energy is its negative pressure. In TGD framework critical and over-critical cosmologies have automatically effective negative pressure. This is essentially due to the constraint that Lorentz invariant vacuum extremal of Kähler action is in question. The mysterious negative pressure would be thus a signal about the representability of space-time as 4-surface in H and there is no need for any microscopic description in terms of exotic thermodynamics.

The values for the TGD counterpart of cosmological constant

One can introduce a parameter characterizing the contribution of dark mass to the mass density during critical periods and call it cosmological constant recalling however that the contribution does not correspond to dark energy. The value of this parameter is same as in the standard cosmology from mere criticality assumption.

What is new that p-adic fractality predicts that Λ scales as $1/L^2(k)$ as a function of the p-adic scale characterizing the space-time sheet implying a series of phase transitions reducing Λ. The order of magnitude for the recent value of the cosmological constant comes out correctly. The gravitational energy density assignable to the cosmological constant is identifiable as that associated with topologically condensed cosmic strings and magnetic flux tubes to which they are gradually transformed during cosmological evolution.

The naive expectation would be the density of cosmic strings would behave as $1/a^2$ as function of M^4_+ proper time. The vision about dark matter as a phase characterized by gigantic Planck constant however implies that large voids do not expand in continuous manner during cosmic evolution but in discrete quantum jumps increasing the value of the gravitational Planck constant and thus increasing the size of the large void as a quantum state. Since the set of preferred values of Planck constant is closed under multiplication by powers of 2, p-adic length scales L_p, $p \simeq 2^k$ form a preferred set of sizes scales for the large voids.

TGD cosmic strings are consistent with the fluctuations of CMB

GUT cosmic strings were excluded by the fluctuation spectrum of the CMB background [64]. In GRT framework these fluctuations can be classified to adiabatic density perturbations and isocurvature density perturbations. Adiabatic density perturbations correspond to overall scaling of various densities and do not affect the vanishing curvature scalar. For isocurvature density fluctuations the net energy density remains invariant. GUT cosmic strings predict isocurvature density perturbations while inflationary scenario predicts adiabatic density fluctuations.

In TGD framework inflation is replaced with quantum criticality of the phase transition period leading from the cosmic string dominated phase to matter dominated phase. Since curvature scalar vanishes during this period, the density perturbations are indeed adiabatic.

Matter-antimatter asymmetry and cosmic strings

Despite huge amount of work done during last decades (during the GUT era the problem was regarded as being solved!) matter-antimatter asymmetry remains still an unresolved problem of cosmology. A possible resolution of the problem is matter-antimatter asymmetry in the sense that cosmic strings contain antimatter and their exteriors matter. The challenge would be to understand the mechanism generating this asymmetry. The vanishing of the net gauge charges of cosmic string allows this symmetry since electro-weak charges of quarks and leptons can cancel each other.

The challenge is to identify the mechanism inducing the CP breaking necessary for the matter-antimatter asymmetry. Quite a small CP breaking inside cosmic strings would be enough.

1. The key observation is that vacuum extremals as such are not physically acceptable: small deformations of vacuum extremals to non-vacua are required. This applies also to cosmic strings since as such they do note present preferred extremals. The reason is that the preferred extremals involve necessary regions with Euclidian signature providing four-dimensional representations of generalized Feynman diagrams with particle quantum numbers at the light-like 3-surfaces at which the induced metric is degenerate.

2. The simplest deformation of vacuum extremals and cosmic strings would be induced by the topological condensation of CP_2 type vacuum extremals representing fermions. The topological condensation at larger space-time surface in turn creates bosons as wormhole contacts.

3. This process induces a Kähler electric fields and could induce a small Kähler electric charge inside cosmic string. This in turn would induce CP breaking inside cosmic string inducing matter antimatter asymmetry by the minimization of the ground state energy. Conservation of Kähler charge in turn would induce asymmetry outside cosmic string and the annihilation of matter and antimatter would then lead to a situation in which there is only matter.

4. Either galactic cosmic strings or big cosmic strings (in the sense of having large string tension) at the centers of galactic voids or both could generate the asymmetry and in the recent scenario big strings are not necessary. One might argue that the photon to baryon ratio $r \sim 10^{-9}$ characterizing matter asymmetry quantitatively must be expressible in terms of some fundamental constant possibly characterizing cosmic strings. The ratio $\epsilon = G/\hbar R^2 \simeq 4 \times 10^{-8}$ is certainly a fundamental constant in TGD Universe. By replacing R with $2\pi R$ would give $\epsilon = G/(2\pi R)^2 \simeq 1.0 \times 10^{-9}$. It would not be surprising if this parameter would determine the value of r.

The model can be criticized.

1. The model suggest only a mechanism and one can argue that the Kähler electric fields created by topological condensates could be random and would not generate any Kähler electric charge. Also the sign of the asymmetry could depend on cosmic string. A CP breaking at the fundamental level might be necessary to fix the sign of the breaking locally.

2. The model is not the only one that one can imagine. It is only required that antimatter is somewhere else. Antimatter could reside also at other p-adic space-time sheets and at the dark space-time sheets with different values of Planck constant.

The needed CP breaking is indeed predicted by the fundamental formulation of quantum TGD in terms of the modified Dirac action associated with Kähler action and its generalization allowing include instanton term as imaginary part of Kähler action inducing CP breaking [B4, F12].

1. The key idea in the formulation of quantum TGD in terms of modified Dirac equation associated with Kähler action is that the Dirac determinant defined by the generalized eigenvalues assignable to the Dirac operator D_K equals to the vacuum functional defined as the exponent of Kähler function in turn identifiable as Kähler action for a preferred extremal for which the second variation of Kähler action vanishes at least for the variations responsible for dynamical symmetries. The interpretation is in terms of quantum criticality with the hierarchy of symmetries defining a hierarchy of criticalities analogous to the hierarchy defined by the rank of the matrix defined by the second derivatives of potential function in Thom's catastrophe theory.

2. This representation generalizes. One can add an imaginary instanton term to the Kähler function and corresponding modified Dirac operator D_K so that the generalized eigenvalues assignable to D_K (analogous to Higgs vacuum expectation) become complex. The natural conjecture is that the resulting Dirac determinant equals to the exponent of Kähler action and imaginary instanton term for the preferred extremal. The instanton term does not contribute to the configuration space metric but provides a first principle description for CP breaking and anyonic effects. It also predicts the dependence of these effects on the page of the book like structure defined by the generalized imbedding space realizing the dark matter hierarchy with levels labeled by the value of Planck constant.

3. In the case of cosmic strings CP breaking could be especially significant and force the generation of Kähler electric charge. Instanton term is proportional to $1/\hbar$ so that CP breaking would be small for the gigantic values of $\hbar$ characterizing dark matter. For small values of $\hbar$ the breaking is large provided that the topological condensation is able to make the CP_2 projection of cosmic string four-dimensional so that the instanton contribution to the complexified Kähler action is non-vanishing and large enough. Since instanton contribution as a local divergence reduces to the contributions assignable to the light-like 3-surfaces X_l^3 representing topologically condensed particles, CP breaking is large if the density of topologically condensed fermions and wormhole contacts generated by the condensation of cosmic strings is high enough.

CP breaking at the level of CKM matrix

The CKM matrix for quarks contains CP breaking phase factors and this could lead to different evaporation rates for baryons and anti-baryons are different (quark cannot appear as vapor phase particle since vapor phase particle must have vanishing color gauge charges and in the recent vision about quantum TGD CP_2 type vacuum extremal which has not suffered topological condensation represents vacuum). The CP breaking at the level of CKM matrix would be implied by the instanton term present in the complexified Kähler action and modified Dirac operator. The mechanism might rely on hadronic Kähler electric fields which are accompanied by color electric gauge fields proportional to induced Kähler form.

The topological condensation of quarks on hadronic strings containing weak color electric fields proportional to Kähler electric fields should be responsible for its string tension and this should in turn generate CP breaking. At the parton level the presence of CP breaking phase factor $exp(ikS_{CS})$, where $S_{CS} = \int_{X^4} J \wedge J + boundary\ term$ is purely topological Chern Simons term and naturally associated with the boundaries of space-time sheets with at most $D = 3$-dimensional CP_2 projection, could have something to do with the matter antimatter asymmetry. Note however that TGD predicts no strong CP breaking as QCD does [C5].

Development of strings in the string dominated cosmology

The development of the string perturbations in the Robertson Walker cosmology has been studied [22] and the general conclusion seems to be that that all the details smaller than horizon are rapidly smoothed out. One must of course take very cautiously the application of these result in TGD framework.

In present case, the horizon has an infinite size so that details in all scales should die away. To see what actually happens consider small perturbations of a static string along z-axis. Restrict the consideration to a perturbation in the y-direction. Using instead of the proper time coordinate t the "conformal time coordinate" τ defined by $d\tau = dt/a$ the equations of motion read [22]

$$\begin{aligned}
(\partial_\tau + \frac{2\dot{a}}{a})(\dot{y}U) &= \partial_z(y'U) \ , \\
U &= \frac{1}{\sqrt{1+(y')^2-\dot{y}^2}} \ .
\end{aligned} \tag{6.2.28}$$

Restrict the consideration to small perturbations for which the condition $U \simeq 1$ holds. For the string dominated cosmology the quantity $\dot{a}/a = 1/\sqrt{K}$ is constant and the equations of motion reduce to a very simple approximate form

$$\ddot{y} + \frac{2}{\sqrt{K}}\dot{y} - y'' = 0 \ . \tag{6.2.29}$$

The separable solutions of this equation are of type

$$\begin{aligned}
y &= g(a)(C\sin(kz) + D\cos(kz)) \ , \\
g(a) &= (\frac{a}{a_0})^r \ .
\end{aligned} \tag{6.2.30}$$

where r is a solution of the characteristic equation $r^2 + 2r/\sqrt{K} + k^2 = 0$:

$$r = -\frac{1}{\sqrt{K}}(1 \pm \sqrt{1-k^2K}) \ . \quad (6.2.31)$$

For perturbations of small wavelength $k > 1/\sqrt{K}$, an extremely rapid attenuation occurs; $1/\sqrt{K} \simeq 10^{27}$! For the long wavelength perturbations with $k << 1/\sqrt{K}$ (physical wavelength is larger than t) the attenuation is milder for the second root of above equation: attenuation takes place as $(a/a_0)^{\sqrt{K}k^2/2}$. The conclusion is that irregularities in all scales are smoothed away but that attenuation is much slower for the long wave length perturbations.

The absence of horizons in the string dominated phase has a rather interesting consequence. According to the well known Jeans criterion the size L of density fluctuations leading to the formation of structures [22] must satisfy the following conditions

$$l_J < L < l_H \ , \quad (6.2.32)$$

where l_H denotes the size of horizon and l_J denotes the Jeans length related to the sound velocity v_s and cosmic proper time as [22]

$$l_J \simeq 10 v_s t \ . \quad (6.2.33)$$

For a string dominated cosmology the size of the horizon is infinite so that no upper bound for the size of the possible structures results. These structures of course, correspond to string like objects of various sizes in the microscopic description. This suggests that primordial fluctuations create structures of arbitrary large size, which become visible at much later time, when cosmology becomes string dominated again.

6.2.4 Thermodynamical considerations

The new view about energy challenging the universal applicability of the second law of thermodynamics, the existence of 'vapor phase' consisting mainly of cosmic strings and critical temperature equal to Hagedorn temperature are basic characteristics of TGD inspired cosmology. The recent view about preferred extremals [B4, D3] requires that cosmic strings are accompanied by a topological condensate of fermions (and possibly also super-symplectic bosons) represented by CP_2 type vacuum extremals. The corresponding light-like 3-surfaces define generalized Feynman diagram associated with the state.

The new view about second law

Quantum classical correspondence suggests negative and positive energy strings (in the sense of zero energy ontology) tend to dissipate backwards in opposite directions of the geometric time in their geometric degrees of freedom. Time reversed dissipation of negative energy states looks from the point of view of systems consisting of positive energy matter self-organization and even self assembly. The matter at the space-time sheet containing strings in turn consists of positive energy matter and negative energy antimatter and also here same competition would prevail.

This tension suggests a general manner to understand the paradoxical aspects of the cosmic and biological evolution.

1. The first paradox is that the initial state of cosmic evolution seems to correspond to a maximally entropic state. Entropy growth would be naturally due to the emergence of matter inside cosmic strings giving them large p-adic entropy proportional to mass squared [C5, D3]. As strings decay to ordinary matter and transform to magnetic flux tubes the entropy related to translation degrees of freedom increases.

2. The dissipative evolution of matter at space-time sheets with positive time orientation would obey second law and evolution of space-time sheets with negative time orientation its geometric time reversal. Second law would hold true in the standard sense as long as one can neglect the interaction with negative energy antimatter and strings.

3. The presence of the cosmic strings with negative energy and time orientation could explain why gravitational interaction leads to a self-assembly of systems in cosmic time scales. The formation of supernovae, black holes and the possible eventual concentration of positive energy matter at the negative energy cosmic strings could reflect the self assembly aspect due to the presence of negative energy strings. An analog of biological self assembly identified as the geometric time reversal for ordinary entropy generating evolution would be in question.

4. In the standard physics framework the emergence of life requires extreme fine tuning of the parameters playing the role of constants of Nature and the initial state of the Universe should be fixed with extreme accuracy in order to predict correctly the emergence of life. In the proposed framework situation is different. The competition between dissipations occurring in reverse time directions means that the analog of homeostasis fundamental for the functioning of living matter is realized at the level of cosmic evolution. The signalling in both directions of geometric time makes the system essentially four-dimensional with feedback loops realized as geometric time loops so that the evolution of the system would be comparable to the carving of a four-dimensional statue rather than approach to chaos.

5. The apparent creation of order by the gravitational interactions is a mystery in the standard cosmology. A naive application of the second law of thermodynamics suggests that in GRT based cosmology the most probable end state corresponds to a black hole dominated Universe since the entropy of the black hole is much larger than the entropy of a typical star with the same mass. TGD allows to consider two alternative solutions of this puzzle.

   (a) If black holes are dark black holes with a gigantic gravitational Planck constant they are not entropic. In the Bohr orbit model for solar system the value of Planck constant for the space-time sheets mediating gravitational interaction has the gigantic value $\hbar_{gr} = GM_1M_2/v_0$, where $v_0 = 2^{-11}$ holds true for inner planets. If $\hbar_{gr} = GM^2/v_0$ holds true for black holes, black hole entropy is of order $1/v_0$. For $v_0 = 1/4$ entropy would be of order single bit and Schwartshild radius would be equal to the scaled up Planck length $l_P = \sqrt{\hbar_{gr}}M$. Positive energy dark black holes as final states of gravitational evolution are therefore not favored by second law.

   (b) The new view about second law inspires the view that gravitational self-organization corresponds to the temporal mirror image of dissipative time evolution for space-time sheets with negative time orientation competing with thermalization. In this situation negative energy dark black holes with small entropy are possible. The formation of black hole would look like breaking of second law from the point of view of observed with standard arrow of geometric time. The self organizing tendency of negative energy cosmic strings would compeee with the opposite tendency of positive energy strings and ordinary matter could give rise to kind of gravitational homeostasis. Although black-hole like structures would result as outcome of gravitational self-organization they would not be sinks of information but have complex internal information carrying structure.

   (c) It is also possible that elementary particles take the role of black holes in TGD framework. CP_2 type extremals are the counterparts of the black holes in TGD. Hawking-Bekenstein area law generalizes and states that elementary particles are carriers of p-adic entropy. Thus this p-adic entropy associated with the thermodynamics of Virasoro generator L_0 could be the counterpart of black hole entropy and the decay of the free cosmic strings to elementary particles would thus generate "invisible" entropy. The upper bound for the p-adic entropy depends on p-adic condensation level as $log(p)$ so that the generation of the new space-time sheets with increasing size (and thus p) generates new entropy since the particles, which are topologically condensed on these sheets, can have entropy of order $log(p)$.

Vapor phase

The structure of $M^4_+ \times CP_2$ suggests kinematic constraints on the cosmology: for the very small values of the M^4_+ proper time a the allowed 3-surfaces are necessarily CP_2 type surfaces or string like objects rather than pieces of M^4. As a consequence, topological evaporation should take place so that the space-time resembles enormous stringy diagram containing inside itself generalized Feynman diagram rather than continuous "classical" space-time. It indeed turns out that although the condensate could be present also in the primordial stage, the dominant contribution to the energy density is in the vapor phase during the primordial cosmology (and as it turns out, also in recent cosmology unless one takes into account the fact that at each level of condensate cosmic expansion is only local!).

The properties of the critical cosmology suggest that space-time sheets representing critical sub-cosmologies are generated only after some value $a_0 \sim R$ of light cone proper time, where $R \sim 10^{3.5}$ Planck times corresponds is CP_2 time. Before this moment there would be no macroscopic space-time but only vapor phase consisting of cosmic strings containing topologically condensed fermions and having purely geometric contact interactions. Thus the idea about primordial cosmology as a stage preceding the formation of space-time in the sense of General Relativity seems to be correct in TGD framework.

The key object of the TGD inspired cosmology is cosmic string with string tension $T \simeq .2 \times 10^{-6}/G$ of same order as the string tension of the GUT strings but with totally different physical and geometric interpretation. Cosmic strings play a key role in the very early string dominated cosmology, they could generate the matter antimatter asymmetry, they would lead to the formation of the large voids and galaxies, they would give rise to the galactic dark matter and also dominate the mass density in the asymptotic cosmology. Vapor phase cosmic strings containing dark might be present also in the cosmology of later times and correspond closely to the vacuum energy density of inflationary cosmologies: now however dark matter rather than dark energy would be in question.

For critical cosmology the gravitational energy of the co-moving volume is proportional to a at the limit $a \rightarrow 0$ and vanishes so that 'Silent Whisper' amplifying to 'Big Bang' is in question. The assumption that also vapor phase gravitational energy density (that is density in imbedding space) behaves in similar manner implies the absence of initial singularities also at vapor phase level. Thus the condition

$$\rho \propto \frac{1}{a^2} , \tag{6.2.34}$$

and hence the string dominated primordial cosmology both in vapor phase and space-time sheets is an attractive hypothesis mathematically. The simplest hypothesis suggested by dimensional considerations is that the mass density of the vapor phase near $a = 0$ behaves as

$$\rho = n\frac{3}{8\pi G a^2} . \tag{6.2.35}$$

Here n is numerical factor of order one. This hypothesis fixes the total energy density of the universe and sets strong constraints on energetics of the cosmology. At later stages topological condensation of the strings reduces the mass density in vapor phase and replaces n by a decreasing function of a. A very attractive hypothesis is that the value of of n is

$$n = 1 . \tag{6.2.36}$$

This gravitational energy density is same as that of critical cosmology at the limit of flatness and can be interpreted as TGD counterpart for the basic hypothesis of inflationary cosmologies. In inflationary cosmologies 70 per cent of the critical mass density is in form of vacuum energy deriving from cosmological constant. In TGD the counterpart of vacuum energy could be the mass density of cosmic strings in vapor phase in these sense that it topologically condensed on string like objects. By quantum classical correspondence it however corresponds to dark matter rather than genuine dark energy.

One can criticize the assumption as un-necessarily strong. There is no absolute necessity for the density of gravitational four-momentum of strings in M^4_+ to be conserved and one can consider the possibility that zero inertial energy string pairs are created from vacuum everywhere inside future light cone.

Long range interactions in the vapor phase are generated only by the exchange of particle like 3-surfaces and the long range interactions mediated by the exchange of the boundary components are impossible. The exchange of CP_2 type vacuum extremals has geometric cross section and the same is expected to be true for the other exchanges of the particle like surfaces. This would mean that the interaction cross sections are determined by the size of the particle of the order of CP_2 radius: $\sigma \simeq l^2 \sim 10^8 G$. In this sense the asymptotic freedom of gauge theories would be realized in the vapor phase. It should be emphasized that this assumption might be wrong and that the gauge interactions between two particles belonging to vapor phase and condensate respectively are certainly present and topological condensation can be indeed seen as this interaction. It should be noticed that the expansion of the Universe in vapor phase is slower than in condensed phase: the ratio of the expansion rates of the universe in vapor and condensed phases is given by the velocity of light in the condensed phase ($c_{\#} = \sqrt{g_{aa}}$).

Also the cross sections for the purely geometric contact interactions of free cosmic strings are extremely low. This suggests that vapor phase is in essentially in temperature zero string dominated state and that the energy density of strings behaves as $1/a^2$.

Limiting temperature

Since particles are extended objects in TGD, one expects the existence of the limiting temperature T_H (Hagedorn temperature as it is called in string models) so that the primordial cosmology is in Hagedorn temperature. A special consequence is that the contribution of the light particles to the energy density becomes negligible: this is in accordance with the string dominance of the critical mass cosmology. The value of T_H is of order $T_H \sim \hbar/R$, where R is CP_2 radius of order $R \sim 10^{3.5}\sqrt{G}$ and thus considerably smaller than Planck temperature. Note that T_H increases with Planck constant and one can wonder whether this increase continues only up to $T_H = \hbar_{cr}/R = \sqrt{\hbar_{cr}/G}$, which corresponds to the critical value $\hbar_{cr} = R^2/G$. The value $R^2/G = 3 \times 20^{23}\hbar_0$ is consistent with p-adic mass calculations and is favored by by number theoretical arguments [C5, D3].

The existence of limiting temperature gives strong constraint to the value of the light cone proper time a_F when radiation dominance must have established itself in the critical cosmology which gave rise to our sub-cosmology. Before the moment of transition to hyperbolic cosmology critical cosmology is string dominated and the generation of negative energy virtual gravitons builds up gradually the huge energy density density, which can lead to gravitational collapse, splitting of the strings and establishment of thermal equilibrium with gradually rising temperature. This temperature cannot however become higher than Hagedorn temperature T_H, which serves thus as the highest possible temperature of the effectively radiation dominated cosmology following the critical period. The decay of the split strings generates elementary particles providing the seeds of galaxies.

If most strings decay to light particles then energy density is certainly of the form $1/a^4$ of radiation dominated cosmology. This is not the only manner to obtain effective radiation dominance. Part of the thermal energy goes to the kinetic energy of the vibrational motion of strings and energy density $\rho \propto 1/a^2$ cannot hold anymore. The strings of the condensate is expected to obey the scaling law $\rho \propto 1/a^4$, $p = \rho/3$ [22]. The simulations with string networks suggest that the energy density of the string network behaves as $\rho \propto 1/a^{2(1+v^2)}$, where v^2 is the mean square velocity of the point of the string [23]. Therefore, if the value of the mean square velocity approaches light velocity, effective radiation dominance results even when strings dominate [24]. In radiation dominated cosmology the velocity of sound is $v = 1/\sqrt{3}$. When v lowers to sound velocity one obtains stationary cosmology which is string dominated.

An estimate for a_F is obtained from the requirement that the temperature of the radiation dominated cosmology, when extrapolated from its value $T_R \simeq .3$eV at the time about $a_R \sim 3 \times 10^7$ years for the decoupling of radiation and matter to $a = a_F$ using the scaling law $T \propto 1/a$, corresponds to Hagedorn temperature. This gives

$$\begin{aligned} a_F &= a_R \frac{T_R}{T_H} \ , \\ T_H &= \frac{n}{R} \ , \qquad a_R \sim 3 \times 10^7 \ y \ , \quad T_R = .27 \ eV \ . \end{aligned} \tag{6.2.37}$$

This gives a rough estimate $a_F \sim 3 \times 10^{-10}$ seconds, which corresponds to length scale of order 7.7×10^{-2} meters. The value of a_F is quite large.

The result does not mean that radiation dominated sub-cosmologies might have not developed before $a = a_F$. In fact, entire series of critical sub-cosmologies could have developed to radiation dominated phase before the final one leading to our sub-cosmology is actually possible. The contribution of sub-cosmology i to the total energy density of recent cosmology is in the first approximation equal to the fraction $(a_F(i)/a_F)^4$. This ratio is multiplied by a ratio of numerical factors telling the number of effectively massless particle species present in the condensate if elementary particles dominate the mass density. If strings dominate the mass density (as expected) the numerical factor is absent.

For some reason the later critical cosmologies have not evolved to the radiation dominated phase. This might be due to the reduced density of cosmic strings in the vapor phase caused by the formation of the earlier cosmologies which does not allow sufficiently strong gravitational collapse to develop and implies that critical cosmology transforms directly to stationary cosmology without the intervening effectively radiation dominated phase. Indeed, condensed cosmic strings develop Kähler electric field compensating the huge positive Kähler action of free string and can survive the decay to light particles if they are not split. The density of split strings yielding light particles is presumably the proper parameter in this respect.

p-Adic length scale hypothesis allows rather predictive quantitative model for the series of sub-cosmologies [D6] predicting the number of them and allowing to estimate the moments of their birth, the durations of the critical periods and also the durations of radiation dominated phases. p-Adic length scale hypothesis allows also to estimate the maximum temperature achieved during the critical period: this temperature depends on the duration of the critical period a_1 as $T \sim n/a_1$, where n turns out to be of order 10^{30}. This means that if the duration of the critical period is long enough, transition to string dominated asymptotic cosmology occurs with the intervening decay of cosmic strings leading to the radiation dominated phase.

The existence of the limiting temperature has radical consequences concerning the properties of the very early cosmology. The contribution of a given massless particle to the energy density becomes constant. So, unless the number of the effectively massless particle families $N(a)$ increases too fast the contribution of the effectively massless particles to the energy density becomes negligible. The massive excitations of large size (string like objects) are indeed expected to become dominant in the mass density.

What about thermodynamical implications of dark matter hierarchy?

The previous discussion has not mentioned dark matter hierarchy labeled by increasing values of Planck constants and predicted macroscopic quantum coherence in arbitrarily long scales. In TGD Universe dark matter hierarchy means also a hierarchy of conscious entities with increasingly long span of memory and higher intelligence [TGDconsc, M3].

This forces to ask whether the second law is really a fundamental law and whether it could reflect a wrong view about existence resulting resulting when all these dark matter levels and information associated with conscious experiences at these levels is neglected. For instance, biological evolution difficult to understand in a universe obeying second law relies crucially on evolution as gradual progress in which sudden leaps occur as new dark matter levels emerge.

TGD inspired consciousness suggests that Second Law holds true only for the mental images of a given self (a system able to avoid bound state entanglement with environment [TGDconsc]) rather than being a universal physical law. Besides these mental images there is irreducible basic awareness of self and second law does not apply to it. Also the hierarchy of higher level conscious entities is there. In this framework second law would basically reflect the exclusion of conscious observers from the physical model of the Universe.

6.3 TGD inspired cosmology

Quantum criticality suggests strongly quantum critical fractal cosmology containing cosmologies inside cosmologies such that each sub-cosmology is critical before transition to hyperbolic phase. The general conceptual framework represented in the previous section give rather strong constraints on fractal cosmology. There are reasons to believe that the scenario to be represented, although by no means the final formulation, contains several essential features of what might be called TGD inspired cosmology.

Some remarks about interpretation are in order.

1. Equivalence Principle is assumed to hold true quite generally and the expression of gravitational four-momentum in terms of Einstein tensor is assumed to make sense in long length scales.

2. Robertson-Walker cosmology is taken as a statistical description replacing the many-sheeted space-time with single space-time sheet. The vanishing of density of inertial energy would be due to the smoothing out of the topological condensate of CP_2 type vacuum extremals and cosmic strings (carrying also these condensates) and giving to the inertial four-momentum a contribution expressible in terms of Einstein tensor in statistical description.

3. TGD inspired cosmology has the structure of Russian doll. Dark matters at various pages of the Big Book defined by the hierarchy of Planck constants defines one hierarchy of cosmologies. There is also a hierarchy of causal diamonds (CDs) defined as the intersection of future and past directed light-cones. Zero energy state associated with CDs could be interpreted as not so big bang followed by not so big crunch as the time scale of CD becomes long enough. In short time scales the interpretation would be in terms of particle reaction. Sub-cosmologies can be generated from vacuum spontaneously so that one has a p-adic hierarchy of cosmologies within cosmologies. If the size of CD is assumed to come as power of 2 as the geometry of CD suggests, p-adic length scale hypothesis follows.

4. The understanding of the non-conservation of gravitational energy associated with a co-moving volume has been a long standing issue in TGD. The conservation of four-momentum is an un-necessarily strong assumption in statistical description since in zero energy ontology four-momentum is conserved only inside causal diamond (CD). The rate for change of the gravitational energy in a given co-moving volume could be interpreted to reflect this statistical non-conservation. The original interpretation for the non-conservation of gravitational energy was in terms of topological evaporation and condensation of space-time sheets and cosmic strings carrying topological condensate of particles, and more generally, in terms of the transfer of energy between different space-time sheets. One cannot exclude the presence of also these mechanisms.

In the following discussion only a sub-cosmology associated with a given CD is discussed and the considerations assume that the time scale of observations is short as compared with the time scale of CD so that positive energy ontology is a good approximation.

6.3.1 Primordial cosmology

TGD inspired cosmology has primordial phase in which only vapor phase containing only cosmic strings containing topological condensate of fermions is present and lasting to $a \sim R$. During this period it is not possible to speak about space-time in the sense of General Relativity. The energy density and 'pressure' of cosmic strings in vapor phase (densities in $M^4_+ \times CP_2$ are assumed to be

$$\begin{aligned} \rho_V &= \frac{3}{8\pi G a^2} \ , \\ p &= -\frac{\rho}{3} \ . \end{aligned} \tag{6.3.1}$$

This assumption would mean that gravitational energy and various gravitational counterparts of the classical charges associated with the isometries of H are conserved during vapor phase period. This assumption guarantees consistency with the critical cosmology and by the requirement that the mass per co-moving volume vanishes at the limit $a \to 0$ so that the Universe is apparently created from nothing. The interactions between cosmic strings are pure contact interactions and extremely weak and it seems natural to assume that the temperature of the vapor phase is zero.

6.3.2 Critical phases

The mere finiteness of Kähler action does not allow vapor phase to endure indefinitely since the Kähler magnetic action of the free cosmic string is positive and infinite at the limit of infinite duration. The topological condensate of fermions necessarily present reduces this action. Second manner to reduce it is creation of space-time sheets at which cosmic strings condense on them and generate Kähler electric fields compensating the positive Kähler magnetic action. Individual cosmic string can however stay as free cosmic string for arbitrarily long time since the finite magnetic Kähler action can be compensated by the correspondingly larger electric Kähler action. In principle cosmic strings can be created as pairs of positive and negative inertial energy cosmic strings from vacuum in vapor phase.

In accordance with this primordial phase is followed by the generation of critical cosmologies as 'Silent Whispers' amplifying to 'Big Bangs' basically by emission of ordinary matter by Hawking radiation, and possibly by gravitational heating made possible by the emission of negative energy virtual gravitons as "acceleration radiation" as matter gains strong inertial energies in gravitational fields. p-Adic length scale hypothesis allows to deduce estimates for the typical time for the creation of a critical cosmology, the duration of the critical phase, the temperature achieved during the critical phase and the duration of the hyperbolic expanding phase possibly following it and transforming to a phase in which cosmic expansion ceases and space-time surface behaves like a particle.

What is of extreme importance is that the deceleration parameter q associated with critical and over-critical cosmologies is negative. It is given by

$$q = -K_0\frac{K_0u^2}{1-u^2-K_0} < 0 \ , \quad u = a/a_1 \ , \tag{6.3.2}$$

where K_0 and a_1 are the parameters appearing in $g_{aa} = 1-K$, $K = K_0/(1-u^2)$.

The rate of change for Hubble constant is

$$\frac{dH/ds}{H^2} = -(1+q) \ , \tag{6.3.3}$$

so that one must have $q < -1$ in order to have acceleration. This holds true for $a > \sqrt{(1-K_0)/(1+K_0)}a_1$. This allows to understand the recently discovered acceleration of late cosmology as assignable to a quantum critical phase transition increasing cosmological constant and thus leading to an increase of the size of the large void.

This model is discussed in detail in [D4] and shown to explain the observed jerk about 13 billion years changing deceleration to acceleration. The recently observed cold spot in cosmic microwave background [62] can be understood as a presence of large void with size of about 10^8 ly already about 10^{10} years ago. This conforms with the hypothesis that large voids increase their size in phase transition like manner rather than participating in cosmic expansion in continuous manner.

6.3.3 Radiation dominated phases

p-Adic length scale hypothesis suggests that the typical moments of birth $a_0(k)$ and durations $a_1(k)$ for the critical cosmologies satisfy $a_0(k) \sim L(k)$ and $a_1(k) \sim L(k)$, where k prime or power of prime, $L(k) = l \times 2^{k/2}$, $l = R \simeq 10^{3.5}$ Planck lengths, and n is a numerical factor. p-Adic length scale hypothesis suggest that the temperature just after the transition to the effectively radiation dominated phase is

$$\begin{aligned} T(k) &= \tfrac{n}{L(k)} \ , \qquad \text{for } k > k_{cr} \ , \\ T(k) &= T_H \sim \tfrac{1}{R} \ , \quad \text{for } k \leq k_{cr} \ . \end{aligned} \tag{6.3.4}$$

Here n is rather large numerical factor. Since $a_F \sim 2.7 \times 10^{-10}$ seconds which corresponds to length scale $L \simeq .08$ meters roughly to p-adic length scale $L(197) \simeq .08$ meters (which by the way corresponds to the largest p-adic length scale associated with brain, a cosmic joke?!), should correspond to the establishment of Hagedorn temperature, one has the conditions

$$\begin{aligned} k_{cr} &= 197 \ , \\ n &\simeq 2^{197/2} \sim 10^{30} \sim \frac{m_{CP_2}^2}{m_p^2} \ . \end{aligned}$$

Thus n is in of same order of magnitude as the ratio of the CP_2 mass squared ($m_{CP_2} \simeq 10^{-3.5}$ Planck masses) to proton mass squared.

Dimensional considerations suggest also that the energy density in the beginning of the radiation dominated phase (in case that it is achieved) is

$$\rho = nT^4(k) \ , \tag{6.3.5}$$

where n a numerical factor of order one. n does not count for the number of light particle species since the thermal energy of strings could give rise to the effective radiation dominance. Furthermore, if ordinary matter is created by Hawking radiation and by radiation generated by the ends of split strings, the large mass and Hagedorn temperature as a limiting temperature could make impossible the generation of particle genera higher the three lowest ones (see [F1] for the argument why $g > 2$ particle families (g denotes the genus of partonic 2-surface) have ultra heavy masses). Thus it seems that the infinite number of fermion families cannot lead to an infinite density of thermal energy and why their presence leaves no trace in present day cosmology.

When the time parameter a_1 of the critical cosmology grows too large, it cannot anymore generate radiation dominated phase since the temperature remains too low. Previous considerations suggest that the maximum value of a_1 is roughly $a_1(max) = a_F \sim 3\times 10^{-10}$. After this critical sub-cosmologies would transform directly to the stationary cosmologies.

Radiation dominated phase transforms to matter dominated phase and possibly decomposes to disjoint 3-surfaces with size of order horizon size at the same time. p-Adic length scale hypothesis suggests that the duration of the radiation dominated phase with respect to the proper time of the space-time sheet is or order

$$s_2 \equiv \int_{a_1}^{a_1+a_2} \sqrt{g_{aa}} da \sim L(k) \ . \tag{6.3.6}$$

In case of 'our' radiation dominated cosmology this gives correct estimate for the moment of time when transition to matter dominated phase occurs since one has $L(k) \sim a_F$ in this case.

That the decomposition to disjoint 3-surfaces occurs after the transition to matter dominated phase is suggested by simple arguments. First of all, the decomposition into regions has obviously interpretation as a formation of visible structures around hidden structures formed by pairs of cosmic strings thickened to magnetic flux tubes. Secondly, of decomposition occurs, the photons coming from distant objects 'drop' to the space-time sheets representing later critical cosmologies. This explains why the optical properties of the Universe seem to be those of a critical cosmology.

6.3.4 Matter dominated phases

The transition to the matter dominated phase followed by the decoupling of the radiation and matter makes possible the formation of structures. This is expected to involve compression of matter to dense regions and to lead to at least a temporary decomposition of the matter dominated cosmology to disjoint 3-surfaces condensed on larger space-time surfaces. The reason is that Jeans length becomes smaller than the size of the horizon. A galaxy model based on the assumption that the region around the two curved ends of a split cosmic string serve as a seed for galaxy formation has been considered in [D4]. In particular, it was found that Jeans criterion leads to a lower bound for the string tension of the galactic strings of same order of magnitude as the string tension of the cosmic strings.

If one assumes that matter dominated regions continue cosmological expansion so that the radius of region equals to the horizon size $R = a^{1/2}$, the fraction of the volume occupied by matter dominated regions grows as $\epsilon(a) = (a/a_R)\epsilon(a_R)$. In recent cosmology the regions have joined together for $\epsilon(a_R) > 10^{-3}$ which would suggest that ultimately asymptotic string dominated cosmology results. One could however argue that matter dominated cosmology does not expand. Taking into account the horizon size of about 5×10^5 light years at the time of the transition to matter dominance, this would mean that galaxies do not participate in cosmic expansion but move as particles on background cosmology.

TGD allows an entire sequence of matter dominated cosmologies associated with the radiation dominated cosmologies labeled by p-adic primes allowed by p-adic length scale hypothesis. Forgetting the delicacies related to nucleo-synthesis, the matter densities associated with these matter dominated cosmologies are scaled down like $(a_1(k)/a_F)^3$ where $a_1(k)\sin L(k)$ is the moment at which the corresponding critical cosmology was created. Thus the latest matter dominated cosmology gives the dominating contribution to the matter density.

Sooner or later matter dominated cosmology becomes string dominated. A good guess is that the transition to string dominance occurs if cosmic expansion of the space-time sheet indeed continues. To see what is involved consider the bounds on the total length of string per large void with size of order $a_* \sim 10^8$ light years. This length can be parameterized as $L = nL(void)$. The requirement that the mass density of the strings is below the critical density gives, when applied to the large void with size of $a_* \simeq 10^8$ light years at recent time a, gives

$$\frac{3}{4\pi}\frac{nT}{a_*^2} < \rho_s = \frac{3}{8\pi G a^2} \quad . \tag{6.3.7}$$

Here one has $T \simeq .22 \times 10^{-6}\frac{1}{G}$. This gives roughly

$$n < 2 \times 10^6 \times (\frac{a_*}{a})^2 \quad . \tag{6.3.8}$$

The second constraint is obtained from the requirement that the ratio of the string mass per void to the mass of the ordinary matter per void is not too large at present time. Using the expression

$$\rho_m \simeq \frac{3}{32\pi G}\frac{a_*}{a^3} \quad ,$$

with $a_* \sim 10^8$ years (time of recombination) and the expression for the string mass per void one has

$$\frac{\rho_s(a)}{\rho_m a(a)} = n \times 1.8 \times 10^{-6}(\frac{a}{a_*})^3 \quad . \tag{6.3.9}$$

for the ratio of the densities. For $a = 10^{10+1/2}$ ly the two conditions give

$$\begin{aligned} n &< 20 \ , \\ \frac{\rho_s(a)}{\rho_m} &\simeq n \times 18 \times \sqrt{10} \ . \end{aligned} \tag{6.3.10}$$

These equations suggest that n cannot be much larger than one and suggest the simple picture in which the Kähler charges associated with the "big" string in the interior of the large void and with the galactic strings on the boundaries of the void cancel each other. The minimal value of n is clearly $n = 4$ corresponding to a straight string in the interior of the void. It must be however emphasized that these estimates are rough.

The rate $dlog(E_{gr})/dlog(a)$ for the change of gravitational energy in co-moving volume at present moment in the matter dominated cosmology is determined by

$$\frac{(d\rho_c/da)}{\rho_c} = -\frac{1}{2a} \sim 10^{-11}\frac{1}{year} \quad . \tag{6.3.11}$$

The rate is of the same order of magnitude as the rate of energy production in Sun [21] so that the rates dE_{I+}/da and dE_{I-}/da for the change of positive and negative contributions to the inertial energy would be of same order of magnitude and sum up to dE_{gr}/da.

6.3.5 Stationary cosmology

The original term was asymptotic cosmology but stationary cosmology is a better choice if one accepts the notion of quantal cosmology. In this kind of situation expects that stationary cosmologies correspond to stationary quantum states during which topologically condensed space-time sheets do not participate the cosmic expansion but co-move as point like particles.

During stationary cosmology one has $dE_{gr}/da = 0$. In zero energy ontology the interpretation is that the apparent non-conservation of gravitational (=inertial) energy due to the change of time scale characterizing typical causal diamond (CD) is not present anymore. The following argument suggests that asymptotic cosmology is equivalent with the assumption that the cosmic expansion of the space-time sheets almost halts. The expression for the horizon radius for the cosmology decomposing into critical, radiation and matter dominated and asymptotic phases. The expression for the radius reads as

$$R = \int_0^a \sqrt{g_{aa}}\frac{da}{a} = R_0 + R_{as} \ ,$$

where R_0 corresponds from the cosmology before the transition to the asymptotic cosmology and R_{as} gives the contribution after that. Formally this expression is infinite since the contribution to R_{as} from the critical period is infinite. Since one has $g_{aa} \rightarrow 1$ asymptotically R_{as} is in good approximation equal to $R_{as} = log(a/a_{as})$, where a_{as} denotes the time for the transition to asymptotic cosmology. This means that the growth of the horizon radius becomes logarithmically slow: $dR(a)/da = 1/a$. A possible interpretation is that the sizes of various structures during asymptotic cosmology are almost frozen. One can however consider the possibility that the disjoint structures formed during the period of matter dominated phase expand and fuse together so that the there is basically single structure of infinite size formed by the join along boundaries condensate of various matter carrying regions.

From the known estimates [22] for the total length of galactic string per void one obtains estimate for the needed string tension of the galactic strings. The resulting string tension is indeed of the order of GUT string tension $T \sim 10^{-6}/G$. It will be found later that Jeans criterion gives same lower bound for the string tension of the galactic strings. The resulting contribution to the mass density is smaller than the critical mass density so that no inconsistencies result.

The simplest mechanism generating galactic strings is the splitting of long strings to pieces resulting from the collisions of the strings during very early string dominated cosmology. This mechanism implies that galaxies should form linear structures: this seems indeed to be the case [22].

The recent mass density of the strings is considerably larger than that associated with the visible matter. This implies string dominance sooner or later. There are two possible alternatives for the string dominated cosmology.

1. Cosmology with co-moving strings.
2. Stationary cosmology, which seems a natural candidate for the asymptotic cosmology.

Consider first the co-moving string dominated cosmology. The mass density for the string dominated Robertson-Walker cosmology (necessarily smaller than critical density now) is given by the expression

$$\begin{aligned} \rho &= \frac{3}{8\pi G a^2}(\frac{1}{K} - 1) \ , \\ H^2 &= \frac{1}{Ka^2} \ , \end{aligned} \tag{6.3.12}$$

and is a considerable fraction of the critical mass density unless the parameter K happens to be very close to 1. Sub-criticality gives the condition

$$c_{\#} = \sqrt{K} > \frac{1}{\sqrt{2}} \ .$$

The requirement that the gravitational force dominates over the Kähler force implies that the value of $g_{aa} = K$ differs considerably from unity. The recent value of the quantity Ka^2 can be evaluated from the known value of the Hubble constant. By the previous argument, the ratio of the string mass density to the matter mass density for the recent time $a \sim 10^{10+1/2}$ years is about $\rho_s/\rho_m \sim 50$. This gives the estimates for the light velocity in the condensate and the ratio of the density to the critical density

$$\begin{aligned} c_{\#} &= \sqrt{K} \simeq .93 \ , \\ \Omega \equiv \frac{\rho}{\rho_{cr}} &\simeq .16 \ . \end{aligned} \tag{6.3.13}$$

One also obtains an estimate for the time a_1 , when the transition to string dominated phase has occurred

$$\begin{aligned}
\rho_{m0} &= \rho_m(\frac{a}{a_1})^3 = \rho_s = \rho_{s0}(\frac{a}{a_1})^2 \ , \\
a_1 &= \frac{\rho_m}{\rho_s} a \sim 6\times 10^8 \ \text{ly} \ .
\end{aligned} \tag{6.3.14}$$

The fraction of the total mass density about the critical mass density is about 4 per cent an perhaps two small.

Consider next the stationary cosmology. The relevant component of the metric and mass density are given by the expressions

$$\begin{aligned}
g_{aa} &= \frac{(1-2x)}{(1-x)} \ , \\
\rho &= \frac{3}{8\pi G a^2}\frac{x}{(1-2x)} \ , \\
x &= (\frac{a_1}{a})^{2/3} \ .
\end{aligned} \tag{6.3.15}$$

Asymptotically the mass density for this cosmology behaves as $\rho \simeq 1/a^{2(1+v^2)}$, $v^2 = 1/3$ and "pressure" ($p \simeq -1/9\rho$) is negative indicating that strings indeed dominate the mass density. The results from the numerical simulation of the GUT cosmic strings suggest the interpretation of v^2 as mean square velocity for a long string [23]: the relative velocities of the big strings seem rather large.

The transition to the stationary cosmology must take place at some finite time since the energy density

$$\rho = \frac{3}{8\pi G a^2}\frac{(\frac{a_1}{a})^{2/3}}{(1-2(\frac{a_1}{a})^{2/3})} \ , \tag{6.3.16}$$

is negative, when the condition $a < a_1(1/2)^{-3/2}$ holds true. An estimate for the parameter a_1 is obtained by requiring that the ratio of the mass density to the recent density of the ordinary matter is of order $r \sim 200$ at time $a \sim 10^{10.5}$ ly (this requires $n = 4$, which corresponds to the lower bound for the length of cosmic string per void): $\frac{\rho}{\rho_m}(a) = r$. This gives for the parameter x, the time parameter a_1, the velocity of light in the condensate and for the fraction of the mass density about the critical mass density the following estimates:

$$\begin{aligned}
x &= \frac{\frac{r}{4}\frac{a_*}{a}}{1+\frac{r}{2}\frac{a_*}{a}} \simeq .16 \ , \\
a_1 &\simeq 2\times 10^9 \ \text{ly} \ , \\
c_\# &\simeq .93 \ , \\
\Omega &\simeq .16 \ .
\end{aligned} \tag{6.3.17}$$

Apart from the value of the transition time, the results are essentially the same as for the string dominated cosmology. By increasing the amount of a string per void one could reduce the value of the light velocity in the condensate. The experimental lower bound on Ω is $\Omega > .016$ and the favored value is $\Omega \sim .3$. The latter value would require $n \simeq 6.8$ instead of the lower bound $n = 4$ and give $c_\# \simeq .87$

If the proposed physical interpretation for dE_{gr}/da in terms of the energy production inside the stars is correct, then stationary cosmology should be a good idealization for the cosmology provided that the rate of the energy production of stars is negligibly small as compared with the total energy density. This is expected to case, when the energy density of the string like objects begins to dominate over the ordinary matter.

String dominated and stationary cosmologies have certain common characteristic features:

1. Horizons are absent. This implies that the formation of the structures of arbitrarily large size should be possible at this stage and in certain sense the formation of these structures can be regarded as a manifestation of the structures already formed during the very early string dominated cosmology.

2. The so called acceleration parameter q_0 vanishes asymptotically for the stationary cosmology and identically for string dominated cosmology: The deceleration parameter

$$q = \frac{1}{3}\frac{x}{(1-2x)(1-x)} \ . \tag{6.3.18}$$

   The value of q is positive and conforms with the identification of stationary cosmology as counterpart of stationary state in which topologically condensed space-time sheets co-move but do not expand.

   For the matter dominated cosmology the value of this parameter is $q_0 = 1/2$ and positive ($a \simeq t^{2/3}$). The earlier attempts made to evaluate the value of this parameter from the observations are consistent with the value $q_0 = 0$ as well as with the value $q_0 = 1/2$ [21]. Quite recent determinations of the parameter [25] are consistent with $q_0 \leq 0$ but exclude large negative values of q_0 typical for the inflationary scenarios with a large value of the cosmological constant.

6.4 Inflationary cosmology or quantum critical cosmology?

The measurements [17] allow to deduce information about the curvature properties of the space-time in cosmological scales. These experimental findings force the conclusion that cosmological time= constant sections are essentially flat after the decoupling of the em radiation from matter which occurred roughly one half million years after the Big Bang. The findings allowed to build a much more detailed model for the many-sheeted cosmology leading also to a considerable increase in the understanding of the general principles of TGD inspired cosmology. In the following the observational facts are discussed first and then TGD based explanation relying on the many-sheeted cosmology is briefly discussed. One ends up to a cosmological realization of quantum criticality in terms of a fractal cosmology having Russian doll like structure. The cosmologies within cosmologies are critical cosmologies before transition to hyperbolicity followed by an eventual decay to disjoint non-expanding 3-surfaces.

Critical cosmologies can be regarded as 'Silent Whispers' amplifying to Big Bangs and are generated from vacuum by the gradual condensation of cosmic strings to initially empty and flat space-time sheets. The transition to hyperbolicity involves topological condensation of the remnants of the earlier sub-cosmologies. Hyperbolic period is followed by a decay to disjoint non-expanding 3-surfaces, remnants of the sub-cosmology. There is thus a strong analogy with biological evolution involving growth, metabolism and death. Sub-cosmologies are characterized by three parameters: moment of birth and durations of the critical period and hyperbolic periods. p-Adic length scale hypothesis makes model quantitative by providing estimates for the moments of cosmic time when the phase transitions generating new critical sub-cosmologies occur and fixes the number of the phase transitions already occurred. What is especially remarkable, that the time for the generation of CMB is predicted correctly from p-adic fractality and from the absence of the second acoustic peak in the spectrum of CMB fluctuations.

The recent measurements [17] allow to deduce information about the curvature properties of the space-time in cosmological scales. The conclusion is that cosmological time= constant sections are essentially flat after the decoupling of the em radiation from matter which occurred roughly one half million years after the Big Bang. This forces to consider a more detailed model for the many-sheeted cosmology provided by TGD. In the following the observational facts are discussed first and then TGD based explanation relying on the many-sheeted cosmology is discussed. One ends up to a cosmological realization of quantum criticality in terms of a fractal cosmology having Russian doll like structure. The cosmologies within cosmologies are critical cosmologies before transition to hyperbolicity followed by an eventual decay to disjoint non-expanding 3-surfaces.

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It must be emphasized that in TGD framework critical cosmology reflects quantum criticality and the presence of two kinds of two-dimensional conformal symmetries acting at the level of imbedding space and space-time [B4]. Thus the correlation function for the fluctuations of the mass density at the surface of a sphere of fixed radius is dictated by conformal invariance and by quantal effects the naive scaling dimension predicted by the scaling invariance can be modified to an anomalous dimension. The implications of replacing scaling invariance with conformal invariance for the correlation function of density fluctuations is discussed at the general level in [53].

6.4.1 Comparison with inflationary cosmology

TGD differs from GRT in several respects. Many-sheeted space-time concept forces fractal cosmology containing cosmologies within cosmologies. A p-adic hierarchy of long ranged electro-weak and color physics assignable to dark matter at various space-time sheets is predicted if one interprets the unavoidable long ranged classical gauge fields as space-time correlates of corresponding quantum fields. Confinement (weak) length scales associated with these physics correspond to p-adic length scales characterizing the sizes of the space-time sheets of corresponding hadrons (weak bosons). Topological condensation involves a formation of # contacts identifiable as parton- antiparton pairs defining a particular instance of dark matter. Infinite variety of dark matters, or more precisely partially dark matters with respect to each other, is predicted.

Z^0 force competes with gravitational force and it will be found that the role of this force seems to be crucial in understanding the formation of the observed large void regions (with recent size of order 10^8 light years) containing ordinary matter predominantly on their boundaries. Einstein's equations provide only special solutions of the field equations for the length scale dependent space-time of TGD. For instance, in case of strongly Kähler charged cosmic strings it seems better to regard the strings as sources of the Kähler electric field rather than gravitational field. Vapor phase containing at least cosmic strings is the crucial element of TGD inspired cosmology.

The proposed scenario for cosmology deserves a comparison with the inflationary scenarios [27, 28].

1. In inflationary cosmologies exponentially expanding phase corresponds to a symmetry non-broken phase and de-Sitter cosmology follows from the vacuum energy density for the Higgs field. The vacuum energy of the Higgs field creates "negative pressure" giving rise to the exponential expansion. The string tension of the topologically condensed cosmic strings creates the "negative pressure" in TGD context.

   In TGD framework situation is diametric opposite of this since exponential expansion is replaced by a logarithmic expansion. This can be seen by solving proper time t in terms of M^4_+ proper time a from the equation

$$\frac{dt}{da} = \sqrt{g_{aa}} = \sqrt{1 - \frac{R^2k^2}{4}\frac{1}{1-k^2a^2}} \ . \tag{6.4.1}$$

   One obtains

$$kt = \int^{sinh(ka)} du\sqrt{cosh^2(u) - \frac{R^2k^2}{4}} \simeq sinh(ka) \tag{6.4.2}$$

since $R^2k^2 \ll 1$ holds true. This gives $kt \sim sinh(ka) \sim exp(ka)$ rather than $a \sim exp(Ht)$ as in inflationary scenarios so that expansion takes place with a logarithmic slowness.

2. In the inflationary scenarios the exponential expansion destroys inhomogenities and implies the isotropy of 3 K radiation and the decay of the Higgs field to radiation creates entropy. In TGD string dominance implies the absence of horizons. There are no horizons associated with the vapor phase neither since it obeys light cone cosmology. Also critical, string dominated and asymptotic cosmologies are horizon free.

3. In inflationary scenarios the transition to the radiation dominated phase corresponds to the transition from the symmetric phase to a symmetry broken phase. In TGD something analogous happens. Cosmic strings are free at primordial stage but unstable against decay to elementary particles because their action has wrong sign. Some of these strings achieve stability by topologically condensing and generating large Kähler electric charge to cancel their Kähler magnetic action. Light particles of matter in turn suffer a gradual condensation around Kähler electric strings. The Kähler charge of the string induces automatically a slight matter-antimatter asymmetry in the exterior space-time. Or vice versa: the surrounding vacuum extremal must suffer a slight deformation to non-vacuum extremal and this requires Kähler electric field and simplest field of this kind is radial one forcing cosmic string to generate small Kähler charge. At the limit $a \rightarrow 0$ the contribution of the condensate to the energy of a given co-moving volume vanishes and in this sense condensate can be regarded as a seed of the symmetry broken phase.

4. In inflationary scenarios the critical mass density is reached from above and final state corresponds to a cosmology with a critical mass density. In TGD scenario in its simplest form, the mass density is exactly critical before the transition to the "radiation dominated phase" and overcritical mass density resides in the vapor phase. In a well defined sense vapor phase makes possible sub-critical cosmology. The mysterious vacuum energy density of the inflationary cosmologies could corresponds in TGD framework to the dark matter density at cosmic strings part of which could be in vapor phase.

6.4.2 Balloon measurements of the cosmic microwave background favor flat cosmos

Inflationary scenario has been one of the dominating candidates for cosmology. The basic prediction of the inflationary cosmology is criticality of the mass density which means that cosmic time=constant sections are flat. Observations about the density of known forms of matter are not consistent with this and the only possible manner to get critical mass density is to assume that there exist some hitherto unknown form of vacuum energy density contributing roughly 70 percent to the energy density of the universe. This vacuum energy density is believed to cause the observed acceleration of the cosmic expansion.

The basic geometrical prediction of the inflationary scenario is that cosmic time=constant sections are flat Euclidian 3-spaces. This prediction has been now tested experimentally and it seems that the predictions are consistent with the observations. The test is based on the study of non-uniformities of the cosmic microwave background (CMB). CMB was created about half million years after the moment of Big Bang when opaque plasma of electrons and ions coalesced into transparent gas of neutral hydrogen and helium. Thermal photons decoupled from matter to form cosmic microwave background and have been propagating practically freely after that. The fluctuations of the temperature of the cosmic microwave background reflect the density fluctuations of the universe at the time when this transition occurred. The prediction is that the relative fluctuations of temperature are proportional to the relative fluctuations of mass density and are few parts to 10^5.

Happily, it is possible to estimate the size spectrum for the regions of unusually high and low density theoretically and compare the predictions with the experimentally determined distribution of hot and cold spots in CMB. Since the light from hot and cold spots propagates through the intervening curved space, its intrinsic geometry reflects itself in the properties of the observed spectrum of CMB fluctuations. Hence it becomes possible to experimentally determine whether the 3-space (cosmic time=constant section) is negatively curved (expansion forever), positively curved and closed (big crunch) or flat.

The acoustic properties of the plasma help in the task of determining the spectrum of CBM fluctuations. The competition between gravity and radiation pressure during radiation dominated period produced regions of slow, attenuated oscillatory contraction and expansion. The maximum size of over-dense region that could have shrunk coherently during the half million years before the plasma became transparent was limited by the velocity of sound which is $c/\sqrt{3}$ in radiation dominated plasma. This gives $R = 5/\sqrt{3}\times 10^5$ light years which is about 300 thousand light years for the maximal size of the hot spot. The observed position and size of the first acoustic peak corresponding to the largest hot spots and its observed position depends on the presence or absence of the distorting cosmic curvature. If the intervening 3-space is positively (negatively) curved the parallel rays coming from hot spot diverge and hot spots look larger (smaller) than they actually are: also distances between hot spots look larger (smaller).

To abstract cosmological details from the observations one calculates the power spectrum of the thermal fluctuations by fitting the CMB temperature map to a spherical harmonic series. The absolute square of the fitted amplitude for l:th order spherical-harmonic component is essentially the mean-square point-to-point temperature fluctuation of the CMB on angular scale about π/l radians. The observed fluctuation power spectrum as function of l has maximum at $l = 200$. This is consistent with flat intervening 3-space and inflationary scenario. The next maximum of power spectrum as function of l corresponds to the second acoustic peak (recall that acoustic oscillations are in question) with smaller size of hot spot and should be observed at $l = 500$ according to inflationary scenario. In fact this peak has not been observed. This might be due to the small statistics or due to the fact that the scale free prediction of the inflationary scenario for the spectrum of fluctuations is quite not correct but that fluctuations have cutoff at some length scale larger than the size of the size of the hot spot associated with the second acoustic peak.

In standard cosmology the result means that 3-space has remained flat for most of the time after the moment when CMB was generated. Of course, the cosmology can have changed hyperbolic after that since the small mass density of the recent day universe implies that the effects of the curvature on the optical properties of the universe are small. Inflationary scenario predicts this if one repeats the biggest blunder of Einstein's life by adding to Einstein's equations cosmological constant, which means that vacuum energy density of an unknown origin contributes about 70 per cent to the mass density of the universe. Besides this one must assume that primordial baryon density is about 50 per cent higher than standard expectation. Thus inflationary model survives the test but not gracefully.

6.4.3 Quantum critical fractal cosmology as TGD counterpart of the inflationary cosmology

In TGD framework Einstein's equations are structural equations relating the energy momentum tensor of topologically condensed matter to the geometry of the space-time surface rather than fundamental equations derivable from a variational principle. Furthermore, the solutions of Einstein's equations are only a special case of the equations characterizing the macroscopic limit of the theory. The simplest assumption is however that Einstein's equations hold true for each sheet of the many-sheeted space-time and is made in TGD inspired cosmology.

Does quantum criticality of TGD imply criticality and fractality of TGD based cosmology?

Quantum criticality of the TGD Universe supports the view that many-sheeted cosmology is in some sense critical. Criticality in turn suggests p-adic fractality. Phase transitions, in particular the topological phase transitions giving rise to new space-time sheets, are (quantum) critical phenomena involving no scales. If the curvature of the 3-space does not vanish, it defines scale: hence the flatness of the cosmic time=constant section of the cosmology implied by the criticality is consistent with the scale invariance of the critical phenomena. This motivates the assumption that the new space-time sheets created in topological phase transitions are in good approximation modelable as critical Robertson-Walker cosmologies for some period of time at least.

Neither inflationary cosmologies nor overcritical cosmologies allow global imbeddings. TGD however allows the imbedding of a one-parameter family of critical and overcritical cosmologies. Imbedding is possible for some critical duration of time. The parameter labeling these cosmologies is a scale factor characterizing the duration of the critical period. The infinite size of the horizon for the imbeddable critical cosmologies is in accordance with the presence of arbitrarily long range fluctuations at criticality and guarantees the average isotropy of the cosmology. These cosmologies have the same optical properties as inflationary cosmologies.

The critical cosmologies can be used as a building blocks of a fractal cosmology containing cosmologies containing ... cosmologies. p-Adic length scale hypothesis allows a quantitative formulation of the fractality. Fractal cosmology provides explanation for the balloon experiments and also for the paradoxical result that the observed density of the matter is much lower than the critical density associated with the largest space-time sheet of the fractal cosmology. Also the observation that some astrophysical objects seem to be older than the Universe, finds a nice explanation.

Cosmic strings and vapor phase

En essential element of TGD inspired cosmology is the presence of vapor phase consisting dominantly of cosmic strings. For the values of light cone proper time a smaller than CP_2 time R, space-time does not exist in sense as it is defined in General Relativity. Instead, very early Universe consists of a primordial soup of cosmic strings. General arguments lead to the hypothesis that the density of the cosmic strings in vapor phase in in this period is

$$\rho_V = \frac{3}{8\pi G a^2} . \tag{6.4.3}$$

The expression of the density is formally same as the critical density of flat critical cosmology (note that future light cone is hyperbolic vacuum cosmology). The topological condensation of free cosmic strings forced by the absolute minimization of Kähler action (free cosmic strings have infinite positive Kähler magnetic action) to critical space-time sheets leads to fractal hierarchy of critical cosmologies and reduces the density of vapor phase. Obviously the energy density in vapor phase is very much analogous to the vacuum energy density needed in inflationary cosmologies.

What happens when criticality becomes impossible?

Given critical sub-cosmology is created at the moment $a = a_0$ of the light cone proper time. The imbeddability of the critical cosmology fails for $a = a_1$. The question is what happens for the space-time sheet before this occurs. A natural assumption is that when the value of the cosmic time for which imbeddability fails is approached, cosmology is transformed to hyperbolic cosmology. One can imagine several scenarios but the following one involving two transitions is the most plausible one. The first step is the transition of the critical cosmology to a hyperbolic cosmology which is either matter or radiation dominated or to a stationary cosmology for which gravitational energy density is conserved. The next step is possible decomposition of $a = constant$ 3-surface of hyperbolic cosmology to disjoint non-expanding 3-surfaces topologically condensing on critical cosmology created later. This process in turn could induce the transition of the critical cosmology to hyperbolicity: when critical sub-cosmology eats the remnants of earlier sub-cosmology it could become hyperbolic itself. Of course, this is not the only mechanism. This scenario resembles to high degree the lifecycle of a biological organism involving gradual growth, metabolism and death.

1. Transition to matter or radiation dominated phase

The critical cosmology is transformed to a hyperbolic cosmology with sub-critical mass density. This option is very general and means that criticality is gradually shifted to increasingly longer length scales when it breaks down in short length scales. The continuity condition in the transformation to hyperbolic cosmology with $\theta = \pi/2$ and $\phi = \phi(a)$ for g_{aa} reads as

$$\begin{aligned} \frac{1}{g_{aa}^H} - 1 &= \frac{1}{1-K} \equiv \epsilon , \\ K &\equiv \frac{R^2}{4a_1^2} \frac{1}{(1-(\frac{a}{a_1})^2)} . \end{aligned} \tag{6.4.4}$$

The light cone projection of the sub-cosmology is sub-ligtcone of M^4_+. a denotes light cone proper time for this sub-light cone: its value is obviously smaller than the value of M^4_+ proper time. Upper index 'H' refers to to the metric of the hyperbolic cosmology. The value of the parameter ϵ must deviate considerably from unity and and since R/a_1 is extremely small number, the transformation to hyperbolic cosmology must happen very near to $a = a_1$: for all practical purposes this fixes the moment of transition to be $a = a_1$. Critical cosmology is also flat in excellent approximation up to $a = a_1$. The mass density of the hyperbolic cosmology behaves during the matter (radiation) dominated phase as

$$\rho = \frac{3}{8\pi G}\epsilon\frac{a_1^{1+n}}{a^{3+n}} . \tag{6.4.5}$$

Here $n = 0$ corresponds to matter dominance and $n = 1$ to radiation dominance.

2. Decomposition of $a = constant$ surface to disjoint non-expanding components

p-Adic length scale hypothesis suggests that hyperbolic sub-cosmology ceases to participate in the cosmic expansion sooner or later and that $a = constant$ 3-surface decomposes to disjoint particle like non-expanding objects topologically condensing at and comoving on the sub-cosmologies generated later. A possible mechanism causing the decomposition of a hyperbolic sub-cosmology into disjoint space-time sheets is the intersection of the sub-light cones defined by the sub-cosmologies initiated at same $a = constant$ hyperboloid. The transition to non-expanding phase has certainly occurred for stellar objects.

The disjoint 3-surfaces generated in this process are topologically condensed at (or are 'metabolized' by) younger critical cosmologies and the simplest assumption is that this condensation process changes the newer cosmology to matter dominated hyperbolic cosmology. This assumption is consistent with the fact that the mass density of the critical cosmologies is very small before the transformation to the matter dominated phase so that they cannot contain topologically condensed matter. Before the condensation process the condensation of free cosmic strings gives rise to the gradual increase of the mass density of the critical cosmology.

This picture implies that cosmic expansion occurs only above some length scale and that the long length scale optical properties of the universe are determined by the competion of sub-cosmologies in hyperbolic and critical stages since photons travel along space-time sheets of both type.

p-Adic fractality

p-Adic fractality suggests that all cosmological phase transitions giving rise to the generation of new space-time sheets should be describable using the same universal Robertson-Walker cosmology during their critical period so that cosmology would contain cosmologies containing cosmologies... like Russian doll contains Russian dolls inside it. The light cone projection of each sub-cosmology is sub-light cone. Lorentz invariance requires that the probability distribution for the position the tip of the sub-light cone is constant along $a = constant$ hyperboloid.

Sub-cosmology is characterized by three parameters a_0, a_1 and a_2. a_0 characterizes the moment of birth for sub-cosmology, a_1 characterizes in excellent approximation the value of the sub-light cone proper time for which the transition from critical to hyperbolic sub-cosmology occurs. $a_1 + a_2$ in turn characterizes the sub-light cone proper time for the decay of the hyperbolic sub-cosmology to comoving non-expanding surfaces. p-Adic length scale hypothesis allows to make educated guesses for the values of a_0, a_1 and a_2 so that TGD inspired cosmology becomes highly predictive.

Since a_0 characterizes the moment of birth for sub-cosmology, it is not expected to reflect in any manner the dynamics of earlier sub-cosmologies. In contrast to this, a_1 and a_2 characterize the internal dynamics of sub-cosmology involving gravitational time dilation effects in an essential manner and this suggests that the fundamental parameters are the values of the proper times s_1 and s_2 for sub-cosmologies to which a_1 and a_2 are related in simple manner.

More quantitatively, the proper time s of the space-time surface representing cosmology is defined as

$$s = \int_0^a \sqrt{g_{aa}}da .$$

The relationship between light cone proper time and proper time of the critical cosmology implies the relationship

$$
\begin{aligned}
s_1 &= \int_0^{a_1} \sqrt{1-K}da \ , \\
K &\equiv \frac{R^2}{4a_1^2}\frac{1}{(1-(\frac{a}{a_1})^2)} \ .
\end{aligned} \qquad (6.4.6)
$$

between a_1 and s_1. Up to to $a \simeq a_1$ the value of the parameter K is nearly vanishing so that $s \simeq a$ holds in a good approximation during the critical period. This means that the values of s_1 and a_1 are in excellent approximation identical:

$$s_1 \simeq a_1 \ .$$

The relationship between s_2 and a_1 and a_2 is

$$s_2 = \int_{a_1}^{a_1+a_2} \sqrt{g_{aa}}da \ . \qquad (6.4.7)$$

The gravitational dilation effects for hyperbolic cosmology are large and s_2 and a_2 can differ by orders of magnitude.

p-Adic length scale hypothesis states two things.

1. Each p-adic prime p corresponds to p-adic length scale $L_p = \sqrt{p} \times l$, where $l \simeq 10^{3.5}$ Planck lengths is CP_2 'radius'.
2. The primes $p \simeq 2^k$, k prime or power of prime are physically preferred so that one has

$$L_p \equiv L(k) \simeq 2^{k/2} \times l \ .$$

p-Adic fractality allows to make educated guesses for the most plausible values of the parameters a_0, a_1 and a_2 characterizing the evolution of the sub-cosmologies.

1. Moments of birth of sub-cosmologies

It seems that the generation of new sub-cosmologies is a process having nothing to do with the internal dynamics of sub-cosmologies themselves. Therefore p-adic fractality suggests that the dips of the sub-light cones associated with the critical cosmologies are concentrated in good approximation at the hyperboloids

$$a_0(k) = x_0 L(k)$$

of the light cone M^4_+ where x_0 is some numerical constant: note that a_0 refers to the proper time of the light cone M^4_+ rather than sub-light cone. The number of primes k in the interval $[2, ..., 401]$ (see Table 2) is rather small which implies that the number of sub-cosmologies created after Big Bang is smaller than 100.

2. Moments for the transition to hyperbolicity

The natural guess is that the imbedding for the cosmology characterized by $p \simeq 2^k$ fails for $a \simeq a_1$ (in excellent approximation) when sub-cosmology also starts to metabolize the remnants of earlier sub-cosmologies. p-Adic length scale hypothesis gives the estimate

$$s_1(k) \simeq a_1(k) = x_1 L(k) \ ,$$

where x_1 is numerical constant of order unity. The most natural interpretation is that transition to radiation or matter dominated cosmology occurs. It is natural to assume that topological condensation of 3-surfaces resulting from earlier cosmology accompanies this transition. One can also say that cosmological metabolism causes transition to hyperbolicity.

3. Moments of death for sub-cosmologies

The death of the sub-cosmology means decay to disjoint 3-surfaces. The simplest assumption is that this occurs when the age of sub-cosmology measured with respect to sub-cosmological proper time s exceeds p-adic time scale defined by the next p-adic prime in the hierarchy. Thus one has

$$s_1 + s_2 \simeq a_1 + s_2 = x_2 L(k(next))$$

giving

$$s_2 = x_2 L(k(next)) - x_1 L(k) \ . \tag{6.4.8}$$

From this one can relate the parameter a_2 with the p-adic length scales $L(k(next)$ and $L(k)$. $L(k)$ gives the size scale of the 3-surfaces resulting when the connected space-time sheet $a_2 = constant$ decomposes to pieces. Due to gravitational time dilation s_2 can be smaller than a_2 by several orders of magnitude so that the duration of the hyperbolic period when measured using sub-light cone proper time is lengthened by gravitational time dilation and topological condensation of the remnants of sub-cosmology can take place to a critical cosmology having $k > k(next)$.

4. Temperature and energy density of the critical cosmology at the moment of transition to hyperbolicity.

p-Adic length scale hypothesis suggest that the temperature just after the transition to the effectively radiation dominated phase is

$$\begin{aligned} T(k) &= \frac{n}{L(k)} \ , \quad &&\text{for } k > k_{cr} \ , \\ T(k) &= T_H \sim \frac{1}{R} \ , \quad &&\text{for } k \leq k_{cr} \ . \end{aligned} \tag{6.4.9}$$

Here n is rather large numerical factor. Since $a_F \sim 2.7 \times 10^{-10}$ seconds which corresponds to length scale $L \simeq .08$ meters roughly to p-adic length scale $L(197) \simeq .08$ meters (which by the way corresponds to the largest p-adic length scale associated with brain, cosmic joke?), should correspond to the establishment of Hagedorn temperature, one has the conditions

$$\begin{aligned} k_{cr} &= 197 \ , \\ n &\simeq 2^{197/2} \sim 10^{30} \sim \frac{m_{CP_2}^2}{m_p^2} \ . \end{aligned}$$

Thus n is in of same order of magnitude as the ratio of the CP_2 mass squared ($m_{CP_2} \simeq 10^{-3.5}$ Planck masses) to proton mass squared.

Dimensional considerations suggest also that the energy density in the beginning of the radiation dominated phase (in case that it is achieved) is

$$\rho = nT(k)^4 \ , \tag{6.4.10}$$

where n a numerical factor of order one. n does not count for the number of light particle species since the thermal energy of strings gives rise to the effective radiation dominance. This explains why infinite number of fermion families does not lead to infinite density of thermal energy and why their presence leaves no trace in present day cosmology.

When the time parameter a_1 of the critical cosmology becomes too high, it cannot anymore generate radiation dominated phase since the temperature remains too low. Previous considerations suggest that the maximum value of a_1 is roughly $a_1(max) = a_F \sim 3 \times 10^{-10}$. After this critical sub-cosmologies transform directly to the stationary cosmologies.

These estimates fix the structure of the fractal cosmology to rather high degree. Note that the expanding space-time surfaces associated with the new critical cosmologies created in the phase transition can fuse since corresponding light cones can intersect. The number of the phase transitions occurred after the light cone proper time corresponding to electron Compton length is roughly forty.

The tables below give the p-adic length scales in the range extending from electron Compton radius to 10^{10} light years.

k	127	131	137	139	149
$L_p/10^{-10}m$	.025	.1	.8	1.6	50
k	151	157	163	167	169
$L_p/10^{-8}m$	1	8	64	256	512
k	173	179	181	191	193
$L_p/10^{-4}m$	.2	1.6	3.2	100	200
k	197	199	211	223	227
L_p/m	.08	.16	10	640	2560

Table 1. p-Adic length scales $L_p = 2^{k-151}L_{151}$, $p \simeq 2^k$, k prime, possibly relevant to astro- and biophysics. The last 3 scales are included in order to show that twin pairs are very frequent in the biologically interesting range of length scales. The length scale $L(151)$ is take to be thickness of cell scale, which is 10^{-8} meters in good approximation.

k	227	229	233	239	241
L_p/m	$2.3E+3$	$4.6E+3$	$1.9E+4$	$1.5E+5$	$3.0E+5$
k	251	257	263	269	271
L_p/m	$.96E+7$	$7.7E+7$	$6.0E+8$	$4.8E+9$	$.9E+10$
k	277	289	293	307	311
L_p/m	$7.7E+10$	$5.0E+12$	$2.0E+13$	$2.5E+15$	$1.0E+16$
k	313	317	329	331	337
L_p/ly	2.2	$5.4E+2$	$1.0E+3$	2.2E+3	$8.4E+3$
k	347	349	353	359	367
L_p/ly	$2.8E+5$	$5.6E+5$	$2.2E+6$	$1.8E+7$	$2.9E+8$
k	373	379	381	391	397
L_p/ly	$2.2E+9$	$1.9E+10$	3.8 E+10	1.2E+12	.96E+13

Table 2. p-Adic length scales $L_p = 2^{(k-127)/2}L_{127}$, $p \simeq 2^k$, k prime, possibly relevant to large scale astrophysics. The definition of the length scale involves an unknown factor r of order one and the requirement $L(151) \simeq 10^{-8}$ meters, the thickness of the cell membrane, implies that this factor is $r \simeq 1.1$.

6.4.4 The problem of cosmological missing mass

In inflationary cosmology the basic problem is related to the missing mass. The experimentally determined recent density of the ordinary matter is about 4 per cent of the critical mass density and it seems that ordinary sources (other than vacuum energy density) can contribute about 30 percent of the critical mass density in inflationary scenarios. In TGD framework the situation is different as following arguments show.

1. *Criticality does not force missing mass in TGD framework.*

There is no absolute need for vacuum energy density since the mass densities of critical cosmologies present in condensate are extremely low before the transition to the hyperbolicity. In TGD framework the observed mass density corresponds to the mass density at 'our' cosmological space-time sheet condensed to some larger space-time sheet... condensed on the largest space-time sheet present in the topological condensate now. If the vapor phase density equals to the critical density of flat critical cosmology, the net energy density of the entire topological condensate is bound to be smaller than the critical density. This is in accordance with experimental facts. In fact, vapor phase energy density corresponds closely to the vacuum energy density of inflationary scenarios. By the conservation of energy the total energy density at various space-time sheets is indeed equal to 'critical' vapor phase density apart from effects caused by different expansion rates. The possibility of negative energy virtual gravitons however makes possible for a given space-time sheet to have energy density much larger than the energy density of the vapor phase.

2. The observed optical properties of the Universe require that photons travel in critical cosmologies for a sufficiently long fraction of time.

The photons coming from a distant source must propagate along a space-time sheet of a critical cosmology for a sufficiently long fraction of time during their travel to detector. If the period of the matter dominance is too long, photons spend too long time fraction in matter dominated phase and the spectrum of anisotropies is seriously affected. This is avoided if the period between the initiation of the matter dominance and decomposition into disjoint 3-surfaces is sufficiently short. Generation of lumps of matter could in fact involve gravitational collapse leading to the decomposition of the 3-surface to pieces. Second possibility is that the topological condensation of photons is more probable on critical and essentially flat cosmologies (present always) than on matter dominated cosmologies. The large rate of topological evaporation from radiation and matter dominated cosmologies is consistent with this. An alternative explanation in terms of zero energy ontology is that topological evaporation is only effective.

3. The mass density of later matter dominated cosmologies should be larger than that of previous matter dominated cosmologies.

Assume that previous cosmology have made transition to non-expanding phase and behaves as co-moving matter with density $\rho(p_1)$ on the next expanding matter dominated cosmology with density $\rho(p_2)$. Under this assumption the condition

$$\rho(p_1) \equiv p\rho(1) < \rho(p_2)$$

implies

$$a_1(p_1)\epsilon(p_1)\frac{1}{a^3(p_1)} = p \times a_1(p_2)\epsilon(p_2)\frac{1}{a^3(p_2)} \quad .$$

The larger the space-time sheet, the later it is created, and therefore one has $a(p_1) > a(p_2)$ as well as $a_1(p_1) < a_1(p_2)$. For large values of $a(p_1)$ and $a(p_2)$ one has $a(p_1) \sim a(p_2)$ in good approximation and one has

$$a_1(p_1)\epsilon(p_1) = p \times a_1(p_2)\epsilon(p_2) \quad . \tag{6.4.11}$$

The parameters ϵ are of order unity in recent day cosmology.

If one assumes the relationship $s_1 \simeq a_1 = xL(k)$, one obtains

$$\frac{\epsilon(k_1)}{\epsilon(k_2)} = p \times 2^{(k_2-k_1)/2} \quad . \tag{6.4.12}$$

It is possible to satisfy this constraint for $p < 1$.

The assumption about cosmologies inside cosmologies implies distribution of ages of the Universe and provides a natural explanation for why the observed mass density is subcritical. Cosmic strings topologically condensed at the larger space-time sheet could correspond to the missing mass. The age of the space-time sheet of an astrophysical object can be much longer than the age of the largest space-time sheet: this could explain the paradoxical observation that some stars seem to be older than the Universe.

6.4.5 TGD based explanation of the results of the balloon experiments

TGD based model explaining the results of balloon experiments relies on the notion of the fractal cosmology.

Under what conditions Universe is effectively critical?

TGD based model explaining the results of balloon experiments relies on the notion of the fractal cosmology. If $a = constant$ sections of hyperbolic cosmologies decompose to disjoint 3-surfaces after sufficiently short matter dominated period, the photons propagating along these space-time sheets must 'drop' on the critical space-time sheets so that situation stays effectively critical and model yields same predictions as inflationary cosmology. The decoupling of radiation from matter involved a topological phase transition leading to a generation of new expanding space-time sheets along which the CMB radiation could propagate.

The following argument shows under what conditions the total duration of the matter dominated periods is negligible as compared with the total duration of the critical periods. The ratio of the observed angular separation $\Delta\phi_{obs}$ between hot spots to real angular separation $\Delta\phi_r$ between them can be deduced from

$$\begin{aligned} \Delta\phi_{obs} \simeq tan(\Delta\phi_{obs}) &= \frac{\sqrt{g_{\phi\phi}}\Delta\phi_r}{R(r)} \ , \\ R(r) &= \int \sqrt{g_{aa}}da = \int \sqrt{g_{rr}}\frac{dr}{da}da \end{aligned} \tag{6.4.13}$$

$R(r)$ is the Euclidian distance calculated along the light like geodesic associated with photon and depends on the curvature properties of the intervening space. Flat cosmology serves as a natural reference and the ratio

$$\begin{aligned} \frac{\Delta\phi_{obs}}{\Delta\phi_{obs}(flat)} &= \frac{R(r,flat)}{R(r)} \\ &= \frac{a-a_1}{\int_{a_1}^{a}\sqrt{g_{aa}}da} \end{aligned} \tag{6.4.14}$$

measures the effect of the intervening space to the observed angular distance between hot spots of CMB. Note that the integral must be expressed in terms of the initial values of the coordinate r.

When photons travel along critical cosmology, $g_{aa} \simeq 1$ holds true and this corresponds to flat situation. For a fixed value of r one has the following approximate expressions in various cosmologies

$$\begin{aligned} & a-a_1 = r-r_1 \ , && \text{(critical cosmology with } g_{aa}=1) \ , \\ & a-a_1 \sim log(\frac{r}{r_1}) \ , && \text{(hyperbolic cosmology with } g_{aa}=1) \ , \\ & \frac{2}{3}ka((\frac{a}{a_R})^{1/2}-(\frac{a_1}{a_R})^{1/2}) && \\ & = log(\frac{r}{r_1}) \ , && \text{(matter dominance with } g_{aa}=k(\frac{a}{a_R})^{1/2}) \ . \end{aligned} \tag{6.4.15}$$

From these expressions one finds that same increment of r gives rise to much smaller increment of a in hyperbolic cosmology than in critical cosmology. Thus the fractions of r spent in critical cosmology gives the dominating contribution to the integral unless this fraction happens to be especially small. From these expressions one finds that for a given distance r the red shift in approximately flat (no horizon) hyperbolic cosmology is exponentially larger than in critical cosmology. The arrival of photons along hyperbolic cosmology could thus explain why their ages when derived from the red shift seem to be larger than the age of the Universe derived assuming that photons travel along critical cosmology.

During periods of matter dominance g_{aa} behaves as $g_{aa} = k\frac{a}{a_2}$ and gives smaller contribution than critical period. Integral can be expressed as sum of critical and matter dominated contributions as

$$\int_{a_2}^{a}\sqrt{g_{aa}}da = \sum_i [\Delta a_0(i) + s_2(i)] \ . \tag{6.4.16}$$

Here the durations of periods are of order $L(k_i)$ and last period gives the dominant contribution. If the last propagation has occurred along critical cosmology for a sufficiently long time, the contribution of the earlier matter dominated periods to the integral are small and the last critical period can dominate in the integral. If the last critical period corresponds to $k = 379$ preceded by $k = 373$, then the ratio for angle separations does not differ more than about 10 per cent from the value guaranteeing ideal criticality.

What the absence of the second acoustic peak implies?

The absence of the second acoustic peak (which might be also a statistical artefact) fixes the TGD based model to a very high degree.

1. By quantum criticality scale free spectrum for the size L of the density fluctuations is a natural assumption when L is above the p-adic length scale $L(k(prev))$ characterizing the size of the remnants of the previous cosmology condensing to the critical space-time sheets in the transition to hyperbolic cosmology. Below this size ($L < L(k(prev))$) the spectrum for fluctuations has however natural cutoff. This cutoff could also correspond to the length of the cosmic strings giving rise to large voids containing cosmic strings inside them in TGD based model of galaxy formation and to the recent size of large voids containing galaxies at their boundaries. The space-time sheets of large voids should have been born in the phase transition generating CMB if this picture is correct.

2. The first acoustic maximum corresponds to $l = 200$ and $L(k_R)$. The second acoustic maximum corresponds to $l = 500$ and has thus size which is 2/5 of the size of the first hot spot. $L(k_R(prev)$ defines the lower bound for the size of the density and temperature fluctuations as the minimum size of topologically condensed space-time sheets. Therefore, if second acoustic maximum is present, the size of the corresponding hot spot must be larger than $L(k_R(prev))$. Thus the condition for the absence of the second acoustic maximum is

$$\frac{L(k_R(prev))}{L(k_R)} < \frac{2}{5} .$$

Thus the experimental absence of the second maximum requires that k_R and $k_R(prev)$ form twin pair ($k_R(prev) = k_R - 2$) so that one has $L(k_R(prev)) = L(k_R)/2$.

There are two candidates for the twin pairs in question: the twin pairs are $(347, 349)$ and $(359, 381)$ (see table 2 for the values of corresponding p-adic length scales). Only the first pair is consistent with the previous considerations related to p-adic fractality.

1. The pair ($k_R(prev) = 347, k_R = 349$) corresponds to the p-adic length scales $L(347) = 2.8E+5$ ly and $L(349) = 5.6E + 5$ ly. $L(347)$ clearly corresponds to the minimum size of the first acoustic peak. Rather remarkably, the length scale $L(347)$, which corresponds also to the size of the typical spatial structures frozen in the transition to matter dominated cosmology, corresponds rather closely to the estimated time $s_R \sim 5E + 5$ years for the transition to matter dominance and also to the typical size of galaxies. In consistency with the general picture, the estimate

$$s_R = s_1 + s_2 = x_2 L(349)$$

gives $s_R = 5.8E + 5$ years for $x_2 = 1$.

2. If one takes seriously the order of magnitude estimate $s = s_R = 5 \times 10^5$ light years for the age of the cosmology when CMB was created, and assumes that hyperbolic cosmology was radiation dominated before s_R, one can estimate the value of light cone proper time a at this time using the formula

$$\begin{aligned} s_R &= \int_{a_1}^{a_R} \sqrt{g_{aa}} da , \\ g_{aa} &\simeq 10^{-3} \frac{a^2}{a_R^2} . \end{aligned} \quad (6.4.17)$$

This gives $a_R \sim 3.3 \times 10^7$ light years: this corresponds to the p-adic length scale $L(359)$. Thus gravitational time dilatation implies that topological condensation does not occur to $L(353)$ next to $L(349)$ but to $L(259)$. 5 new cosmologies corresponding to $k = 353, 359, 367, 373$ and 379 should have emerged after the transition to matter dominated cosmology and could correspond to cosmological structures. Large voids are certainly this kind of structures and correspond to the p-adic length scale $L(367) \sim 2.9E + 8$ ly. The predicted age of the Universe is about $L(381) \sim 1.9E + 10$ years in this scenario.

Fluctuations of the microwave background as a support the notion of many-sheeted space-time

The fluctuations of the microwave background temperature are due to the un-isotropies of the mass density: enhanced mass density induces larger red shift visible as a local lowering of the temperature. Hence the fluctuations of the microwave temperatures spectrum provide statistical information about the deviations of the geometry of the 3-space from global homogenuity. The symmetries of the fluctuation spectrum can also provide information about the global topology of 3-space and for over-critical topologies the presence of symmetries is easily testable [51].

The first year Wilkinson microwave anisotropy probe observations [49] allow to deduce the angular correlation function. For angular separations smaller the 60 degrees the correlation function agrees well with that predicted by the inflationary scenarios and deriving essentially from the assumption of a flat 3-space (due to quantum criticality in TGD framework). For larger angular separations the correlations however vanish, which means the existence of a preferred length scale. The correlation function can be expressed as a sum of spherical harmonics. The $J = 1$ harmonic is not detectable due to the strong local perturbation masking it completely. The strength of $J = 2$ partial wave is only $1/7$ of the predicted one whereas $J = 3$ strength is about 72 per cent of the predicted. The coefficients of higher harmonics agree well with the predictions based on infinite flat 3-space.

Later some interpretational difficulties have emerged: there is evidence that the shape of spectrum might reflect local conditions. There are differences between northern and southern galactic hemispheres and largest fluctuations are in the plane of the solar system. In TGD framework these anomalies could be interpreted as evidence for the presence of galactic and solar system space-time sheets.

1. Dodecahedral cosmology?

The WMAP result means a discrepancy with the inflationary scenario and explanations based on finite closed cosmologies necessarily having $\Omega > 1$ but very near to $\Omega = 1$ have been proposed. In [50] Poincare dodecahedral space, which is globally homogenous space obtained by identifying the points of S^3 related by the action of dodecahedral group, or more concretely, by taking a dodecahedron in S^3 (12 faces, 20 vertices, and 30 edges) and identifying opposite faces after 36 degree rotation, was discussed. It was found to fit quadrupole and octupole strengths for $1.012 < \Omega < 1.014$ without an introduction of any other parameters than Ω.

However, according to [45] the quadrupole and octupole moments have a common preferred spatial axis along which the spectral power is suppressed so that dodecahedron model seems to be excluded. The analysis of [44] led to the same result. According to the article of Luminet [46], the situation is however not yet completely settled, and there is even some experimental evidence for the predicted icosahedral symmetry of the thermal fluctuations.

The possibility to imbed also a very restricted family of over-critical cosmologies raises the question whether it might be possible to develop a TGD based version of the dodecahedral cosmology. The dodecahedral property could have two interpretations in TGD framework.

1. Space-time sheet with boundaries could correspond to a fundamental dodecahedron of S^3. If temperature fluctuations are assumed to be invariant under the so called icosahedral group, which is subgroup of $SO(3)$ leaving the vertices of dodecahedron invariant as a point set, the predictions of the dodecahedral model result.

2. An alternative interpretation is that the temperature fluctuations for S^3 decomposing to 120 copies of fundamental dodecahedron are invariant under the icosahedral group.

For neither option topological lensing phenomenon is present since icosahedral symmetry is not due to the identification of points of 3-space in widely different directions but due to symmetry which is not be strict. An objection against both options is that there is no obvious justification for the G invariance of the thermal fluctuations. The only justification that one can imagine is in terms of quantum coherent dark matter.

The finding of WMAP that the ratio Ω of the mass density of the Universe to critical mass density is $\Omega = 1 + g_{aa} = 1 + \epsilon$, $\epsilon = 0.02 \pm 02$. This is consistent with critical cosmology. If only slightly overcritical cosmology is realized, there must be a very good reason for this.

The WMAP constraint implies that the value of a which corresponds to the value of cosmic time a_s which characterizes the thermal fluctuations must be such that $g_{aa} = \epsilon$ holds true. The inspection of the explicit form of g_{aa} deduced in the subsection "Critical and over-critical cosmologies" requires that a_s is extremely near to the value a_0 of cosmic time for which $g_{aa} = 0$ holds true: the deviation of a from a_0 should be of order $(R/_0)R$ and most of the thermal radiation should have been generated at this moment.

Since gravitational mass density approaches infinity at $a \rightarrow a_0$ one can imagine that the spectrum of thermal fluctuations reflects the situation at the transition to sub-criticality occurring for $\Omega = 1+\epsilon$. Thermal fluctuations would be identifiable as long ranged quantum critical fluctuations accompanying this transition and realized as a hierarchy of space-time sheets inducing the formation of structures. The scaling invariance of the fluctuation spectrum generalizes in TGD framework to conformal invariance. This means that the correlation function for fluctuations can have anomalous scaling dimension [53]. The hadron physics analogy would be the transition from hadronic phase to quark gluon plasma via a critical phase discussed in section "Simulating Big Bang in laboratory".

The transition $k = 1 \rightarrow 0 \rightarrow -1$ would involve the change in the shape of the $S^2 \subset CP_2$ angle coordinate Φ as a function $f(r)$ of radial coordinate of RW cosmology. The shape is fixed by the value of $k = 1, 0, -1$. In particular, Φ would become constant in the transition to subcriticality. $k = 1 \rightarrow 0$ phase transition would be accompanied by the increase of the maximal size of space-time sheets to infinite in accordance with the emergence of infinite quantum coherence length at criticality. Whether this could be regarded as the TGD counterpart for the exponential expansion during inflationary period is an interesting question. In the transition to subcriticality also the shape of Θ as function of a necessarily changes since $sin(\Theta(a > a_0)) > 1$ would be required otherwise.

2. Hyperbolic cosmology with finite volume?

Also hyperbolic cosmologies allow infinite number of non-simply connected variants with 3-space having finite volume. For these cosmologies the points of $a = constant$ hyperboloid are identified under some discrete subgroup G of $SO(3,1)$. Also now fundamental domain determines the resulting space and it has a finite volume.

It has been found that a hyperbolic cosmology with finite-sized 3-space based on so called Picard hyperbolic space [47, 48], which in the representation of hyperbolic space H^3 as upper half space $z > 0$ with line element $ds^2 = (dx^2+dy^2+dz^2)/z^2$ can be modeled as the space obtained by the identifications $(x, y, z) = (x + ma, y + nb, z)$. This space can be regarded as an infinitely long trumpet in z-direction having however a finite volume. The cross section is obviously 2-torus. This metric corresponds to a foliation of H^3 represented as hyperboloid of M^4 by surfaces $m^3 = f(\rho)$, $\rho^2 = (m^1)^2 + (m^2)^2$ with f determined from the requirement that the induced metric is flat so that x, y correspond to Minkowski coordinates (m^1, m^2) and z a parameter labeling the flat 2-planes corresponds to m^3 varying from ∞ to ∞.

This model allows to explain the small intensities of the lowest partial waves as being due to constraints posed by G invariance but requires $\Omega = .95$. This is not quite consistent with $\Omega = 1.02 \pm .02$.

Also now two interpretations are possible in TGD framework. Thermal photons could originate from a space-time sheet identifiable as the fundamental domain invariant under G. Alternatively, $a = constant$ hyperboloid could have a lattice-like structure having fundamental domain as a lattice cell with thermal fluctuations invariant under G. The shape of the fundamental domain interpreted as a surface of M^4 is rather weird and one could argue that already this excludes this model.

Quantum criticality and the presence of quantum coherent dark matter in arbitrarily long length scales could explain the invariance of fluctuations. If Ω reflects the situation after the transition to subcriticality, one has $\Omega = g_{aa} - 1 = .95$. This gives $g_{aa} = 1.95$ which is in conflict with $g_{aa} < 1$ holding true for the imbeddings of all hyperbolic cosmologies. Thus Ω must correspond to the critical period and one should explain the deviation from $\Omega = 1$. A detailed model for the temperature fluctuations possibly fixed by conformal invariance alone would be needed in order to conclude whether many-sheeted space-time might allow this option.

3. Is the loss of correlations due to the finite size of the space-time sheet?

One can imagine a much more concrete explanation for the vanishing of the correlations at angles larger than 60 degrees in terms of the many-sheeted space-time. Large angular separations mean large spatial distances. Too large spatial distance, together with the fact that the size of the space-time sheet containing the two astrophysical objects was smaller than now, means that they cannot belong to the same space-time sheet if the red shift is large enough, and cannot thus correlate. The size of the space-time sheet defines the preferred scale. The preferred direction would be most naturally defined by cosmic string(s) in the length scale of the space-time sheet. For instance, closed cosmic string would define an expanding 3-space with torus topology and thus having symmetries. This option would explain also the WMAP anomalies suggesting local effects as effects due to galactic and solar space-time sheets.

Empirical support for the hyperbolic period

TGD inspired cosmology predicts that critical cosmology is followed by a hyperbolic cosmology. A natural question is whether the travel of microwave photons through the negative curvature cosmology might induce some signatures in microwave background. This is indeed the case.

The geodesics in negative curvature 3-space diverge exponentially. The divergence of the nearly parallel light-like geodesic lines is due to the negative curvature making 2-dimensional sections of 3-space analogous to saddle surfaces. The scatterings during the travel of light induce geodesic mixing so that light from regions with differing temperature mix. Hence negative curvature tends to smooth out the anisotropies of the temperature distribution.

Negative curvature has also a more dramatic signature. Gurzadyan [30, 31] has developed a very refined argument involving algorithmic information theory and complexity theory to show that in the hyperbolic cosmology the hot and cold spots of the temperature distribution of the cosmic microwave radiation look elongated. The direction of elongation is random but the shape of the ellipse is characterized by the curvature of 3-space and does not depend on temperature or size of the spot. For a flat or positively curved space this kind of elongation does not occur.

The emergence of a preferred direction in a Lorentz invariant cosmology looks highly counter-intuitive. My humble understanding is that a scattering of photons from a large geometric structure must be involved somehow. The elongation should relate to what happens at the last scattering surface whose position together with the positions of observer and previous scattering surface define a plane whose normal defines the preferred direction, which would presumably correspond to the shorter axis of the ellipse. In TGD framework the transfer of photons from a larger space-time sheet to that of observer might correspond to this scattering process. Scattering surface would correspond to the boundary of the space-time sheet of the observer whereas scattering would correspond to refraction at the boundary.

The analysis of BOOMERanG, COBE and WMAP CMB maps indeed shows that the spots have elliptic shape with ellipticity parameter ~ 2 whereas the prediction for hyperbolic RW cosmology is 1.4. [32]. This would suggest that some additional effect is involved and TGD inspired bet have been already described.

6.5 Some problems of cosmology

In this chapter some problems, most of them common to both standard and TGD inspired cosmology, are discussed.

6.5.1 Why some stars seem to be older than the Universe?

There exists experimental evidence that some stars are older than the Universe [29, 38, 34]. A related problem is the problem of the two Hubble constants. These paradoxical results can be understood in TGD inspired cosmology. In TGD light can propagate via several routes. In the topological condensate light ray can propagate along one of the many curved space-time sheet as a small condensed particle and in the vapor phase as a small 3-surface in imbedding space $H = M^4_+ \times CP_2$, where M^4_+ is future light cone of M^4. The time needed to travel from point A to point B is shorter in the vapor phase than in any space-time surface since the geodesic length along the space-time surface in the induced metric is obviously longer than in free Minkowski space. This time depends also on the space-time sheet so that entire spectrum of effective light velocities and Hubble constants results. The failure to distinguish between vapor phase photons and photons propagating along various space-time sheets leads to the paradox as following arguments shows and possibly also to the problem of two (or in fact more than two) different Hubble constants. The possibility of the vapor phase photons or photons propagating along almost flat space-time sheets emitted by the objects outside the space-time horizon of 'our' space-time sheet explains also objects with anomalously large red shifts.

Basic facts

To understand these results one must study TGD based cosmology in more quantitative level.

1. The most general cosmological imbedding of M_+^4 to $M_+^4 \times CP_2$, is of form

$$\begin{aligned} s^k &= s^k(a) \ , \\ g_{aa} &= 1 - s_{kl}\frac{ds^k}{da}\frac{ds^l}{da} \ , \\ ds^2 &= g_{aa}da^2 - a^2(\frac{dr^2}{1+r^2} + r^2 d\Omega^2) \ . \end{aligned} \tag{6.5.1}$$

   Here s_{kl} is CP_2 metric tensor and describes always expanding cosmology with subcritical or at most critical mass density.

2. The age of the Universe defined as M_+^4 proper time a of the co-moving observer (the co-moving observer on the space-time surfaces is also co-moving in M_+^4) is larger than the age defined as the proper time $s(a)$ of the co-moving observer on space-time surface. For the matter dominated Universe one has $g_{aa} = Ka$, which gives

$$\frac{age(cond)}{age(vapor)} = \frac{s(a)}{a} = \frac{2}{3}\sqrt{g_{aa}} \ , \tag{6.5.2}$$

   for the ratio of the ages.

3. The recent value of g_{aa} can estimated from the expression for the mass density in the expanding cosmology

$$\begin{aligned} \rho &= \frac{3}{8\pi G}(\frac{1}{g_{aa}} + k) \ , \\ k &= -1 \ . \end{aligned} \tag{6.5.3}$$

   $k = 0$ mass density corresponds to the critical mass density ρ_c. The mass density is believed to be a fraction of order $\epsilon = 0.1 - 0.5$ of the critical mass density and this gives estimate for $\sqrt{g_{aa}}$:

$$\begin{aligned} \sqrt{g_{aa}} &= \sqrt{1-\epsilon} \ , \\ \epsilon &= \frac{\rho}{\rho_c} \ . \end{aligned} \tag{6.5.4}$$

   $\sqrt{g_{aa}} = 2/3$ suggested by the proposed solution to the Hubble constant discrepancy gives $\epsilon = \frac{9}{4}$. $\epsilon = .1$ gives $\sqrt{g_{aa}} \simeq .95$.

4. The ratio of the condensate travel time to the vapor phase travel time for short distances is given by

$$\frac{\tau(cond)}{\tau(vapor)} = \frac{1}{\sqrt{g_{aa}}} . \tag{6.5.5}$$

This effect is in principle observable. The effect provides also a means of measuring the mass density of the Universe.

5. The light travelling in the vapor phase can reach the observer from a region, which is the intersection of the past light cone of the observer with the boundary of M^4_+ and therefore finite region of M^4. The M^4 radius of this region in the rest frame of the observer is equal $r_M = a/2$ by elementary geometry.

6. For a null geodesic of the space-time surface representing cosmology, starting at (a_0, r) and ending at $(a, 0)$, one has

$$\begin{aligned} & r = sinh(X) \ , && \text{(hyperbolic cosmology)} \ , \\ & r = X \ , && \text{(critical cosmology)} \ , \\ & X = \int_{a_0}^{a} \frac{\sqrt{g_{aa}}}{a} da \ . && \end{aligned} \tag{6.5.6}$$

If g_{aa} approaches zero for $a_0 \to 0$, as it does for the radiation dominated cosmology, the integral defining X is finite. This means that the value of $r_M(a_0)$ (M^4 distance of the object from the observer) approaches zero at this limit. All radiation from the moment of the big bang comes from the tip of the light cone. The very early cosmology with a critical mass density corresponds to $g_{aa} = 1 - K$, K a very small number, and also in this case the radiation comes from the origin.

Maximum Minkowski distance from which light can propagate

It is interesting to find the maximum value of M^4_+ distance r_M from which it is possible to receive information in various cosmologies. The radius $r_M(a_0)$ has maximum for some finite value of a_0 and this radius defines the M^4 radius of the Universe observed using the condensate photons. For a_0 corresponding to maximum the condition

$$\begin{aligned} \sqrt{g_{aa}} &= tanh(X) \ , \ \text{(hyperbolic cosmology)} \ , \\ \sqrt{g_{aa}} &= X \ , \ \text{(critical cosmology)} \ . \end{aligned} \tag{6.5.7}$$

The maximum corresponds to a rather large value of a_0. Consider now various cases.

i) In case of matter dominated cosmology one has $g_{aa} = Ka$ and one has the condition

$$u_0 = tanh(2(u - u_0)) \simeq 2(u - u_0) \ , \quad u = \sqrt{Ka} \ , \quad u_0 = \sqrt{Ka_0} \ . \tag{6.5.8}$$

This gives in good approximation

$$u_0 = r = \tfrac{2}{3}u \ , \quad a_0 = \tfrac{4}{9}a \ , \quad r_M^0 = \tfrac{8}{27}ua = \tfrac{16}{81}\sqrt{Ka} \times a \ . \tag{6.5.9}$$

ii) In case of vapor phase and also for asymptotic cosmology in the limit of flatness one obviously has

$$r_M^0 = a \ . \tag{6.5.10}$$

iii) In case of critical cosmology with $g_{aa} = 1$ one has

$$a_0 = \frac{a}{e} \ , \quad r_0 = 1 \ , \quad r_M^0 = \frac{a}{e} \ . \tag{6.5.11}$$

The value of r_M^0 is clearly smallest in matter dominated cosmology.

Many-sheeted space-time allows several snapshots from the evolution of astrophysical objects

Vapor phase photons and condensate photons propagating along various space-time sheets provide in principle a possibility to obtain simultaneous information about the astrophysical object in various different phases of its development. For an object situated at distance r and observed at $(a, r = 0)$, the emission moments a_0 and $a_1 > a_0$ (in Minkowski proper time) for the condensate photon and vapor phase photon are related by the formula

$$\frac{a}{a_1} = exp(2\sqrt{K_1}(a^{1/2} - a_0^{1/2})) \ . \tag{6.5.12}$$

in the matter dominated cosmology $g_{aa} = K_1 a$ ($K_1 a \sim 1$). Hence a sufficiently nearby Super Nova would provide a test for this effect. The first burst of light corresponds to vapor phase photons and subsequent bursts to the condensate photons. The time lag between the bursts provides a manner to measure the value of $\sqrt{g_{aa}}$. Unfortunately, the time lag in case of SN1987A is quite too large since the distance of order $1.5 \cdot 10^5$ ly. The observation of the same spectral line with two different cosmological red-shifts is second effect of this kind and might be erratically interpreted as the existence of two different objects on same line of sight.

Why some stars seem to be older than the Universe?

Red-shifts are determined by the apparent velocity of astrophysical object which is in good approximation given $v = Hr$, where H is Hubble constant which in TGD depends on space-time sheet along which photons propagate. One has $r = sinh(X)$ for hyperbolic cosmology and $r = X$ for critical cosmology, where the function X is defined by Eq. 6.5.6. For matter dominated cosmology with $g_{aa} = Ka$ and for almost flat hyperbolic cosmology with $g_{aa} = 1 - \epsilon$ one has

$$\begin{aligned} X &= 2\left[(Ka)^{1/2} - (Ka_0)^{1/2}\right] < 1 \ , \quad &&\text{(matter dominance)} \ , \\ X &= \sqrt{(1-\epsilon)}log(\tfrac{a}{a_0}) \ , &&\text{(almost flat hyperbolic)} \ . \end{aligned} \tag{6.5.13}$$

From this it is clear that the approximation $sinh(X) \simeq X$ makes sense in case of matter dominated cosmology and the red-shifts do not differ much from those predicted by critical cosmology.

For almost flat hyperbolic cosmology and for vapor phase situation is dramatically different since red-shifts can be exponentially larger. Therefore, if most of radiation comes along matter dominated or critical space-time sheets, then the radiation coming in vapor phase or along almost flat hyperbolic space-time sheets can give rise to huge red-shifts and stars which seem to be older than the Universe. The presence of several space-time sheets means that using common value of Hubble constant one obtains entire spectrum of ages of the Universe. Same astrophysical can also give rise to several images corresponding to the photons propagating along various space-time sheets. It might be that this mechanism might be involved with the observed multiple images of stars.

The puzzle of several Hubble constants

Each cosmic space-time has its own Hubble constant defined as

$$H = \frac{1}{a\sqrt{g_{aa}}} , \tag{6.5.14}$$

where the value of the light cone proper time corresponds to the light cone proper time of observer in the sub-light cone defined by the sub-cosmology. The value of Hubble constant is smallest at almost flat space-time sheets. Photons propagating along almost flat space-time sheet or in vapor phase provide a possible solution to the puzzle of two different Hubble constants if the mass density is sufficiently large. The distances derived from type Ia super-novae give $H_0^a = 54 \pm 8\ kms^{-1}Mpc^{-1}$ to be compared with the Hubble result $H_0^b = 80 \pm 17\ kms^{-1}Mpc^{-1}$ [38].

The discrepancy is resolved if the measurement of the distance is correct and made using photons propagating in vapor phase or along almost flat hyperbolic space-time sheets so that H_0^a corresponds in good approximation to the Hubble constant of M_+^4, which is by a factor

$$\frac{H_0^a}{H_0^b} = \frac{H_0(M_+^4)}{H_0(X^4)} = \sqrt{g_{aa}} = \sqrt{1-\epsilon} \sim 2/3 \tag{6.5.15}$$

smaller than the Hubble constant of the space-time surface. The needed mass density $\epsilon = 5/9$ and the ratio of the propagation velocities of light differs considerably from unity. For $\epsilon = .1$ the ratio of two Hubble constants is predicted to be .95 and some other explanation for discrepancy is needed. The model for the stationary cosmology indeed suggests that the density of matter is much below the value needed to explain the Hubble discrepancy in this manner.

For instance, for the space-time outside the Kähler charged cosmic string, discussed in [D4], one has

$$g_{tt} = 1 - \frac{R^2\omega^2}{4}(1-u^2) \ , \ -1 < u(\rho) < 1).$$

The model for the galaxy formation requires $exp(4\omega R) \sim 10^3$ and this gives $\frac{\omega^2 R^2}{4} \simeq .86$ implying $\sqrt{g_{tt}} \geq .37$ so that the reduction of the local light velocity can be rather large and explain the Hubble controversy.

In fact, there are quite recent results [41], which can be interpreted as a support for the many-sheeted space-time picture with separate Hubble constant associated with each sheet. The preliminary result is that the Hubble constant determined from the nearby supernovas is larger than that determined from the faraway supernovas. The proposed interpretation is that the rate of the expansion of the Universe is increasing in the course of time. The increase could be due to the non-vanishing cosmological constant corresponding to a vacuum energy density about 40 per cent of the critical density: the origin of this vacuum energy density remains a mystery.

TGD suggests suggests that Hubble constant depends on the (p-adic) length scale associated with the space-time sheet and decreases as the length scale increases. [This could also solve the problem of the two different Hubble constants since entire spectrum of Hubble constants is predicted]. Photons from nearby supernovas have suffered a topological condensation on a smaller space-time sheet as those from faraway supernovas. Hence the Hubble constant for nearby supernovas is larger and the rate of the expansion of the Universe is found to apparently increase in the course of time.

The decrease of the Hubble constant as a function of the (p-adic) length scale characterizing a given space-time sheet would follow from the fractality of the TGD Universe implying that the mass density as a function of the p-adic length scale decreases in the long length scales. Fractality could in turn would follow from the basic hypothesis necessary to get a sensible cosmology in TGD, namely that a space-time sheet corresponding to a given p-adic length scale expands until it reaches critical size not too much larger than the p-adic length scale in question. This does not exclude the possibility that the matter topologically condensed on the space-time sheet in question continues expanding and is therefore gradually drifted to the boundaries of the space-time sheet. The presence of the large voids with galaxies on their boundaries, is consistent with this assumption. From the view point of a given space-time sheet, smaller space-time sheets behave like particles of fixed size, whose density is gradually reduced in the cosmic expansion.

6.5.2 Mechanism of accelerated expansion in TGD Universe

In TGD framework the most plausible identification for the accelerated periods of cosmic expansion is in terms of phase transitions increasing gravitational Planck constant. These phase transitions would in average sense provide quantum counterpart for smooth cosmic expansion. These phase transitions might be initiated by the repulsive Coulomb interaction between cosmic strings driven to the boundaries of the large voids. It is interesting to see how this view relates with the assumption of positive cosmological constant.

How accelerated expansion results in standard cosmology?

The accelerated of cosmic expansion means that the deceleration parameter

$$q = -(ad^2a/ds^2)/(da/ds)^2$$

is negative. For Robertson-Walker cosmologies one has

$$\begin{aligned} H^2 &\equiv (\frac{da/ds}{a})^2 = \frac{8\pi G\rho + \Lambda}{3} - K/a^2, \quad K = 0, \pm 1 \ , \\ 3\frac{d^2a/ds^2}{a} &= \Lambda - 4\pi G(\rho + 3p) \equiv -4\pi G(1+3w)\rho \ . \end{aligned} \tag{6.5.16}$$

It is clear that the accelerated expansion requires positive value of Λ.

The deceleration parameter can be expressed as $q = \frac{1}{2}(1+3w)(1+K/(aH)^2)$. $K =, 0, 1, -1$ tells whether the cosmology is flat, hyper-spherical, or hyperbolic. The rate for the change of Hubble constant can be expressed as $(dH/ds)/H^2 = (1+q)$ and the acceleration of cosmic expansion means $q < -1$. All particle models predict $q \geq -1$.

On basis of modified Einstein's equations written for the recent metric convention (+,-,-.-) (note that opposite signature changes the sign of the left hand side)

$$-G^{\alpha\beta} - \Lambda g^{\alpha\beta} = 8\pi G T^{\alpha\beta} \tag{6.5.17}$$

it is clear that the introduction of a positive cosmological constant could be interpreted by saying that for gravitational vacuum carries energy density equal to $\Lambda/8\pi$ and negative pressure. The negative gravitational pressure would induce the acceleration.

Cosmological term at the level of field equations could be also interpreted by saying that Einstein's equations hold true in the original sense but that energy momentum tensor contains besides the density of inertial mass also a positive density of purely gravitational mass: $T \rightarrow T + \Lambda g$ so that Equivalence Principle fails. Since cosmological constant means effectively negative pressure $p = -\Lambda/8\pi$ the introduction of the cosmological constant means the effective replacement $\rho + 3p \rightarrow \rho + 3p - 2\Lambda/8\pi$). In the so called $\Lambda - CDM$ model [32] the densities of dark energy, ordinary matter, and dark matter are assumed to sum up to critical mass density $\rho_{cr} = 3/(8\pi g_{aa} G a^2)$. The fraction of dark matter density is deduced to be $\Omega_\Lambda = .74$ from mere criticality.

Critical cosmology predicts accelerated expansion

In order to get clue about the mechanism of accelerated cosmic expansion in TGD framework it is useful to study the deceleration parameter for various cosmologies in TGD framework.

In standard Friedmann cosmology with non-vanishing cosmological constant one has

$$3\frac{d^2a/ds^2}{a} = \Lambda - 4\pi G(\rho + 3p) \ . \tag{6.5.18}$$

From this form it is obvious why $\Lambda > 0$ is required in order to obtain accelerating expansion.

Deceleration parameter is a purely geometric property of cosmology and defined as

$$q \equiv -a\frac{d^2a/ds^2}{(da/ds)^2} \ . \tag{6.5.19}$$

During radiation and matter dominated phases the value of q is positive. In TGD framework there are several metrics which are independent of details of dynamics.

1. String dominated cosmology

String dominated cosmology is hyperbolic cosmology and might serve as a model for very early cosmology corresponds to the metric

$$g_{aa} \equiv (ds/da)^2 = 1 - K_0 \ . \tag{6.5.20}$$

In this case one has $q = 0$.

2. Critical cosmology

Critical cosmology with flat 3-space corresponds to

$$\begin{aligned} g_{aa} &= 1 - K \ , \\ K &\equiv \frac{K_0}{1-u^2} \ , \\ u &\equiv \frac{a}{a_1} \ . \end{aligned} \tag{6.5.21}$$

g_{aa} has the same form also for over-critical cosmologies. Both cosmologies have finite duration. In this case q is given by

$$q = -K_0 \frac{K_0 u^2}{1 - u^2 - K_0} < 0 \ , \tag{6.5.22}$$

and is negative. The rate of change for Hubble constant is

$$\frac{dH/ds}{H^2} = -(1+q) \ , \tag{6.5.23}$$

so that one must have $q < -1$ in order to have acceleration. This holds true for $a > \sqrt{(1-K_0)/(1+K_0)}a_1$.

Quantum critical cosmology could be seen as a universal characteristic of quantum critical phases associated with phase transition like phenomena. No assumptions about the mechanism behind the transition are made. There is great temptation to assign this cosmology to the phase transitions increasing the size of large voids occurring during late cosmology. The observed jerk assumed to lead from de-accelerated to accelerated expansion for about 13 billion years ago might have interpretation as a transition of this kind.

3. Stationary cosmology

TGD predicts a one-parameter family of stationary cosmologies from the requirement that the density of gravitational 4-momentum is conserved. This is guaranteed if curvature scalar is extremized. These cosmologies are expected to define asymptotic cosmologies or at least characterize the stationary phases between quantum phase transitions. The metric is given by

$$\begin{aligned} g_{aa} &= \frac{1-2x}{1-x} \ , \\ x &= (\frac{a_0}{a})^{2/3} \ . \end{aligned} \tag{6.5.24}$$

The deceleration parameter

$$q = \frac{1}{3}\frac{x}{(1-2x)(1-x)} \ . \tag{6.5.25}$$

is positive so that it seems that TGD does not lead to a continual acceleration which might be regarded as tearing galaxies into pieces.

If quantum critical phases correspond to the expansion of large voids induced by the accelerated radial motion of galactic strings as they reach the boundaries of the voids, one can consider a series of phase transitions between stationary cosmologies in which the value of gravitational Planck constant and the parameter a_0 characterizing the stationary cosmology increase by some even power of two as the ruler-and-compass integer hypothesis [A9, D3] and p-adic length scale hypothesis suggests.

4. Summary

One can safely conclude that TGD predict accelerated cosmic expansion during critical periods and that dark energy is replaced with dark matter in TGD framework. There is also a rather clear view about detailed mechanism leading to the accelerated expansion at "microscopic" level. Some summarizing remarks are in order.

1. Accelerated expansion is predicted only during periods of over-critical and critical cosmologies parameterized essentially by their duration. The microscopic description would be in terms of phase transitions increasing the size scale of large void. This phase transition is basically a quantum jump increasing gravitational Planck constant and thus the size of the large void. p-Adic length scales are favored sizes of the large voids. A large piece of 4-D cosmological history would be replaced by a new one in this transition so that quite a dramatic event would be in question.

2. p-Adic fractality forces to ask whether there is a fractal hierarchy of time scales in which Equivalence Principle in the formulation provided by General Relativity sense fails locally (no failure in stringy sense). This would predict a fractal hierarchy of large voids and phase transitions during which accelerated expansion occurs.

3. Cosmological constant can be said to be vanishing in TGD framework and the description of accelerated expansion in terms of a positive cosmological constant is not equivalent with TGD description since only effective pressure is negative. TGD description has some resemblance to the description in terms of quintessence [60], a hypothetical form of matter for which equation of state is of form $p = -w\rho$, $w < -1/3$, so that one has $\rho + 3p = 1 - w < 0$ and deceleration parameter can be negative. The energy density of quintessence is however positive. TGD does not predict endlessly accelerated acceleration tearing galaxies into pieces if the total purely gravitational energy of large voids is assumed to vanish so that Equivalence Principle holds above this length scale.

TGD counterpart of Λ as a density of dark matter rather than dark energy

The value of Λ is expressed usually as a fraction of vacuum energy density from the critical mass density. Combining the data about acceleration of cosmic expansion with the data about cosmic microwave background gives $\Omega_\Lambda \simeq .74$.

1. Critical mass density requires also in TGD framework the presence of dark contribution since visible matter contribute only a few percent of the total mass density and $\Omega_\Lambda \simeq .-74$ characterizes this contribution. Since the acceleration mechanism has nothing to do with dark energy, dark energy can be replaced with dark matter in TGD framework.

2. The dark matter hierarchy labeled by the values of Planck constant suggests itself. The $1/a^2$ behavior of dark matter density suggests an interpretation as dark matter topologically condensed on cosmic strings. Besides ordinary particles also super-symplectic bosons and their super partners playing a key role in the model of hadrons and black holes suggest themselves.

3. Stationary cosmology predicts that the density of stringy matter and thus dark matter decreases like $1/a^2$ as a function of M^4_+ proper time. This behavior is very natural in cosmic string dominated cosmology and one expects that the TGD counterpart of cosmological constant should behave as $\Lambda \propto 1/a^2$ in average sense. At primordial period cosmological constant would be gigantic but its recent value would be extremely small and naturally of correct order of magnitude if the fraction of positive gravitational energy is few per cent about negative gravitational energy. Hence the basic problem of the standard cosmology would find an elegant solution.

Piecewise constancy of TGD counterpart of Λ and p-adic length scale hypothesis

There are good reasons to believe that TGD counterpart of Λ is piecewise constant. Classical picture suggests that the sizes of large voids increase in discrete jumps. The transitions increasing the size of the void would occur when the galactic strings end up to the boundary of the large void and large repulsive Coulomb energy forces the phase transition increasing Planck constant.

Also the quantum astrophysics based on the notion of gravitational Planck constant strongly suggests that astrophysical systems are analogous to stationary states of atoms so that the sizes of astrophysical systems remain constant during the cosmological expansion, and can change only in quantum jumps increasing the value of Planck constant and therefore increasing the radius of the large void regarded as dark matter bound state.

Since the set of preferred values of Planck constant is closed under multiplication by powers of 2, p-adic length scales L_p, $p \simeq 2^k$ form a preferred set of sizes scales for the large voids with phase transitions increasing k by even integer. What values of k are realized depends on the time scale of the dynamics driving the galactic strings to the boundaries of expanded large void. Even if all values of k are realized the transitions becomes very rare for large values of a.

p-Adic fractality predicts that the effective cosmological constant Λ scales as $1/L^2(k)$ as a function of the p-adic scale characterizing the space-time sheet implying a series of phase transitions reducing the value of effective cosmological constant Λ. As noticed, the allowed values of k would be of form $k = k_0 + 2n$, where however all integer value need not be realized. By p-adic length scale hypothesis primes are candidates for k. The recent value of the effective cosmological constant can be understood. The gravitational energy density usually assigned to the cosmological constant is identifiable as that associated with topologically condensed cosmic strings and magnetic flux tubes to which they are gradually transformed during cosmological evolution.

p-Adic prediction is consistent with the recent study [61] according to which cosmological constant has not changed during the last 8 billion years: the conclusion comes from the reshifts of supernovae of type I_a. If p-adic length scales $L(k) = p \simeq 2^k$, k any positive integer, are allowed, the finding gives the lower bound $T_N > \sqrt{(2)}/(\sqrt{2}-1)) \times 8 = 27.3$ billion years for the recent age of the universe.

Brad Shaefer from Lousiana University has studied the red shifts of gamma ray bursters up to a red shift $z = 6.3$, which corresponds to a distance of 13 billion light years [62], and claims that the fit to the data is not consistent with the time independence of the cosmological constant. In TGD framework this would mean that a phase transition changing the value of the cosmological constant must have occurred during last 13 billion years. In principle the phase transitions increasing the size of large voids could be observed as sudden changes of sign for the deceleration parameter.

The reported cosmic jerk as an accelerated period of cosmic expansion

There is an objection against the hypothesis that cosmological constant has been gradually decreasing during the cosmic evolution. Type Ia supernovae at red shift $z \sim .45$ are fainter than expected, and the interpretation is in terms of an accelerated cosmic expansion [42]. If a period of an accelerated expansion has been preceded by a decelerated one, one would naively expect that for older supernovae from the period of decelerating expansion, say at redshifts about $z > 1$, the effect should be opposite. The team led by Adam Riess [43] has identified 16 type Ia supernovae at redshifts $z > 1.25$ and concluded that these supernovae are indeed brighter. The conclusion is that about about 5 billion years ago corresponding to $z \simeq .48$, the expansion of the Universe has suffered a cosmic jerk and transformed from a decelerated to an accelerated expansion.

The apparent dimming/brightening of supernovae at the period of accelerated/decelerated expansion the follows from the luminosity distance relation

$$\mathcal{F} = \frac{\mathcal{L}}{4\pi d_L^2} \ , \tag{6.5.26}$$

where $\mathcal{L}$ is actual luminosity and $\mathcal{F}$ measured luminosity, and from the expression for the distance d_L in flat cosmology in terms of red shift z in a flat Universe

$$\begin{aligned} d_L &= (1+z)\int_0^z \frac{du}{H(u)} \\ &= (1+z)H_0^{-1}\int_0^z exp\left[-\int_0^u du\,[1+q(u)]\,d(ln(1+u)\right] du \ , \end{aligned} \tag{6.5.27}$$

where one has

$$\begin{aligned} H(z) &= \frac{dln(a)}{ds} \ , \\ q &\equiv -\frac{d^2a/ds^2}{aH^2} = \frac{dH^{-1}}{ds} - 1 \ . \end{aligned} \tag{6.5.28}$$

In TGD framework a corresponds to the light-cone proper time and s to the proper time of Robertson-Walker cosmology. Depending on the sign of the deceleration parameter q, the distance d_L is larger or smaller and accordingly the object looks dimmer or brighter.

The natural interpretation for the jerk would be as a period of accelerated cosmic expansion due to a phase transition increasing the value of gravitational Planck constant.

6.5.3 New anomaly in Cosmic Microwave Background

A new anomaly in CMB has been found. The article by L. Rudnick, S. Brown, L. R. Williams is *Extragalactic Radio Sources and the WMAP Cold Spot* tells that a cold spot in the microwave background has been discovered. The amplitude of the temperature variation is -73 μK at maximum. The authors argue that the variation can be understood if there is a void at redshift $z \leq 1$, which corresponds to $d \leq 1.4 \times 10^{10}$ ly. The void would have radius of 140 Mpc making 5.2×10^8 ly.

In New Scientist [63] there is a story titled about Neil Turoks recent talk at PASCOS entitled *Is the Cold Spot in the CMB a Texture?*. Turok has proposed that the cold spot results from a topological defect associated with a cosmic string of GUT type theories.

Comparison with sizes and distances of large voids

It is interesting to compare the size and distance of the argued CMB void to those for large voids [34].

The largest known void has size of 163 Mpc making 5.3×10^8 ly which does not differ significantly from the size $8 \times 6.5 \times 10^8$ ly of CMB void. The distance is 201 Mpc making about 6.5×10^8 ly and roughly by a factor 1/22 smaller than CMB void.

Is it only an accident that the size of CMB void is same as that for largest large void? If large voids follow the cosmic expansion in a continuous manner, the size of the CMB void should be roughly 1/22 time smaller. Could it be that large voids might follow cosmic expansion by rather seldomly occurring discrete jumps? TGD inspired quantum astrophysics indeed predicts that expansion occurs in discrete jumps [D8].

The explanation of CMB void

Concerning the explanation of CMB void one can consider two options.

1. p-Adic evolution of cosmological constant as explanation for the constancy of the void size

If the large CMB void is similar to the standard large voids it should have emerged much earlier than these or the durations of constant value of v_0 could be rather long so that also the nearby large voids should have existed for a very long time with same size. Even in the case that all values of k corresponds to possible p-adic length scales characterizing effective Λ it is possible that no transitions reducing effective Λ have occurred during the time interval considered.

The constancy of the size of the large void during the time interval considered is predicted by other experimental findings. As alrady found, there is empirical evidence that cosmological constant has remained constant during last 8 billion years at least and the observed jerk suggests that this kind of phase transition has occurred for 13 billion years ago. This would predict that large voids have had the same size between 13 and 8 billion years.

2. Are fractally scaled up variants of large voids possible?

One can also consider the possibility that CMB void is a fractally scaled up variant of large void. The p-adic length scale of the CMB void would be $L_p \equiv L(k)$, $p \simeq 2^k$, $k = 263$ (prime). If it has participated cosmic expansion in the average sense its recent p-adic size scale would be about $16 < 22$ times larger and p-adic scale would be $L(k)$, $k = 271$ (prime). This explanation has no obvious connection with the empirical findings about the behavior of cosmological constant and does not therefore look promising.

6.5.4 Could many-sheeted cosmology explain the claimed time dependence of the fine structure constant?

There is recent evidence for the time dependence of the fine structure constant in cosmological time scales [36]. The spectroscopic observations of a number of absorption systems in the spectra of distant quasars indicate a smaller value of α in the past. The comparison of the ratios of the frequencies for relativistic atomic transitions depending non-linearly on α^2 gives the average value $\Delta\alpha/\alpha = -0.72 \pm .18 \times 10^{-5}$ in the red shift range $z = .5 - 3.5$.

On the other hand, the data about the isotopic abundances in Oklo natural reactor which operated at 1.8×10^9 years ago gives the upper bound $\Delta\alpha/\alpha \leq 10^{-7}$ [39]: this corresponds to the red shift $z = .13$. This suggests an abrupt change of the fine structure constant in the range $.13 < z_0 \leq .5$.

A further important piece of data is about type Ia super-novae in distant galaxies. These data have extended the Hubble diagram to red shifts $z \geq 1$ [40]. The data imply an accelerated expansion of the universe in the framework of standard cosmology requiring the introduction of cosmological constant and vacuum energy density of unknown origin. More recent measurements have measured no variation [56]. Despite this it is an interesting exercise to see whether the variation might have some explanation in TGD framework.

The notion of the many-sheeted cosmology might explain the apparent acceleration of the cosmological expansion. The notion of the many-sheeted space-time could also explain the apparent time variation of the fine structure constant as the following arguments tend to demonstrate.

Classical model based on many-sheeted space-time

Assume that new space-time sheets with size determined by the p-adic length scale $L(k)$ emerge at values $t \sim L(k)$ of the time coordinate during the cosmological evolution. It is also assumed that the proper description of atoms involves in an essential manner the concept of classical em field. This is indeed the case in TGD framework but not for the Bether-Salpeter equation relying on correlation functions and the abstraction of the basic features of perturbative QED.

1. The basic idea is that atomic nuclei need not feed their entire electric gauge fluxes to the atomic space-time sheet, which presumably corresponds to $p \simeq 2^k$, $k = 131$ or $k = 137$, but can feed a small fraction of the electric flux also to the larger space-time sheets. The simplest assumption is that each new cosmological space-time sheet receives a constant fraction of the existing nuclear gauge charge. Stability requirement suggests that also each electron feeds a negative fraction of its electric flux to the larger space-time sheet so that an overall charge neutrality is preserved. The fraction must be negative to guarantee that the nuclear and electronic charges effectively increase in magnitude when new larger space-time sheets emerge during the cosmological evolution. Negative fraction is favored also by the fact that the effective nuclear charge would otherwise approach zero in the sufficiently distant geometric future. The effect corresponds to an apparent renormalization of the fine structure constant having nothing to do with the ordinary QED renormalization or the renormalization of the fine structure constant suggested by the p-adic coupling constant evolution.

2. The experimental findings suggest that the distribution of the electric gauge fluxes between different space-time sheets could have changed in some abrupt manner during the period $.16 < z_0 < .5$. The lower bound follows from the fact that Oklo natural reactor data are consistent with the laboratory value of the effective fine structure constant. Assume that this abrupt change corresponds to the emergence of a new space-time sheet at $z = z_0$ taking a negative fraction of order $\epsilon \sim -10^{-5}$ of the nuclear and electronic gauge fluxes so that the effective

nuclear and electronic charges increase correspondingly in magnitude. More generally, assume that this occurs for all values of cosmic time $t(k) \sim L(k)$ corresponding to p-adic length scales.

3. If the p-adic length scale L_p appears at $t = a \simeq L_p$ then p-adic length scales appear at $a(k_n) = 2^{(k_n-k_0)/2}a_{k_0}$. The effective fine structure constant is predicted to be constant inside intervals $[a(k_n), a(k_{n-1})]$. The minimum value for the increment of k_n is $\Delta k = k_n - k_{n-1} = 2$ and corresponds to a variation of a by single octave and to a pair of twin primes $k_n = k_{n-1} + 2$. This predicts the constancy of the effective fine structure constant after $z = z_0$ in accordance with the experimental facts. If $z_0 = a_{now}/a_0 - 1$ corresponds to the first abrupt change in the range $.13 < z_0 < .5$ then for $\Delta k = 2$ another abrupt change would occur at $z_1 = 2z_0 + 1$, $1.26 < z_1 < 3$. If each space-time sheet receives the same amount of electric flux, one has $\Delta[log(\alpha)](z_1) \simeq 2\Delta[log(\alpha)](z_0)$, which is excluded in the range considered. For $\Delta k = 4$ the next abrupt change would correspond to $z_2 = 4z_0+3$: $3.52 < z_2 < 5$. Unfortunately, this value of z is slightly above the range studied in [37]. For $\Delta k = 6$ one would have $z_3 = 8z_0 + 7$, $8 < z_3 < 11$.

4. The negative em flux which is fraction of order $\epsilon \sim -10^{-5}$ of nuclear electromagnetic charge flowing to single space-time sheet does not lead to any inconsistencies since the number of the primary p-adic length scales between atomic length scale and cosmological length scales is only 45. Therefore the total variation between $a = a_{now} \sim 10^{10}$ years and $a = 10^7$ years (this is the range probed by the cosmic microwave background) would correspond to something like five p-adic length scales for $t = a$ and the predicted net variation in the red shift interval $.13 < z < 10^3$ would not be larger than $\Delta[log(\alpha)] \sim 10^{-4}$ if each p-adic space-time sheet receives the same amount of the electric flux.

Note that this model might be seen as a topological and microscopic version of the Bekenstein's field theory model [52] based on the assumption that fine structure constant is a slowly varying scalar field Φ having naturally the needed linear coupling to the Maxwell action. In [39] it was suggested that Φ could correspond to the so called quintessence field believed to give rise to cosmological vacuum energy and that Bekenstein's model could explain the observed variation of the fine structure constant. Note that in many-sheeted cosmology charge conservation is not lost although the effective fine structure constant depends on cosmological time.

Could hierarchy of Planck constants be involved?

The introduction of hierarchy of Planck constants [A9, F12] suggests also mechanisms based on charge fractionization and change of Planck constant from its standard value.

Fine structure constant is proportional to $1/\hbar$. In the lowest order perturbative QED the predictions are more or less same as the predictions of classical theory and do not depend at all on $\hbar$. Radiation corrections appear in higher orders in powers of α, and would allow to deduce the value of $\hbar$ associated with the dark matter system. The possibility that the value of $\hbar/\hbar_0$, which is rational number, has changed a little bit in past for what we regard as visible matter does not however look very plausible.

One can imagine also another effect related to the hierarchy of Planck constants.

1. The pages of the book like structures associated with causal diamond CD and CP_2 are labeled by integers n_a and n_b characterizing the cyclic group associated with the singular covering or factor space defining the page. Both n_a and n_b could make themselves visible physical if the Kähler gauge potential has a pure gauge part ΔA in both CD and CP_2 degrees of freedom (with g_K included as scaling factor so that ΔA has dimension of $\hbar$) [F12]. This would give a fractional shift to both spin and color hyper charge and color isospin.

2. Since the holonomy group of CP_2 identifiable as electro-weak gauge group corresponds in natural manner to the $U(2)$ subgroup of color group, the interpretation of the anomalous color hyper charge and color isospin in terms of anomalous weak isospin and hyper charge can be considered.

3. This contribution to the charge in units of $\hbar_0$ would be of form $(a\Delta A_\psi + b\Delta A_\Phi)/\hbar_0$, where Ψ and Φ denote the phases assignable to the complex coordinates of CP_2 transforming linearly under $U(2)$. For a page of CP_2 book, which corresponds to a singular covering characterized by integer n_b, the physically most plausible scenario would give $\Delta A_\Psi = \Delta A_\Phi = \hbar_0/n_b$ for coverings

so that for coverings em charge would be shifted by $1/n_b$ units. For singular factor spaces formal guess would be $\Delta A_\Psi = \Delta A_\Phi = \hbar_0 n_b$. One can argue that ΔA can be eliminated by a global gauge transformation: this transformation however induces a phase into induced spinor field giving rise to anomalous charge. This fractionization means a shift of the charge so that even neutrino would receive a small fractional em charge. Nothing prevents from asking whether this kind of fractionization could actually take place and seeing the trouble of demonstrating that it cannot be involved with the claimed anomaly.

is based on charge fractionization predicted for dark matter.

6.5.5 The problem of fermion families

The generation-genus correspondence implies that the number of the particle families is apparently infinite. The arguments developed in the second part of the book however suggest that $g > 2$ particle families have masses of order $m_0 \sim 10^{-3.5} m_{Pl}$ except possibly at the very early stages of the cosmology in the vapor phase. One should somehow understand how the effective number of particle families manages to be finite and whether very early TGD inspired cosmology allows infinite number of light particle families. In the following I shall consider the possibility that the existence of the vapor phase might provide solutions to this problem.

Without additional constraints TGD predicts infinite number of particles families (both bosonic and fermionic) since each boundary topology characterized by the handle number corresponds to a separate elementary particle. On the other hand, GRT based cosmology poses stringent bounds on the number of the fermion families. The number of the light fermion families is generally believed to be not larger than 3 or 4. In TGD the problem is even more acute if all elementary particles are massless in the vapor phase.

The original proposal for the solution of the problem was based on the following arguments.

1. The masses $M(g)$ of the topologically condensed elementary fermions increase as a function of the genus of the boundary component. In particular, higher genus neutrinos are (very) massive. The properties of the elementary particle vacuum functionals suggest that condensed $g > 2$ particle families have masses of order CP_2 mass.

2. Massive condensed fermions with mass $M(g)$ begin to decay at temperature $T \simeq M(g)$. If $M(g)$ increases sufficiently rapidly the number $N(a)$ of the effectively massless fermions in the topological condensate is always finite due to the decay of the massive fermions. The temperature equals to the critical temperature $T_H \sim 1/R$ before $a = a_F \sim 10^{-11}$ *sec*. If the masses of the higher fermion families are larger than T_H, their contribution to the mass density is exponentially suppressed and they are effectively absent from cosmology. Thus the number of fermion families is effectively finite and equal to three if the argument based on elementary particle vacuum functionals holds true.

3. Massless fermions could be present in vapor phase but their fraction of energy density is presumably negligible since vapor phase is expected to be in zero temperature.

It has turned out [F1] that under very general conditions the number of fermion families is three. The idea is that the property of being fermion has some space-time correlate. There are reasons to believe that this correlate is Z_2 conformal symmetry for the corresponding partonic 2-surfaces. This symmetry implies that fermionic elementary particle vacuum functionals vanish identically for $g > 2$. This holds true also for gauge bosons which can be regarded as fermion anti-fermion pairs associated with the light-like throats of wormhole contact. The argument is represented in detail in [F1].

6.6 Simulating Big Bang in laboratory

Ultra-high energy collisions of heavy nuclei at Relativistic Heavy Ion Collider (RHIC) can create so high temperatures that there are hopes of simulating Big Bang in laboratory. The experiment with PHOBOS detector [65] probed the nature of the strong nuclear force by smashing two Gold atoms together at ultrahigh energies. The analysis of the experimental data has been carried out by Prof. Manly and his collaborators at RHIC in Brookhaven, NY [31]. The surprise was that the hydrodynamical flow for non-head-on collisions did not possess the expected longitudinal boost invariance.

This finding stimulates in TGD framework the idea that something much deeper might be involved.

1. The quantum criticality of the TGD inspired very early cosmology predicts the flatness of 3-space as do also inflationary cosmologies. The TGD inspired cosmology is 'silent whisper amplified to big bang' since the matter gradually topologically condenses from decaying cosmic string to the space-time sheet representing the cosmology. This suggests that one could model also the evolution of the quark-gluon plasma in an analogous manner. Now the matter condensing to the quark-gluon plasma space-time sheet would flow from other space-time sheets. The evolution of the quark-gluon plasma would very literally look like the very early critical cosmology.

2. What is so remarkable is that critical cosmology is not a small perturbation of the empty cosmology represented by the future light cone. By perturbing this cosmology so that the spherical symmetry is broken, it might possible to understand qualitatively the findings of [31]. Even more, the breaking of the spherical symmetry in the collision could be understood as a strong gravitational effect on distances transforming the spherical shape of the plasma ball to a non–spherical shape without affecting the spherical shape of its M^4_+ projection.

3. The model seems to work and predicts strong gravitational effects in elementary particle length scales so that TGD based gravitational physics would differ dramatically from that predicted by the competing theories. Standard cosmology cannot produce these effects without a large breaking of the cherished Lorentz and rotational symmetries forming the basis of elementary particle physics. Thus the PHOBOS experiment gives direct support for the view that Poincare symmetry is symmetry of the imbedding space rather than that of the space-time.

4. This picture was completed a couple of years later by the progress made in hadronic mass calculations [F4]. It has already earlier been clear that quarks are responsible only for a small part of the mass of baryons (170 GeV in case of nucleons). The assumption that hadronic $k = 107$ space-time sheet carries a many-particle state of super-symplectic particles with vanishing electro-weak quantum numbers (meaning darkness in the strongest sense of the word) allows a model of hadrons predicting their masses with accuracy better than one per cent. The large value of Kähler coupling strength $\alpha_K = \alpha_s = 1/4$ for ordinary value of Planck constant motivates the hypothesis that a transition to large $\hbar$ phase occurs: $\hbar = 26 \times \hbar_0$ would leave the value of α_K for gauge boson field bodies ($\alpha_K = 1/104$) invariant [C5]. $J = 2$ excitations have identification as strong gravitons. In this framework color glass condensate can be identified as a state formed when the hadronic space-time sheets of colliding hadrons fuse to single long stringy object and collision energy is transformed to super-symplectic hadrons.

6.6.1 Experimental arrangement and findings

Heuristic description of the findings

In the experiments using PHOBOS detector ultrahigh energy Au+Au collisions at center of mass energy for which nucleon-nucleon center of mass energy is $\sqrt{s_{NN}} = 130$ GeV, were studied [65].

1. In the analyzed collisions the Au nuclei did not collide quite head-on. In classical picture the collision region, where quark gluon plasma is created, can be modeled as the intersection of two colliding balls, and its intersection with plane orthogonal to the colliding beams going through the center of mass of the system is defined by two pieces of circles, whose intersection points are sharp tips. Thus rotational symmetry is broken for the initial state in this picture.

2. The particles in quark-gluon plasma can be compared to a persons in a crowded room trying to get out. The particles collide many times with the particles of the quark gluon plasma before reaching the surface of the plasma. The distance $d(z, \phi)$ from the point $(z, 0)$ at the beam axis to the point $(0, \phi)$ at the plasma surface depends on ϕ. Obviously, the distance is longest to the tips $\phi = \pm\pi/2$ and shortest to the points $\phi = 0, \phi = \phi$ of the surface at the sides of the collision region. The time $\tau(z, \phi)$ spent by a particle to the travel to the plasma surface should be a monotonically increasing function $f(d)$ of d:

$$\tau(z,\phi) = f(d(z,\phi)) \ .$$

For instance, for diffusion one would have $\tau \propto d^2$ and $\tau \propto d$ for a pure drift.

3. What was observed that for $z = 0$ the difference

$$\Delta\tau = \tau(z = 0, \pi/2) - \tau(z = 0, 0)$$

was indeed non-vanishing but that for larger values of z the difference tended to zero. Since the variation of z correspond that for the rapidity variable y for a given particle energy, this means that particle distributions depend on rapidity which means a breaking of the longitudinal boost invariance assumed in hydrodynamical models of the plasma. It was also found that the difference vanishes for large values of y: this finding is also important for what follows.

A more detailed description

Consider now the situation in a more quantitative manner.

1. Let z-axis be in the direction of the beam and ϕ the angle coordinate in the plane E^2 orthogonal to the beam. The kinematical variables are the rapidity of the detected particle defined as $y = log[E + p_z)/(E - p_z)]/2$ (E and p_z denote energy and longitudinal momentum), Feynman scaling variable $x_F \simeq 2E/\sqrt{s}$, and transversal momentum p_T.

2. By quantum-classical correspondence, one can translate the components of momentum to space-time coordinates since classically one has $x^\mu = p^\mu a/m$. Here a is proper time for a future light cone, whose tip defines the point where the quark gluon plasma begins to be generated, and $v^\mu = p^\mu/m$ is the four-velocity of the particle. Momentum space is thus mapped to an $a = constant$ hyperboloid of the future light cone for each value of a.

   In this correspondence the rapidity variable y is mapped to $y = log[(t + z)/(t - z)]$, $|z| \leq t$ and non–vanishing values for y correspond to particles which emerge, not from the collision point defining the origin of the plane E^2, but from a point above or below E^2. $|z| \leq t$ tells the coordinate along the beam direction for the vertex, where the particle was created. The limit $y \to 0$ corresponds to the limit $a \to \infty$ and the limit $y \to \pm\infty$ to $a \to 0$ (light cone boundary).

3. Quark-parton models predict at low energies an exponential cutoff in transverse momentum p_T; Feynman scaling $dN/dx_F = f(x_F)$ independent of s; and longitudinal boost invariance, that is rapidity plateau meaning that the distributions of particles do not depend on y. In the space-time picture this means that the space-time is effectively two-dimensional and that particle distributions are Lorentz invariant: string like space-time sheets provide a possible geometric description of this situation.

4. In the case of an ideal quark-gluon plasma, the system completely forgets that it was created in a collision and particle distributions do not contain any information about the beam direction. In a head-on collision there is a full rotational symmetry and even Lorentz invariance so that transverse momentum cutoff disappears. Rapidity plateau is predicted in all directions.

5. The collisions studied were not quite head-on collisions and were characterized by an impact parameter vector with length b and direction angle ψ_2 in the plane E^2. The particle distribution at the boundary of the plane E^2 was studied as a function of the angle coordinate $\phi - \psi_2$ and rapidity y which corresponds for given energy distance to a definite point of beam axis.

The hydrodynamical view about the situation looks like follows.

1. The particle distributions $N(p^\mu)$ as function of momentum components are mapped to space-time distributions $N(x^\mu, a)$ of particles. This leads to the idea that one could model the situation using Robertson-Walker type cosmology. Co-moving Lorentz invariant particle currents depending on the cosmic time only would correspond in this picture to Lorentz invariant momentum distributions.

2. Hydrodynamical models assign to the particle distribution $d^2N/dyd\phi$ a hydrodynamical flow characterized by four-velocity $v^\mu(y,\phi)$ for each value of the rapidity variable y. Longitudinal boost invariance predicting rapidity plateau states that the hydrodynamical flow does not depend on y at all. Because of the breaking of the rotational symmetry in the plane orthogonal to the beam, the hydrodynamical flow v depends on the angle coordinate $\phi - \psi_2$. It is possible to Fourier analyze this dependence and the second Fourier coefficient v_2 of $cos(2(\phi - \psi_2)$ in the expansion

$$\frac{dN}{d\phi} \simeq 1 + \sum_n v_n cos(n(\phi - \psi_2)) \tag{6.6.1}$$

was analyzed in [31].

3. It was found that the Fourier component v_2 depends on rapidity y, which means a breaking of the longitudinal boost invariance. v_2 also vanishes for large values of y. If this is true for all Fourier coefficients v_n, the situation becomes effectively Lorentz invariant for large values of y since one has $v(y,\phi) \rightarrow 1$.

   Large values of y correspond to small values of a and to the initial moment of big bang in cosmological analogy. Hence the finding could be interpreted as a cosmological Lorentz invariance inside the light cone cosmology emerging from the collision point. Small values of y in turn correspond to large values of a so that the breaking of the spherical symmetry of the cosmology should be manifest only at $a \rightarrow \infty$ limit. These observations suggest a radical re-consideration of what happens in the collision: the breaking of the spherical symmetry would not be a property of the initial state but of the final state.

6.6.2 TGD based model for the quark-gluon plasma

Consider now the general assumptions the TGD based model for the quark gluon plasma region in the approximation that spherical symmetry is not broken.

1. Quantum-classical correspondence supports the mapping of the momentum space of a particle to a hyperboloid of future light cone. Thus the symmetries of the particle distributions with respect to momentum variables correspond directly to space-time symmetries.

2. The M^4_+ projection of a Robertson-Walker cosmology imbedded to $H = M^4_+ \times CP_2$ is future light cone. Hence it is natural to model the hydrodynamical flow as a mini-cosmology. Even more, one can assume that the collision quite literally creates a space-time sheet which locally obeys Robertson-Walker type cosmology. This assumption is sensible in many-sheeted space-time and conforms with the fractality of TGD inspired cosmology (cosmologies inside cosmologies).

3. If the space-time sheet containing the quark-gluon plasma is gradually filled with matter, one can quite well consider the possibility that the breaking of the spherical symmetry develops gradually, as suggested by the finding $v_2 \rightarrow 1$ for large values of $|y|$ (small values of a). To achieve Lorentz invariance at the limit $a \rightarrow 0$, one must assume that the expanding region corresponds to $r = constant$ "coordinate ball" in Robertson-Walker cosmology, and that the breaking of the spherical symmetry for the induced metric leads for large values of a to a situation described as a "not head-on collision".

4. Critical cosmology is by definition unstable, and one can model the Au+Au collision as a perturbation of the critical cosmology breaking the spherical symmetry. The shape of $r = constant$ sphere defined by the induced metric is changed by strong gravitational interactions such that it corresponds to the shape for the intersection of the colliding nuclei. One can view the collision as a spontaneous symmetry breaking process in which a critical quark-gluon plasma cosmology develops a quantum fluctuation leading to a situation described in terms of impact parameter. This kind of modeling is not natural for a hyperbolic cosmology, which is a small perturbation of the empty M^4_+ cosmology.

The imbedding of the critical cosmology

Any Robertson-Walker cosmology can be imbedded as a space-time sheet, whose M^4_+ projection is future light cone. The line element is

$$ds^2 = f(a)da^2 - a^2(K(r)dr^2 + r^2 d\Omega^2) \ . \tag{6.6.2}$$

Here a is the scaling factor of the cosmology and for the imbedding as surface corresponds to the future light cone proper time.

This light cone has its tip at the point, where the formation of quark gluon plasma starts. (θ, ϕ) are the spherical coordinates and appear in $d\Omega^2$ defining the line element of the unit sphere. a and r are related to the spherical Minkowski coordinates (m^0, r_M, θ, ϕ) by $(a = \sqrt{(m^0)^2 - r_M^2}, r = r_M/a)$. If hyperbolic cosmology is in question, the function $K(r)$ is given by $K(r) = 1/(1 + r^2)$. For the critical cosmology 3-space is flat and one has $K(r) = 1$.

1. The critical cosmologies imbeddable to $H = M^4_+ \times CP_2$ are unique apart from a single parameter defining the duration of this cosmology. Eventually the critical cosmology must transform to a hyperbolic cosmology. Critical cosmology breaks Lorentz symmetry at space-time level since Lorentz group is replaced by the group of rotations and translations acting as symmetries of the flat Euclidian space.

2. Critical cosmology replaces Big Bang with a silent whisper amplified to a big but not infinitely big bang. The silent whisper aspect makes the cosmology ideal for the space-time sheet associated with the quark gluon plasma: the interpretation is that the quark gluon plasma is gradually transferred to the plasma space-time sheet from the other space-time sheets. In the real cosmology the condensing matter corresponds to the decay products of cosmic string in 'vapor phase'. The density of the quark gluon plasma cannot increase without limit and after some critical period the transition to a hyperbolic cosmology occurs. This transition could, but need not, correspond to the hadronization.

3. The imbedding of the critical cosmology to $M^4_+ \times S^2$ is given by

$$\begin{aligned} sin(\Theta) &= \frac{a}{a_m} \ , \\ \Phi &= g(r) \ . \end{aligned} \tag{6.6.3}$$

Here Θ and Φ denote the spherical coordinates of the geodesic sphere S^2 of CP_2. One has

$$\begin{aligned} f(a) &= 1 - \frac{R^2k^2}{(1-(a/a_m)^2)} \ , \\ (\partial_r\Phi)^2 &= \frac{a_m^2}{R^2} \times \frac{r^2}{1+r^2} \ . \end{aligned} \tag{6.6.4}$$

Here R denotes the radius of S^2. From the expression for the gradient of Φ it is clear that gravitational effects are very strong. The imbedding becomes singular for $a = a_m$. The transition to a hyperbolic cosmology must occur before this.

This model for the quark-gluon plasma would predict Lorentz symmetry and $v = 1$ (and $v_n = 0$) corresponding to head-on collision so that it is not a realistic model.

TGD based model for the quark-gluon plasma without breaking of spherical symmetry

There is a highly unique deformation of the critical cosmology transforming metric spheres to highly non–spherical structures purely gravitationally. The deformation can be characterized by the following formula

$$sin^2(\Theta) = (\frac{a}{a_m})^2 \times (1+\Delta(a,\theta,\phi)^2) \ . \tag{6.6.5}$$

1. This induces deformation of the g_{rr} component of the induced metric given by

$$g_{rr} = -a^2\left[1+\Delta^2(a,\theta,\phi)\frac{r^2}{1+r^2}\right] \ . \tag{6.6.6}$$

   Remarkably, g_{rr} does not depend at all on CP_2 size and the parameter a_m determining the duration of the critical cosmology. The disappearance of the dimensional parameters can be understood to reflect the criticality. Thus a strong gravitational effect independent of the gravitational constant (proportional to R^2) results. This implies that the expanding plasma space-time sheet having sphere as M^4_+ projection differs radically from sphere in the induced metric for large values of a. Thus one can understand why the parameter v_2 is non-vanishing for small values of the rapidity y.

2. The line element contains also the components $g_{ij}, \ i,j \in \{a,\theta,\phi\}$. These components are proportional to the factor

$$\frac{1}{1-(a/a_m)^2(1+\Delta^2)} \ , \tag{6.6.7}$$

   which diverges for

$$a_m(\theta,\phi) = \frac{a_m}{\sqrt{1+\Delta^2}} \ . \tag{6.6.8}$$

   Presumably quark-gluon plasma phase begins to hadronize first at the points of the plasma surface for which $\Delta(\theta,\phi)$ is maximum, that is at the tips of the intersection region of the colliding nuclei. A phase transition producing string like objects is one possible space-time description of the process.

6.6.3 Further experimental findings and theoretical ideas

The interaction between experiment and theory is pure magic. Although experimenter and theorist are often working without any direct interaction (as in case of TGD), I have the strong feeling that this disjointness is only apparent and there is higher organizing intellect behind this coherence. Again and again it has turned out that just few experimental findings allow to organize separate and loosely related physical ideas to a consistent scheme. The physics done in RHIC has played completely unique role in this respect.

Super-symplectic matter as the TGD counterpart of CGC?

The model discussed above explained the strange breaking of longitudinal Lorentz invariance in terms of a hadronic mini bang cosmology. The next twist in the story was the shocking finding, compared to Columbus's discovery of America, was that, rather than behaving as a dilute gas, the plasma behaved like a liquid with strong correlations between partons, and having density 30-50 times higher than predicted by QCD calculations [54]. When I learned about these findings towards the end of 2004, I proposed how TGD might explain them in terms of what I called conformal confinement [F2]. This idea - although not wrong for any obvious reason - did not however have any obvious implications. After the progress made in p-adic mass calculations of hadrons leading to highly successful model for both hadron and meson masses [F4], the idea was replaced with the hypothesis that the condensate in question is Bose-Einstein condensate like state of super-symplectic particles formed when the hadronic space-time sheets of colliding nucleons fuse together to form a long string like object.

Fireballs behaving like black hole like objects

The latest discovery in RHIC is that fireball, which lasts a mere 10^{-23} seconds, can be detected because it absorbs jets of particles produced by the collision [67]. The association with the notion black hole is unavoidable and there indeed exists a rather esoteric M-theory inspired model "The RHIC fireball as a dual black hole" by Hortiu Nastase [69] for the strange findings.

The Physics Today article [33] "What Have We Learned From the Relativistic Heavy Ion Collider?" gives a nice account about experimental findings. Extremely high collision energies are in question: Gold nuclei contain energy of about 100 GeV per nucleon: 100 times proton mass. The expectation was that a large volume of thermalized Quark-Gluon Plasma (QCP) is formed in which partons lose rapidly their transverse momentum. The great surprise was the suppression of high transverse momentum collisions suggesting that in this phase strong collective interactions are present. This has inspired the proposal that quark gluon plasma is preceded by liquid like phase which has been christened as Color Glass Condensate (CGC) thought to contain Bose-Einstein condensate of gluons.

The theoretical ideas relating CGC to gravitational interactions

Color glass condensate relates naturally to several gravitation related theoretical ideas discovered during the last year.

1. *Classical gravitation and color confinement*

Just some time ago it became clear that strong classical gravitation might play a key role in the understanding of color confinement [E2]. Whether the situation looks confinement or asymptotic freedom would be in the eyes of beholder: one example of dualities filling TGD Universe. If one looks the situation at the hadronic space-time sheet one has asymptotic freedom, particles move essentially like free massless particles. But, and this is absolutely essential, in the induced metric of hadronic space-time sheet. This metric represents classical gravitational field becoming extremely strong near hadronic boundary. From the point of view of outsider, the motion of quarks slows down to rest when they approach hadronic boundary: confinement. The distance to hadron surface is infinite or at least very large since the induced metric becomes singular at the light-like boundary! Also hadronic time ceases to run near the boundary and finite hadronic time corresponds to infinite time of observer. When you look from outside you find that this light-like 3-surface is just static surface like a black hole horizon which is also a light-like 3-surface. Hence confinement.

2. *Dark matter in TGD*

The evidence for hadronic black hole like structures is especially fascinating. In TGD Universe dark matter can be (not always) ordinary matter at larger space-time sheets in particular magnetic flux tubes. The mere fact that the particles are at larger space-time sheets might make them more or less invisible.

Matter can be however dark in much stronger sense, should I use the word "black"! The findings suggesting that planetary orbits obey Bohr rules with a gigantic Planck constant [30, D6] would suggest quantum coherence of dark matter even in astrophysical length scales and this raises the fascinating possibility that Planck constant is dynamical so that fine structure constant for these charged coherent states would be proportional to $1/\hbar_{gr}$ and extremely small: hence darkness. This quantization saves from black hole collapse just as the quantization of hydrogen atom saves from the infrared catastrophe.

The obvious questions are following. Could black hole like objects/magnetic flux tubes/cosmic strings consist of quantum coherent dark matter? Does this dark matter consist dominantly from hadronic space-time sheets which have fused together and contain super-symplectic bosons and their super-partners (with quantum numbers of right handed neutrino) having therefore no electro-weak interactions.

Since $\alpha_K = \alpha_s = 1/4$ would indeed justify large value of Planck constant, $\hbar = 26\hbar_0$ would leave α_K unchanged and predicts that the size of the hadronic space-time sheet is that of a large nucleus. The hadronic string tension would be predicted correctly and strong gravitation would correspond to the exchange of super-symplectic $J = 2$ quanta.

This overall view would be of enormous importance even for the understanding of living matter since dark matter at magnetic flux tubes would be responsible for the quantum control of the ordinary matter. Note however that TGD based quantum model for living matter involves also dark variants of ordinary elementary particles.

From outside non-stringy TGD analogs of black holes would look just like ordinary black holes but the interior metric would be of course different from the usual one since matter would not be collapsed to a point.

Dark matter option cannot be realized in a purely hadronic system at RHIC energies since the product GM_1M_2 characterizing the interaction strength of two masses must be larger than unity ($\hbar = c = 1$) for the phase transition increasing Planck constant to occur. Hence the collision energy should be above Planck mass for the phase transition to occur if gravitational interactions are responsible for the transition.

The hypothesis is however much more general and states that the system does its best to stay perturbative by increasing its Planck constant in discrete steps and applies thus also in the case of color interactions and governs the phase transition to the TGD counterpart of non-perturbative QCD. Criterion would be roughly $\alpha_s Q_s^2 > 1$ for two color charges of opposite sign. Hadronic string picture would suggests that the criterion is equivalent to the generalization of the gravitational criterion to its strong gravity analog $nL_p^2M^2 > 1$, where L_p is the p-adic length scale characterizing color magnetic energy density (hadronic string tension) and M is the mass of the color magnetic flux tube and n is a numerical constant. Presumably L_p, $p = M_107 = 2^{107} - 1$, is the p-adic length scale since Mersenne prime M_{107} labels the space-time sheet at which partons feed their color gauge fluxes. The temperature during this phase could correspond to Hagedorn temperature (for the history and various interpretations of Hagedorn temperature see the CERN Courier article [70]) for strings and is determined by string tension and would naturally correspond also to the temperature during the critical phase determined by its duration as well as corresponding black-hole temperature. This temperature is expected to be somewhat higher than hadronization temperature found to be about $\simeq 176$ MeV. The density of inertial mass would be maximal during this phase as also the density of gravitational mass during the critical phase.

Lepto-hadron physics [F7], one of the predictions of TGD, is one instance of a similar situation. In this case electromagnetic interaction strength defined in an analogous manner becomes larger than unity in heavy ion collisions just above the Coulomb wall and leads to the appearance of mysterious states having a natural interpretation in terms of lepto-pion condensate. Lepto-pions are pairs of color octet excitations of electron and positron.

One can ask whether the Bose-Einstein condensed gluons at color magnetic flux tubes possess complex super-symplectic conformal weights and whether conformal confinement could be responsible for the particle like behavior of CGC. An equally interesting question is whether ordinary liquid flow could involve Bose-Einstein condensates of particles which are not "conformal singlets".

3. Description of collisions using analogy with black holes

The following view about RHIC events represents my immediate reaction to the latest RHIC news in terms of black-hole physics instead of notions related to big bang. Since black hole collapse is roughly time reversal of big bang, the description is complementary to the earliest one.

In TGD context one can ask whether the fireballs possibly detected in RHIC are produced when a portion of quark-gluon plasma in the collision region formed by to Gold nuclei separates from hadronic space-time sheets which in turn fuse to form a larger space-time sheet separated from the remaining collision region by a light-like 3-D surface (I have used to speak about light-like causal determinants) mathematically completely analogous to a black hole horizon. This larger space-time sheet would contain color glass condensate of super-symplectic gluons formed from the collision energy. A formation of an analog of black hole would indeed be in question.

The valence quarks forming structures connected by color bonds would in the first step of the collision separate from their hadronic space-time sheets which fuse together to form color glass condensate. Similar process has been observed experimentally in the collisions demonstrating the experimental reality of Pomeron, a color singlet state having no Regge trajectory [30] and identifiable as a structure formed by valence quarks connected by color bonds. In the collision it temporarily separates from the hadronic space-time sheet. Later the Pomeron and the new mesonic and baryonic Pomerons created in the collision suffer a topological condensation to the color glass condensate: this process would be analogous to a process in which black hole sucks matter from environment.

Of course, the relationship between mass and radius would be completely different with gravitational constant presumably replacement by the square of appropriate p-adic length scale presumably of order pion Compton length: this is very natural if TGD counterparts of black-holes are formed by color magnetic flux tubes. This gravitational constant expressible in terms of hadronic string tension of .9 GeV^2 predicted correctly by super-symplectic picture would characterize the strong gravitational interaction assignable to super-symplectic $J = 2$ gravitons. I have long time ago in the context of p-adic mass calculations formulated quantitatively the notion of elementary particle black hole analogy making the notion of elementary particle horizon and generalization of Hawking-Bekenstein law [E5].

The size L of the "hadronic black hole" would be relatively large using protonic Compton radius as a unit of length. For $hbar = 26\hbar_0$ the size would be $26 \times L(107) = 46$ fm,and correspond to a size of a heavy nucleus. This large size would fit nicely with the idea about nuclear sized color glass condensate. The density of partons (possibly gluons) would be very high and large fraction of them would have been materialized from the brehmstrahlung produced by the de-accelerating nuclei. Partons would be gravitationally confined inside this region. The interactions of partons or conformal confinement would lead to a generation of a liquid like dense phase and a rapid thermalization would occur. The collisions of partons producing high transverse momentum partons occurring inside this region would yield no detectable high p_T jets since the matter coming out from this region would be somewhat like a thermal radiation from an evaporating black hole identified as a highly entangled hadronic string in Hagedorn temperature. This space-time sheet would expand and cool down to QQP and crystallize into hadrons.

4. Quantitative comparison with experimental data

Consider now a quantitative comparison of the model with experimental data. The estimated freeze-out temperature of quark gluon plasma is $T_f \simeq 175.76$ MeV [33, 69], not far from the total contribution of quarks to the mass of nucleon, which is 170 MeV [F4]. Hagedorn temperature identified as black-hole temperature should be higher than this temperature. The experimental estimate for the hadronic Hagedorn temperature from the transversal momentum distribution of baryons is $\simeq 160$ MeV. On the other hand, according to the estimates of hep-ph/0006020 the values of Hagedorn temperatures for mesons and baryons are $T_H(M) = 195$ MeV and $T_H(B) = 141$ MeV respectively.

D-dimensional bosonic string model for hadrons gives for the mesonic Hagedorn temperature the expression [70]

$$T_H = \frac{\sqrt{6}}{2\pi(D-2)\alpha'} , \qquad (6.6.9)$$

For a string in $D = 4$-dimensional space-time and for the value $\alpha' \sim 1\ \mathrm{GeV}^{-2}$ of Regge slope, this would give $T_H = 195$ MeV, which is slightly larger than the freezing out temperature as it indeed should be, and in an excellent agreement with the experimental value of [71]. It deserves to be noticed that in the model for fireball as a dual 10-D black-hole the rough estimate for the temperature of color glass condensate becomes too low by a factor 1/8 [69]. In light of this I would not yet rush to conclude that the fireball is actually a 10-dimensional black hole.

Note that the baryonic Hagedorn temperature is smaller than mesonic one by a factor of about $\sqrt{2}$. According to [71] this could be qualitatively understood from the fact that the number of degrees of freedom is larger so that the effective value of D in the mesonic formula is larger. $D_{eff} = 6$ would give $T_H = 138$ MeV to be compared with $T_H(B) = 141$ MeV. On the other hand, TGD based model for hadronic masses [F4] assumes that quarks feed their color fluxes to $k = 107$ space-time sheets. For mesons there are two color flux tubes and for baryons three. Using the same logic as in [71], one would have $D_{eff}(B)/D_{eff}(M) = 3/2$. This predicts $T_H(B) = 159$ MeV to be compared with 160 MeV deduced from the distribution of transversal momenta in p-p collisions.

6.6.4 Are ordinary black-holes replaced with super-symplectic black-holes in TGD Universe?

Some variants of super string model predict the production of small black-holes at LHC. I have never taken this idea seriously but in a well-defined sense TGD predicts black-holes associated with super-symplectic gravitons with strong gravitational constant defined by the hadronic string tension. The proposal is that super-symplectic black-holes have been already seen in Hera, RHIC, and the strange cosmic ray events.

Baryonic super-symplectic black-holes of the ordinary M_{107} hadron physics would have mass 934.2 MeV, very near to proton mass. The mass of their M_{89} counterparts would be 512 times higher, about 478 GeV. "Ionization energy" for Pomeron, the structure formed by valence quarks connected by color bonds separating from the space-time sheet of super-symplectic black-hole in the production process, corresponds to the total quark mass and is about 170 MeV for ordinary proton and 87 GeV for M_{89} proton. This kind of picture about black-hole formation expected to occur in LHC differs from the stringy picture since a fusion of the hadronic mini black-holes to a larger black-hole is in question.

An interesting question is whether the ultrahigh energy cosmic rays having energies larger than the GZK cut-off of 5×10^{10} GeV are baryons, which have lost their valence quarks in a collision with hadron and therefore have no interactions with the microwave background so that they are able to propagate through long distances.

In neutron stars the hadronic space-time sheets could form a gigantic super-symplectic black-hole and ordinary black-holes would be naturally replaced with super-symplectic black-holes in TGD framework (only a small part of black-hole interior metric is representable as an induced metric). This obviously means a profound difference between TGD and string models.

1. Hawking-Bekenstein black-hole entropy would be replaced with its p-adic counterpart given by

$$S_p = (\frac{M}{m(CP_2)})^2 \times log(p) \ , \tag{6.6.10}$$

   where $m(CP_2)$ is CP_2 mass, which is roughly $10^{-3.5}$ times Planck mass. M is the contribution of p-adic thermodynamics to the mass. This contribution is extremely small for gauge bosons but for fermions and super-symplectic particles it gives the entire mass.

2. If p-adic length scale hypothesis $p \simeq 2^k$ holds true, one obtains

$$S_p = klog(2) \times (\frac{M}{m(CP_2)})^2, \tag{6.6.11}$$

   $m(CP_2) = \hbar_0/R$, R the "radius" of CP_2, corresponds to the standard value of $\hbar_0$ for all values of $\hbar$ so that the entropy does not depend on $\hbar$ for given mass.

3. Hawking-Bekenstein area law gives in the case of Schwartschild black-hole

$$S = \frac{A}{4\hbar G} \times \hbar = \frac{\pi G M^2}{\hbar} \ . \tag{6.6.12}$$

   Entropy is inversely proportional to $\hbar$. For the p-adic variant of the law Planck mass is replaced with CP_2 mass and $klog(2) \simeq log(p)$ appears as an additional factor and the dependence on $\hbar$

is absent. Area law is obtained in the case of elementary particles if k is prime and wormhole throats have M^4 radius given by p-adic length scale $L(k) = \sqrt{k}R$ which is exponentially smaller than L_p. For macroscopic super-symplectic black-holes modified area law results if the radius of the large wormhole throat equals to Schwartschild radius. Schwartschild radius is indeed natural: in [D3] I have shown that a simple deformation of the Schwartschild exterior metric to a metric representing rotating star transforms Schwartschild horizon to a light-like 3-surface at which the signature of the induced metric is transformed from Minkowskian to Euclidian.

4. The formula for the gravitational Planck constant appearing in the Bohr quantization of planetary orbits and characterizing the gravitational field body mediating gravitational interaction between masses M and m [D6] reads as

$$\hbar_{gr} = \frac{GMm}{v_0}\hbar_0 \quad .$$

$v_0 = 2^{-11}$ is the preferred value of v_0. One could argue that the value of gravitational Planck constant is such that the Compton length $\hbar_{gr}/M$ of the black-hole equals to its Schwartshild radius $r_S = 2GM$. This would give

$$\hbar_{gr} = \frac{GM^2}{v_0}\hbar_0 \ , \quad v_0 = 1/2 \quad . \tag{6.6.13}$$

Black hole entropy would be equal to $S = 2\pi$, which is not nice result from the point of view of number theoretical universality. The requirement that $\hbar_{gr}$ is a ratio of ruler-and-compass integers expressible as a product of distinct Fermat primes (only four of them are known) and power of 2 would quantize the mass spectrum of black hole [D6]. Even without this constraint M^2 is integer valued using p-adic mass squared unit and if p-adic length scale hypothesis holds true this unit is in an excellent approximation power of two.

5. The gravitational collapse of a star would correspond to a process in which the initial value of v_0 , say $v_0 = 2^{-11}$, increases in a stepwise manner to some value $v_0 \leq 1/2$. For a supernova with solar mass with radius of 9 km the final value of v_0 would be $v_0 = 1/6$. The star could have an onion like structure with largest values of v_0 at the core as suggested by the model of planetary system. Powers of two would be favored values of v_0. If the formula holds true also for Sun one obtains $1/v_0 = 3 \times 17 \times 2^{13}$ with 10 per cent error.

6. Black-hole evaporation could be seen as means for the super-symplectic black-hole to get rid of its electro-weak charges and fermion numbers (except right handed neutrino number) as the antiparticles of the emitted particles annihilate with the particles inside super-symplectic black-hole. This kind of minimally interacting state is a natural final state of star. Ideal super-symplectic black-hole would have only angular momentum and right handed neutrino number.

7. In TGD light-like partonic 3-surfaces are the fundamental objects and space-time interior defines only the classical correlates of quantum physics. The space-time sheet containing the highly entangled cosmic string might be separated from environment by a wormhole contact with size of black-hole horizon.

   This looks the most plausible option but one can of course ask whether the large partonic 3-surface defining the horizon of the black-hole actually contains all super-symplectic particles so that super-symplectic black-hole would be single gigantic super-symplectic parton. The interior of super-symplectic black-hole would be a space-like region of space-time, perhaps resulting as a large deformation of CP_2 type vacuum extremal. Black-hole sized wormhole contact would define a gauge boson like variant of the black-hole connecting two space-time sheets and getting its mass through Higgs mechanism. A good guess is that these states are extremely light.

6.6.5 Very cautious conclusions

The model for quark-gluon plasma in terms of valence quark space-time sheets separated from hadronic space-time sheets forming a color glass condensate relies on quantum criticality and implies gravitation like effects due to the presence of super-symplectic strong gravitons. At space-time level the change of the distances due to strong gravitation affects the metric so that the breaking of spherical symmetry is caused by gravitational interaction. TGD encourages to think that this mechanism is quite generally at work in the collisions of nuclei. One must take seriously the possibility that strong gravitation is present also in longer length scales (say biological), in particular in processes in which new space-time sheets are generated. Critical cosmology might provide a universal model for the emergence of a new space-time sheet.

The model supports TGD based early cosmology and quantum criticality. In standard physics framework the cosmology in question is not sensible since it would predict a large breaking of the Lorentz invariance, and would mean the breakdown of the entire conceptual framework underlying elementary particle physics. In TGD framework Lorentz invariance is not lost at the level of imbedding space, and the experiments provide support for the view about space-time as a surface and for the notion of many-sheeted space-time.

The attempts to understand later strange events reported by RHIC have led to a dramatic increase of understanding of TGD and allow to fuse together separate threads of TGD.

1. The description of RHIC events in terms of the formation of hadronic black hole and its evaporation seems to be also possible and essentially identical with description as a mini bang.

2. It took some time to realize that scaled down TGD inspired cosmology as a model for quark gluon plasma predicts a new phase identifiable as color glass condensate and still a couple of years to realize the proper interpretation of it in terms of super-symplectic bosons having no counterpart in QCD framework.

3. Also dark matter could be identified as a macroscopic quantum phase in which individual particles have complex conformal weights. This phase could be even responsible for the properties of living matter. There is also a connection with the dramatic findings suggesting that Planck constant for dark matter has a gigantic value.

4. Black holes and their scaled counterparts would not be merciless information destroyers in TGD Universe. The entanglement of particles in anyonic states having particle like integrity would make black hole like states ideal candidates for quantum computer like systems. One could even imagine that the galactic black hole is a highly tangled cosmic string in Hagedorn temperature performing quantum computations the complexity of which is totally out of reach of human intellect! Indeed, TGD inspired consciousness predicts that evolution leads to the increase of information and intelligence, and the evolution of stars should not form exception to this. Also the interpretation of black hole as consisting of dark matter follows from this picture.

Summarizing, it seems that thanks to some crucial experimental inputs the new physics predicted by TGD is becoming testable in laboratory.

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Chapter 7

TGD and Astrophysics

7.1 Introduction

The concept of 3-space in TGD is considerably more general than in the conventional theories. 3-space is not any more connected but can have arbitrary many disjoint components. Even macroscopic boundaries are allowed: macroscopic bodies are interpreted as 3-surfaces having outer boundary. There are strong indications that 3-space has a hierarchical fractal structure: 3-surfaces topologically condensed on 3-surfaces condensed on..., where topological condensation means that 'small' 3-surface is 'glued' to a larger 3-surface by connected sum operation.

The fundamental feature of the topological condensation is the generation of Kähler electric fields implied by the minimization of Kähler action: gravitational gauge fields are always accompanied by long range electro-weak gauge fields with Kähler charge, which in the astrophysical scales is apart from a small but non-vanishing numerical factor equal the mass of particle using Planck mass as unit. In shorter length scales the Kähler charge can be larger and reflects the development of long range Z^0 fields. Topological field quantization is a central concept: the presence of Kähler charge implies that 3-surface has outer boundary: the larger the charge the smaller the size of the 3-surface. This makes it possible to relate the size of the 3-surface (topological field quantum) to the Kähler charge of a typical particle in the condensate. The formation of macroscopic quantum systems, such as super conductors, corresponds to the formation of bonds between the boundaries of the neighboring topological field quanta. A possible astrophysical example is neutron star: join along boundaries bonds are formed between neutrons so that single giant nucleus results.

7.1.1 p-Adic length scale hypothesis and astrophysics

Various levels of the topological condensate obey effective p-adic topology and form p-adic hierarchy ($p_1 < p_2$ can condense on p_2). Physically interesting length scales should come as square roots of powers of 2: $L(k) \simeq 2^{\frac{k}{2}} l$, $l = 1.288 \cdot 10^4 \sqrt{G}$ and various considerations suggest that prime powers are especially interesting values of k. For astrophysical applications interesting prime values of n are: $n = 229, 233, 239, 241, 251, 257, 263...$ and it is of considerable interest to find whether these length scales correspond to astro-physically interesting length scales.

The combination of p-adic length scale hierarchy idea with the concepts of topological evaporation and condensation, join along boundaries bond and long ranged weak and color forces, is an exciting challenge. In this chapter these concepts are applied in astrophysical length scales. The identification of the prime power length scales as fundamental astrophysical length scales is proposed and the identification of the fundamental cosmological length scale identified by Einasto *et al* [16] as a p-adic length scale is proposed. One of the most interesting implications of p-adicity is the possibility of series of phase transitions changing the value of cosmological constant behaving as $\Lambda \propto 1/L^2(k)$ as a function of p-adic length scale characterizing the size of the space-time sheet.

7.1.2 Quantum criticality, hierarchy of dark matters, and dynamical $\hbar$

Quantum criticality is the basic characteristic of TGD Universe and quantum critical superconductors provide an excellent test bed to develop the ideas related to quantum criticality into a more concrete form.

Quantization of Planck constants and the generalization of the notion of imbedding space

The recent geometric interpretation for the quantization of Planck constants is based on Jones inclusions of hyper-finite factors of type II_1 [A9].

1. One can argue that different values of Planck constant correspond to imbedding space metrics involving scalings of M^4 *resp.* CP_2 parts of the metric deduced from the requirement that distances scale as $\hbar(CP_2)$ *resp.* $\hbar(M^4)$. Denoting the Planck constants by $\hbar(M^4) = n_a\hbar_0$ and $\hbar(CP_2) = n_b\hbar_0$, one has that covariant metric of M^4 is proportional to n_b^2 and covariant metric of CP_2 to n_a^2.

   This however leads to difficulties with the isometric gluing of CP_2 factors of different copies of H together. Kähler action is however invariant under over-all scaling of H metric so that one can scale it down by $1/n_a^2$ meaning that M^4 covariant metric is scaled by $(n_b/n_a)^2$ and CP_2 metric remains invariant and the difficulties in isometric gluing are avoided. This means that if one regards Planck constant as a mere conversion factor, the effective Planck constant scales as n_a/n_b.

   In Kähler action only the effective Planck constant $\hbar_{eff}/\hbar_0 = \hbar(M^4)/\hbar(CP_2)$ appears and by quantum classical correspondence same is true for Schödinger equation. Elementary particle mass spectrum is also invariant. Same applies to gravitational constant. The alternative assumption that M^4 Planck constant is proportional to n_b would imply invariance of Schrödinger equation but would not allow to explain Bohr quantization of planetary orbits and would to certain degree trivialize the theory.

2. M^4 and CP_2 Planck constants do not fully characterize a given sector $M^4_\pm \times CP_2$. Rather, the scaling factors of Planck constant given by the integer n characterizing the quantum phase $q = exp(i\pi/n)$ corresponds to the order of the maximal cyclic subgroup for the group $G \subset SU(2)$ characterizing the Jones inclusion $\mathcal{N} \subset \mathcal{M}$ of hyper-finite factors realized as subalgebras of the Clifford algebra of the "world of the classical worlds". This means that subfactor $\mathcal{N}$ gives rise to G-invariant configuration space spinors having interpretation as G-invariant fermionic states.

3. $G_b \subset SU(2) \subset SU(3)$ defines a covering of M^4_+ by CP_2 points and $G_a \subset SU(2) \subset SL(2,C)$ covering of CP_2 by M^4_+ points with fixed points defining orbifold singularities. Different sectors are glued together along CP_2 if G_b is same for them and along M^4_+ if G_a is same for them. The degrees of freedom lost by G-invariance in fermionic degrees of freedom are gained back since the discrete degrees of freedom provided by covering allow many-particle states formed from single particle states realized in G group algebra. Among other things these many-particle states make possible the notion of N-atom.

4. Phases with different values of scalings of M^4 and CP_2 Planck constants behave like dark matter with respect to each other in the sense that they do not have direct interactions except at criticality corresponding to a leakage between different sectors of imbedding space glued together along M^4 or CP_2 factors. In large $\hbar(M^4)$ phases various quantum time and length scales are scaled up which means macroscopic and macro-temporal quantum coherence. In particular, quantum energies associated with classical frequencies are scaled up by a factor n_a/n_b which is of special relevance for cyclotron energies and phonon energies (superconductivity). For large $\hbar(CP_2)$ the value of $\hbar_{eff}$ is small: this leads to interesting physics: in particular the binding energy scale of hydrogen atom increases by the factor $(n_b/n_a)^2$.

Preferred values of Planck constants

Number theoretic considerations favor the hypothesis that the integers corresponding to Fermat polygons constructible using only ruler and compass and given as products $n_F = 2^k \prod_s F_s$, where $F_s = 2^{2^s} + 1$ are distinct Fermat primes, are favored. The reason would be that quantum phase $q = exp(i\pi/n)$ is in this case expressible using only iterated square root operation by starting from rationals. The known Fermat primes correspond to $s = 0, 1, 2, 3, 4$ so that the hypothesis is very strong and predicts that p-adic length scales have satellite length scales given as multiples of n_F of fundamental p-adic length scale. $n_F = 2^{11}$ corresponds in TGD framework to a fundamental constant expressible as a combination of Kähler coupling strength, CP_2 radius and Planck length appearing in the expression for the tension of cosmic strings, and the powers of 2^{11} seem to be especially favored as values of n_a in living matter [M3].

How Planck constants are visible in Kähler action?

$\hbar(M^4)$ and $\hbar(CP_2)$ appear in the commutation and anticommutation relations of various superconformal algebras. Only the ratio of scalings of M^4 and CP_2 metrics appears in Kähler action. The most natural assumption at the level of hyper-octonion space $HO = M^8$ is that M^4 metric is proportional to n_b^2 and E^4 metric to n_a^2. For $H = M^4 \times CP_2$ the assumption that CP_2 metric is proportional to n_a^2 however leads to mathematical difficulties and to a rather weird looking prediction that CP_2 can have arbitrarily large size. Hence the most natural conclusion is that the scaling of CP_2 metric is universal [A9]. This is achieved elegantly by performing over-all scaling of scaled up H metric allowed by the invariance of Kähler action in this scaling so that a scaling of M^4 covraint metric by $(n_b/n_a)^2$ results and effective Planck constant as a mere conversion factor is scaled by n_a/n_b.

This implies that Kähler function through its dependence on n_a/n_b codes for radiative corrections to the classical action, which makes possible to consider the possibility that higher order radiative corrections to functional integral vanish as one might expect at quantum criticality. For a given p-adic length scale space-time sheets with all allowed values of Planck constants are possible. Hence the spectrum of quantum critical fluctuations could in the ideal case correspond to the spectrum of $\hbar$ coding for the scaled up values of Compton lengths and other quantal lengths and times. If so, large $\hbar$ phases could be crucial for understanding of quantum critical superconductors, in particular high T_c superconductors.

Phase transitions changing the level in dark matter hierarchy

The identification of the precise criterion characterizing dark matter phase is far from obvious. TGD actually suggests an infinite number of phases which are dark relative to each other in some sense and can transform to each other only via a phase transition which might be called de-coherence or its reversal and which should be also characterized precisely.

A possible solution of the problem comes from the general construction recipe for S-matrix. Fundamental vertices correspond to partonic 2-surfaces representing intersections of incoming and outgoing light-like partonic 3-surfaces.

1. If the characterization of the interaction vertices involves all points of partonic 2-surfaces, they must correspond to definite value of Planck constant and more precisely, definite groups G_a and G_b characterizing dark matter hierarchy. Particles of different phases could not appear in the same vertex and a phase transition changing the particles to each other analogous to a de-coherence would be necessary.

2. If transition amplitudes involve only a discrete set of common orbifold points of 2-surface belonging to different sectors then the phase transition between relatively dark matters can be described in terms of S-matrix. It seems that this option is the correct one. In fact, also propagators are essential for the interactions of visible and dark matter and since virtual elementary particles correspond at space-time level CP_2 type extremals with 4-dimensional CP_2 projection, they cannot leak between different sectors of imbedding space and therefore cannot mediate interactions between different levels of the dark matter hierarchy. This would suggest that the direct interactions between dark and ordinary matter are very weak.

   If the matrix elements for real-real partonic transitions involve all or at least a circle of the partonic 2-surface as stringy considerations suggest [C2], then one would have clear distinction between quantum phase transitions and ordinary quantum transitions. Of course, the fact that the points which correspond to zero of Riemann Zeta form only a small subset of points common to real partonic 2-surface and corresponding p-adic 2-surface, implies that the rate for phase transition is in general small. On the other hand, for the non-diagonal S-matrix elements for ordinary transitions would become very small by almost randomness caused by strong fluctuations and the rate for phase transition could begin to dominate.

Transition to large $\hbar$ phase and failure of perturbation theory

A further idea is that the transition to large $\hbar$ phase occurs when perturbation theory based on the expansion in terms of gauge coupling constant ceases to converge: Mother Nature would take care of the problems of theoretician. The transition to large $\hbar$ phase obviously reduces gauge coupling strength α so that higher orders in perturbation theory are reduced whereas the lowest order "classical" predictions remain unchanged. A possible quantitative formulation of the criterion is that maximal 2-particle gauge interaction strength parameterized as $Q_1Q_2\alpha$ satisfies the condition $Q_1Q_2\alpha \simeq 1$.

A justification for this picture would be that in non-perturbative phase large quantum fluctuations are present (as functional integral formalism suggests). At space-time level this would mean that space-time sheet is near to a non-deterministic vacuum extremal. At parton level this would mean that partonic surface contains large number of CP_2 orbifold points so that S-matrix elements for the phase transition becomes large. At certain critical value of coupling constant strength one expects that the transition amplitude for phase transition becomes very large.

Dark matter as large $\hbar$ phase

D. Da Rocha and Laurent Nottale have proposed that Schrödinger equation with Planck constant $\hbar$ replaced with what might be called gravitational Planck constant $\hbar_{gr} = \frac{GmM}{v_0}$ ($\hbar = c = 1$). v_0 is a velocity parameter having the value $v_0 = 144.7 \pm .7$ km/s giving $v_0/c = 4.6 \times 10^{-4}$. This is rather near to the peak orbital velocity of stars in galactic halos. Also subharmonics and harmonics of v_0 seem to appear. The support for the hypothesis coming from empirical data is impressive.

Nottale and Da Rocha believe that their Schrödinger equation results from a fractal hydrodynamics. Many-sheeted space-time however suggests astrophysical systems are not only quantum systems at larger space-time sheets but correspond to a gigantic value of gravitational Planck constant. The gravitational (ordinary) Schrödinger equation would provide a solution of the black hole collapse (IR catastrophe) problem encountered at the classical level. The resolution of the problem inspired by TGD inspired theory of living matter is that it is the dark matter at larger space-time sheets which is quantum coherent in the required time scale. Schrödinger equation need not be involved. Rather, Bohr orbitology could reflect the fact that dark matter is in anyonic phase and confined by charge fractionization at large partonic 2-surfaces with a gigantic value of Planck constant. These surfaces could have complex topologies involving flux tubes around planetary orbits connected by radial spokes to a spherical surface associated with Sun.

Prediction for the parameter v_0

TGD predicts correctly the value of the parameter v_0 assuming that cosmic strings and their decay remnants are responsible for the dark matter. The harmonics of v_0 can be understood as corresponding to perturbations replacing cosmic strings with their n-branched coverings so that tension becomes n^2-fold: much like the replacement of a closed orbit with an orbit closing only after n turns. $1/n$-subharmonic would result when a magnetic flux tube split into n disjoint magnetic flux tubes.

Also a heuristic formula for the dependence of v_0 on p-adic length scale can be deduced and predicts a logarithmic dependence on the p-adic length scale. This gives some flexibility so that the prediction of mass ratios following from ruler and compass quantum phases is not so deadly strong anymore. The planetary mass ratios can be produced with an accuracy better than 10 per cent assuming ruler and compass phases, and the dependence of v_0 on p-adic length scale characterizing the space-time sheets carrying the planet-Sun gravitational force might relate to the discrepancies.

Further predictions

The study of inclinations (tilt angles with respect to the Earth's orbital plane) leads to a concrete model for the quantum evolution of the planetary system. Only a stepwise breaking of the rotational symmetry and angular momentum Bohr rules plus Newton's equation (or geodesic equation) are needed, and gravitational Shrödinger equation holds true only inside flux quanta for the dark matter.

1. During pre-planetary period dark matter formed a quantum coherent state on the (Z^0) magnetic flux quanta (spherical cells or flux tubes). This made the flux quantum effectively a single rigid body with rotational degrees of freedom corresponding to a sphere or circle (full SO(3) or SO(2) symmetry).

2. In the case of spherical shells associated with inner planets the $SO(3) \rightarrow SO(2)$ symmetry breaking led to the generation of a flux tube with the inclination determined by m and j and a further symmetry breaking, kind of an astral traffic jam inside the flux tube, generated a planet moving inside flux tube. The semiclassical interpretation of the angular momentum algebra predicts the inclinations of the inner planets. The predicted (real) inclinations are 6 (7) resp. 2.6 (3.4) degrees for Mercury resp. Venus). The predicted (real) inclination of the Earth's spin axis is 24 (23.5) degrees.

3. The $v_0 \rightarrow v_0/5$ transition allowing to understand the radii of the outer planets in the model of Da Rocha and Nottale can be understood as resulting from the splitting of (Z^0) magnetic flux tube to five flux tubes representing Earth and outer planets except Pluto, whose orbital parameters indeed differ dramatically from those of other planets. The flux tube has a shape of a disk with a hole glued to the Earth's spherical flux shell.

   It is important to notice that effectively a multiplication $n \rightarrow 5n$ of the principal quantum number is in question. This allows to consider also alternative explanations. Perhaps external gravitational perturbations have kicked dark matter from the orbit or Earth to $n = 5k$, $k = 2, 3, ..., 7$ orbits: the fact that the tilt angles for Earth and all outer planets except Pluto are nearly the same, supports this explanation. Or perhaps there exist at least small amounts of dark matter at all orbits but visible matter is concentrated only around orbits containing some critical amount of dark matter and these orbits satisfy $n \ mod \ 5 = 0$ for some reason.

4. A remnant of the dark matter is still in a macroscopic quantum state at the flux quanta. It couples to photons as a quantum coherent state but the coupling is extremely small due to the gigantic value of $\hbar_{gr}$ scaling alpha by $\hbar/\hbar_{gr}$: hence the darkness.

   The rather amazing coincidences between basic bio-rhythms and the periods associated with the states of orbits in solar system suggest that the frequencies defined by the energy levels of the gravitational Schrödinger equation might entrain with various biological frequencies such as the cyclotron frequencies associated with the magnetic flux tubes. For instance, the period associated with $n = 1$ orbit in the case of Sun is 24 hours within experimental accuracy for v_0.

7.1.3 Dark matter as a source of long ranged weak and color fields

Long ranged classical electro-weak and color gauge fields are unavoidable in TGD framework. The smallness of the parity breaking effects in hadronic, nuclear, and atomic length scales does not however seem to allow long ranged electro-weak gauge fields. The problem disappears if long range classical electro-weak gauge fields are identified as space-time correlates for massless gauge fields created by dark matter. The identification explains chiral selection in living matter and unbroken $U(2)_{ew}$ invariance and free color in bio length scales become characteristics of living matter and of bio-chemistry and bio-nuclear physics. An attractive solution of the matter antimatter asymmetry is based on the identification of also antimatter as dark matter.

7.2 p-Adic length scale hypothesis at astrophysical and cosmological length scales

p-Adic length scale hierarchy gives quantitative contents for the idea about fractal many-sheeted cosmology and therefore deserves a brief discussion.

7.2.1 List of long p-adic length scales

There are not very many p-adic lengths scales $L(k)$ ($p \simeq 2^k$, k power of prime) between 1 meter and 10^{11} light years as the approximate density $\Psi(n) \simeq \frac{1}{ln(n)}$ of prime numbers as function of n shows. Therefore the length scale hypothesis is nontrivial and the attempt to identify physically the length scales is perhaps worth of the trouble although detailed identifications are not attempted in the following. If physics is indeed p-adic below length scale L_p at level p, one expects p-adic fractality, when length scale resolution is smaller than L_p. Length scales $L(k)$ coming as twin pairs corresponding to primes k and $k+2$ seem to define particularly interesting biological length scales. Therefore it is of interest look whether something similar might happen in astrophysical context. L_p is the infrared cutoff scale for p-adic field theory limit of TGD but the idea that quantum effects might be important in astrophysical length scales looks admittedly rather wild.

k	227	229	233	239	241
L_p/m	$2.3E+3$	$4.6E+3$	$1.9E+4$	$1.5E+5$	$3.0E+5$
k	251	257	263	269	271
L_p/m	$.96E+7$	$7.7E+7$	$6.0E+8$	$4.8E+9$	$.9E+10$
k	277	289	293	307	311
L_p/m	$7.7E+10$	$5.0E+12$	$2.0E+13$	$2.5E+15$	$1.0E+16$
k	313	317	329	331	337
L_p/ly	2.2	$5.4E+2$	$1.0E+3$	2.2E+3	$8.4E+3$
k	347	349	353	359	367
L_p/ly	$2.8E+5$	$5.6E+5$	$2.2E+6$	$1.8E+7$	$2.9E+8$
k	373	379			
L_p/ly	$2.2E+9$	$1.9E+10$			

Table 1. p-Adic length scales $L_p = 2^{(k-127)/2}L_{127}$, $p \simeq 2^k$, k prime, $L_{127} \equiv \sqrt{5+Y}\pi/m_e$, $Y \simeq .0317$ possibly relevant to astrophysics. The definition of the length scale involves an unknown factor r of order one and the requirement $L(151) \simeq 10^{-8}$ meters, the thickness of the cell membrane, implies that this factor is $r \simeq 1.1$.

The length scales can contain some overall factor r of order order one. If this factor is chosen so that the length scale $L(151)$ is the thickness of the cell membrane, one must multiply p-adic length scales of the table by a factor $r \simeq 1.1$ to obtain $\hat{L}(k) = r * L(k)$.

1. $L(227) \sim 2.3$ kilometers, $L(229) \sim 4.6$ kilometers (twin pair) and $L(233) = 19.0$ kilometers. It would be interesting to find whether these length scales could be identified as geo-physically important length scales or/and length scales relevant to the internal structure of stars or planets. $L(233)$ is the order of magnitude for the size of neutron star.

2. $L(239) \simeq 1.5E+5\ m$ and $L(241) \simeq 3.0E+5\ m$ form a twin pair and could represent geophysically/astrophysically interesting length scales.

3. $L(251) = .96E+7\ m$ and $L(257) = 7.7E+7\ m$. The radii of the planets are of this order of magnitude.

4. $L(263) = 6.0E+8\ m$ is of same order of magnitude as solar radius ($\sim 6.96E+8\ m$). Note that $\hat{L}(263) \simeq 6.6E+8$ m is considerably nearer to the solar radius. $L(269) \simeq 4.8E+9$ meters and $L(271) \simeq .9E+10$ meters form a twin pair. Titius-Bode law for planetary distances reads as $r = r_0 + r_1 2^n\ AU$, $r_0 = .4$ and $r_1 = .3$. A(stronomical) U(nit) corresponds to distance between Earth and Sun: $r_1 \simeq .3AU \simeq 4.5E+10m \sim 2^2 L(271)$ holds in a reasonable approximation. $2^2\hat{L}(271) \simeq 4.4E+10$ m is quite near to r_1! $L(271)$ is a member of twin pair and it might be that length scales corresponding to twin primes lead to approximate 2-adicity of the mass distribution. If primordial mass distribution is 2-adic and of form $((r-r_0)/r_1)^n$ it has peaks at $r - r_0 = r_1 2^k$ and Titius-Bode law is natural consequence. If this is the case then the planetary distance ratios might be universal!

5. For $k = 277, 289 = 17^2, 293, 307$, $L(k)$ varies between $7.7E+10\ m$ and about $2.5E+15\ m$. $L(277)$ is of same order as the distance from Earth to Sun. The size of the solar system is about $L(289)$. $L(311) \simeq 1.0\ ly$ and $L(313) \simeq 2.0\ ly$ form a twin pair. Could these distances have a tendency to appear as distances between binaries? Or could the distances have a tendency to come as powers $2^n L(313)$?

6. $L(329) \simeq 1.0E+3$ and $L(331) \simeq 2.0E+3$ light years form a twin pair. Sizes for the galactic nuclei are of this order of magnitude. The very powerful energy sources in the nuclei of the galaxies are associated with regions of this distance. A suggested explanation is black hole in

the region between the object and also TGD allows galactic black holes. $L(337) \simeq 8.4 \cdot 10^3$ light years corresponds to the size of the central region of the galaxy. $L(353) \simeq 2.2 \cdot 10^6$ light years corresponds to a typical size scale of the galaxy [18].

7. $L(367) \simeq 2.2 \cdot 10^8$ light years is same order of magnitude as the size of the large voids and perhaps corresponds to the length scale identified by Einasto.

7.2.2 p-Adic evolution of cosmological constant

One of the most fascinating outcomes of the new view about gravitational energy is the resolution of the most gigantic failure in the art of order magnitude estimates. The naive estimate for the cosmological constant predicted also by TGD is by a factor 10^{120} larger than its value deduced from the accelerated expansion of the Universe. The resolution comes naturally from the p-adic fractality predicting that cosmological constant is reduced by a factor of 2 in a step wise manner in phase transitions occurring at times $T(k) \propto 2^{k/2}$, which correspond to p-adic time scales. On the average $\Lambda(k)$ behaves as $1/a^2$, where a is the light-cone proper time. This predicts correctly the observed value of Λ.

p-Adic length scale hypothesis plus the detailed study of membrane like vacuum extremals lead to the hypothesis that cosmological constant depends on p-adic length scale $\Lambda/R^2 \propto 1/R^2L^2(k) \propto 2^{-k}$. Amazingly, the recent value of the cosmological constant suggested by the accelerated expansion of the Universe comes out as a correct prediction!

Cosmological expansion at a particular space-time sheet becomes a TGD counterpart for a sequence of periods of increasingly slow inflation which a reduction of Λ by a factor of 2 at each time when the size of space-time sheet exceeds a p-adic length scale. It must be however emphasized that Kähler action determines the classical dynamics and it is by no means clear that exponential expansion is involved. What certainly occurs is liberation of gravitational energy, which means that the difference of inertial energy densities for matter and antimatter is reduced in a phase transition like manner. Maybe the interpretation in terms of annihilation of matter and antimatter is appropriate. Perhaps particles with masses of order p-adic length scale become non-relativistic and annihilate to lighter particles, most naturally those corresponding to the next p-adic length scale.

7.2.3 Evidence for a new length scale in cosmology

There is evidence [16] for a cubic lattice structure in the length scale of the large cosmic voids containing matter near their boundaries. Single void having galaxies on its boundaries would be the basic unit of this structure. This means a characteristic length scale of order 1.2 Megaparsecs, which in light years makes $7.8E + 8$ light years. As noticed in the paper, these observations do not fit with the prediction of the cold dark matter scenarios predicting random distribution of galaxies and galaxy clusters at long length scales.

The first task is to find whether one could understand the length scale of order 1.2 Megaparsecs p-adically. In TGD, the cosmological evolution means the gradual emergence of longer and longer p-adic length scales, that is space-time sheets with size of order not too many p-adic length scales $L(p)$, where p is assumed to be near prime power of two by experience with the p-adic mass calculations: $p \simeq 2^k$, k power of prime. These regions (3-surfaces with outer boundaries!) do not expand any more but move like comoving particles in the expanding background (surface of larger p-adic prime).

There are not too many physically interesting p-adic primes near prime powers of two and the p-adic length scale associated with the prime $p \simeq 2^k$, $k = 367$ is $\hat{L}(367) \simeq 3.2E + 8$ light years, whereas the length scale $L(Einasto) = 7.8E + 8$ light years, deduced by Einasto *et al* is roughly *two times* this length scale. The two nearest length scales correspond to $p \simeq 2^k$, $k = 359$ with 16 times smaller length scale and $k = 373$ with 8 times larger length scale so that identification is unique. Therefore, it seems that p-adic length scale hypothesis might work even in the cosmological length scales.

The problem is to understand the origin of the lattice like structure. The least radical suggestion mentioned in [16] is that some kind of acoustic waves during the early cosmology have left their trace in the background and caused the periodicity. Also a new physics in the inflation period has been speculated.

A priori, one can consider in TGD framework two alternative scenarios for the origin of the lattice structure. Either the structure is created during the very early cosmology and during cosmic expansion its size has gradually increased to its recently measured value. Or the structure is created later. TGD inspired cosmology is based on the hypothesis that new p-adic length scales emerge in the topological condensate during the cosmic evolution. Therefore one can consider the possibility that the large voids are structures, which have appeared later rather than having been present all the time. Of course, nothing excludes the possibility that the voids have expanded until they have reached the critical p-adic size for which the expansion has ceased.

The mechanism creating lattice structure could be based on so called p-adic fractals and be a consequence of the effective p-adic topology rather than result from some delicate dynamical mechanism. Already the existence of the p-adic length scales implies one kind of fractality. There is however also a second kind of fractality associated with a given value of the p-adic prime p. This latter kind of fractality, p-adic fractality for short, might provide an explanation for the lattice like structures as the following argument suggests.

p-Adic fractality for the real mass density ρ_R means that the density can be regarded as a map

$$\rho_R = I^{-1} \circ \rho \circ I \ ,$$

where ρ is the p-adic valued mass density in p-adic space-time and I denotes the so called *canonical identification* ,

$$I : \sum_n x_n p^n \rightarrow \sum_n x_n p^{-n} \ ,$$

mapping p-adics to reals and inducing a map from real space-time region to p-adic space-time region. Thus, given a p-adically analytic mass density function ρ, the map $\rho_R = I \circ \rho \circ I^{-1}$ induces real density function ρ_R, which turns out to be a fractal as the numerical study of simple examples for small values of p shows.

This lattice structure of the p-adic fractals follows directly from the basic properties of the canonical identification mapping p-adics to reals. The point is that canonical identification in range $[0, p)$ for the real numbers induces discontinuities of the real density $\rho_R = I \circ \rho \circ I^{-1}$ at the points $x = k = 0, 1, ...p-1$. Same occurs in each interval $[n, n+1)$ at $x = n + kp$, k integer, which are mapped to the reals in the interval $[n, n+1)$ and so on ad infinitum. Therefore the powers $p^{k/2}$ of the basic length scale are preferred scales for this structure. In higher-dimensional case one clearly obtains lattice like structure for the discontinuities. The lattice structure is not quite obvious in the illustrations of the 2-dimensional p-adic fractals represented in the first part of the book. If one plots p-adic fractal of the planar coordinates using different colors for different value ranges of the function, the cubic structure becomes manifest and one obtains extremely beautiful pictures.

7.2.4 Sunspot cycle

To begin with, consider the general properties of the solar magnetic fields and Sunspots [19].

1. The average magnetic field of the Sun is dipole field and reverses its polarity with a period of eleven years. The actual solar magnetic field consists of the discrete elements (flux tubes) and all element sizes and magnetic field strengths seem to be possible. The appearance of the discrete structures is not in accordance with the naive magnetohydrodynamics expectations [19]: the stability argument (magnetic pressure plus the plasma pressure inside the flux tube equals to the plasma pressure outside the flux tube) gives a lower bound of about 0.1 T for the magnetic field of a stable flux tube and smaller field strengths have been observed.

2. The short time scales associated with the dynamics of the magnetic structures are not in accordance with the magnetohydrodynamics expectations [19]: in magnetohydrodynamics diffusion determines the time scale for the change of the magnetic fields and the time scale for changes in length scale L is of the order of $T \simeq L^2/\sigma$, where σ is the conductivity of the plasma. For the changes taking place in the length scale of Sun the time is of the order of $T \simeq 10^{10}$ years: dipole field changes its direction during a year! For Sunspots having typically the size of the order of $L \simeq 10^7\ m$, the corresponding time is of the order of $T \simeq 10^6$ years.

3. The appearance of the Sunspots is related to the change of the polarity of the Solar magnetic field. Sunspots appear first at latitudes ± 40 *degrees* and gradually the region, where new

Sunspots appear, drifts to the direction of the equator. Sunspot magnetic field is bipolar and the field strength is typically about 0.1 T. The magnetic pole is referred to as p or f pole depending on whether the pole in question precedes or follows in the solar rotation (the western pole is by definition the leading pole). The polarity of the leading spots is same (Hale-Nicholson law) for all Sunspots in a given hemisphere and for a given solar cycle. The polarity of the p spot is opposite for the two hemispheres and for two successive cycles. The opposite polarity of the southern and northern p spots guarantees the dipole field nature of the average magnetic field. The change of the polarity in the beginning of the solar cycle (implying the change of the polarity of the dipole field) is however not well understood in the present models.

4. Sunspots seem to be related to the convective motion of the matter. There is a net outward and inward flow of the matter with a velocity of order $\beta \simeq 10^{-5}$ at p and f poles of the Sunspot respectively so that Sunspots take part in the convection. There are also indications that the fibril like structures on the penumbra of p pole are convective rolls [19]. These features suggest that Sunspots are magnetized helical vortices.

5. The appearance of the Sunspots is accompanied by a reduction of the solar constant: a possible explanation is that part of the solar energy is stored as a kinetic energy of the fluid motion associated with the Sunspots and as a magnetic field energy [19].

7.2.5 Sunspots as helical vortices

TGD suggests an explanation of the discrete magnetic structures as a direct manifestation of the CP_2 geometry. The TGD inspired model for the Sunspot is motivated by the general ideas described earlier and by the basic features of Sunspots. For the reader's convenience only the general ideas are described and calculational details are left later.

1. In accordance with the ideas about the generation of hydrodynamical turbulence as spontaneous Z^0 magnetization, it is assumed that the structures of the solar magnetic field correspond to Z^0 magnetized domains, i.e. vortices of some kind.

2. The TGD based concept of the 3-space suggests strongly that vortices correspond to topological field quanta, that is 3-surfaces of a finite size and with outer boundary, glued to a background 3-space. The outer boundary corresponds to the critical radius for the imbedding of the Z^0 magnetic field created by the moving matter. The requirement that the critical radius of the magnetic flux tube is of the order of Sunspot size or smaller, implies that the values of the vacuum quantum numbers associated with the Sunspots must be considerably smaller than those associated with the background 3-space.

3. Also the background space is a carrier of a Z^0 magnetic field (which can be weak) and helical vortex interacts with this field by Z^0 magnetic dipole interaction, which explains the motion of the ends of the helical vortex in the Sunspot cycle.

4. The simplest (Z^0) magnetized domains are vortex like structures and Sunspots are identified as helical vortices, one of whose functions, besides maximizing Kähler function, is the convective transport of heat. This function explains why the ends of the Sunspot are at the surface of the Sun and why the main part of the structure is beneath the surface of the Sun, possibly at the bottom of the convective zone. It should be emphasized that Sunspots are not the only structures of this type: also smaller structures are possible and the radius of the vortex is determined by the value of the fractal quantum number m and magnetic quantum numbers. The small size of these structures however makes them invisible.

5. The velocity field of the vortex serves as a source of Z^0 magnetic field:

$$\nabla \times \bar{B}_Z = N K_Z \bar{v} \ , \tag{7.2.1}$$

where $N \equiv \rho_m/m_p$ denotes nucleon density and $K_Z = \epsilon_1 10^{-19} = g_Z/\sqrt{\epsilon_Z}$ describes the strength of the Z^0 force. By neutrino screening, the average Z^0 charge density is expected to be much smaller than the density of the nuclei. It has been assumed that neutrinos do not participate in the rotational motion so that nucleons serve effectively as the source of the Z^0 magnetic field. This means that ϵ_Z appearing in the formula refers to the Z^0 gauge flux coming from the 'previous' condensate level. For the condensate level at which the elementary particles feed their Z^0 charges, one has therefore $\epsilon_Z = 1$. At the astrophysical scales ϵ_1 is smaller than one.

6. The magnetic field of the Sunspot is generated, when the integers n_i change so that their ratio differs from the value $n_1/n_2 = \omega_1/\omega_2$ guaranteing the vanishing of the electromagnetic fields. This process implies that Z^0 magnetic line dipole becomes also an ordinary magnetic line dipole and therefore visible, when the ends of the vortex are at the surface of the Sun. This mechanism implies also that magnetic and Z^0 magnetic fields are parallel to each other.

7. Magnetohydrodynamic stability conditions are satisfied if the magnetic field of the Sunspot is parallel with the electric current so that the Lorentz force vanishes: $\nabla \times \bar{B} = \bar{v} \propto \bar{B}_{em}$ [19]. This condition holds true also for the Z^0 magnetic field. If the magnetic field is generated by changing the values of the magnetic quantum numbers n_1 and n_2, then Z^0 magnetic and magnetic fields are parallel so that also Z^0 magnetic and velocity fields are parallel:

$$\bar{B}^Z \propto \bar{v} \ . \tag{7.2.2}$$

Helical vortices are the simplest objects allowing this kind of structure. A more detailed model for the helical vortices is postponed to the last subsection.

7.2.6 A model for the Sunspot cycle

Consider now a simplified model of the Sunspot cycle in terms of the helical vortices.

1. Sunspots correspond to helical vortices, whose main part is parallel to the surface of the Sun and whose ends are vertical vortices. In accordance with the idea that 3-space is a hierarchical condensate of 3-surfaces of various sizes, it is assumed that helical vortices correspond to topological field quanta condensed to the background 3-space. Also the background 3-space is a carrier of Z^0 magnetic field B_Z, which might be identified as the "average" or "self consistent" magnetic field created by the other topological field quanta.

   Helical vortices possess a definite Z^0 magnetic moment $d\bar{\mu}_Z/dl$ per unit length in the direction of the vortex: magnetic moment is due to the rotational motion of the matter inside the helical vortices. Therefore the vortices interact with the average Z^0 magnetic field of the Sun by the usual dipole interaction. Observations suggests that the poles of the Sunspot behave like independent dynamical objects so that in the first approximation the constraint forces can be neglected the ends of the vortex and vortices suffer a force per unit length given as the gradient of the dipole interaction energy per unit length

$$\frac{d\bar{F}}{dl} = \nabla(\frac{d\bar{\mu}_Z}{dl} \cdot \bar{B}_Z) \ . \tag{7.2.3}$$

   At the beginning of the Sun spot cycle only the radial component of the magnetic field contributes to the force since p and f poles of the Sunspot are to a good approximation at the same latitude. The force is in the direction of the meridian. Since the sign of $d\bar{\mu}/dl$ is opposite for p and f poles they begin to move in opposite directions. The contribution of B_r to the force changes its sign at equator and this motivates the assumption that the p end of the Sunspots oscillates between the latitudes $+40$ and -40 degrees.

   The nice feature of the proposal is that the force is indeed in the right direction at the beginning of the solar cycle and the forces on p and f have opposite directions. The details of the force are not important for the estimate of the duration of solar cycle. It is the latitude at which the Sunspot formation begins, which depends on the detailed properties of the force.

2. The motion of poles and in particular, differential rotation of the Sun implies the stretching of the vortex. If the flow is incompressible the volume of the vortex remains constant (V_0) so that the area (S) of the vortex decreases as $1/L$ as function of the vortex length L:

$$L = L_0\frac{S_0}{S} \ . \tag{7.2.4}$$

   Typical initial values of S and L are $S_0 \simeq \pi \cdot 10^{12}\ m^2$ and $L_0 \simeq 10^7\ m$. The decrease of the cross sectional area implies that the Sunspot becomes invisible after having reached some critical radius.

3. After having reached a certain critical radius of the order of the radiation length $L_{rad} \simeq 3\cdot 10^4\ m$, vortex becomes unstable against pinch and splits to two pieces. The reason is that vortex must be cooler than its surroundings by the magnetic equilibrium conditions ($B^2/2 + nkT_{in} = nT_{out}$) and this is not possible if the radius of the vortex is too small since the radiation flux of the Sun destroys all temperature gradients in the length scales smaller than $L_{rad} \simeq 3 \cdot 10^4\ m$. The critical length of the vortex is therefore given by $L_f \sim L_0S_0/S_f \simeq 4 \cdot 10^{11}\ m$.

4. Since the stretching of the vortex results mainly from the differential rotation of the Sun (rotation period is $T_{rot} = 25\ d(ays)$ and $T_{rot} = 30\ d$ on poles and equator respectively). This means that the upper bound for the time required to achieve instability is of the order of $T_{cycle} \leq (L_f/R_{Sun})T_{rot} \simeq 4 \cdot 11$ years ($R_{Sun} \simeq 8 \cdot 10^8\ m$) and of the same order of magnitude as the period of the Sunspot cycle (recall that the naive magnetohydrodynamic estimate is about 10^{10} years!). The actual value is smaller since in the beginning of the cycle the effect of the differential rotation is considerably smaller than at the end of the cycle.

5. The stretched magnetized vortices give the dominant contribution to the average dipole field of the Sun and the entanglement of the dipole field lines resulting from the freezing of the magnetic field lines to differentially rotating matter corresponds to the stretching of the co-rotating vortices. The dipole nature of the average solar magnetic field requires that p type poles must have same polarity on the given hemisphere and that the polarities of p type poles are opposite for Southern and Northern hemispheres.

6. The vortices started from the latitude of 40 (-40) degrees achieve critical length at the latitude -40 (40) degrees begin to split to pieces. The resulting pieces achieve their equilibrium volume V_0 by increasing their transverse size from the critical size S_f to S_0 implying the increase of the radius by a factor of order $10^{3/2}$. The pieces are observed as new Sunspots and the gradual splitting starting from the end explains why the Sunspot active region proceeds gradually to the direction of equator. The mysterious reversal of p type polarity results from the opposite polarities of p poles at Northern and Southern hemispheres. This in turn implies the change of polarity of the solar magnetic field at each Sunspot cycle.

7. The energy needed to generate the magnetic field of the thickened vortex and the kinetic energy of the vortex motion is provided by the energy production in the interior of the Sun and the process explains the decrease of the Solar constant.

7.2.7 Helical vortex as a model for a magnetic flux tube

The detailed model of the magnetic flux tube as a helical vortex is based on the following physical picture.

1. The velocity field of the vortex serves as source of Z^0 magnetic field

$$\begin{aligned} \nabla \times \bar{B}^Z &= K_Z N\bar{v} \ , \\ K_Z &= -\frac{g_Z^2}{4\sqrt{\epsilon_Z}}\frac{A-Z}{A} \ . \end{aligned} \tag{7.2.5}$$

where $N \equiv \rho_m/m_p$ denotes nucleon density and K_Z describes the strength of Z^0 force. $\epsilon_1 \leq 1$ measures the relative strength of Z^0 and gravitational forces. For the gravitational interaction to dominate over Z^0 force the condition $\epsilon_Z > 10^{36}$ must hold true.

2. The magnetic field is generated, when the integers n_i change so that their ratio differs from the value $n_1/n_2 = \omega_1/\omega_2$ guaranteing electrovac property. This mechanism implies that magnetic and Z^0 magnetic fields are parallel to each other.

3. Magnetohydrodynamic stability conditions are satisfied if the magnetic field of the Sunspot is parallel with the electric current so that the Lorentz force vanishes: $\nabla \times \bar{B} = \bar{v} \propto \bar{B}_{em}$ [19]. If the magnetic field is generated by changing the values of the magnetic quantum numbers n_1 and n_2 then Z^0 magnetic and magnetic fields are parallel so that also Z^0 magnetic and velocity fields are parallel:

$$\bar{B}^Z \propto \bar{v} \ . \tag{7.2.6}$$

Helical vortices are the simplest objects allowing this kind of structure and cylindrical symmetry fixes the structure of the helical vortex almost completely.

The helical vortex possesses cylindrical symmetry in the sense that Z^0 magnetic field and velocity field have only z and ϕ components, which depend on the cylindrical coordinate ρ only, so that one has

$$\begin{aligned}
\Phi &= \omega_1 t + k_1 z + n_1\phi \ , \\
\Psi &= k\Phi = \omega_2 t + k_2 z + n_2\phi \ , \\
r &= tan(X(u)) \ , \\
X(u) &= ln((k+u)/C)\epsilon/2 \qquad u = u(\rho) \ , \\
\frac{\omega_2}{\omega_1} &= \frac{k_2}{k_1} = \frac{n_2}{n_1} \ .
\end{aligned} \tag{7.2.7}$$

The relationship between the velocity field and Z^0 magnetic field is dictated by the condition that matter flow serves as source of the Z^0 magnetic field.

The expressions for the non-vanishing components of the induced Z^0 magnetic field are given by

$$\begin{aligned}
B^Z_z &= -\frac{3}{(3+p)} n_1 sin^2 X \frac{\partial_\rho u}{\rho} \ , \\
B^Z_\phi &= -\frac{3}{(3+p)} k_z sin^2 X \frac{\partial_\rho u}{\rho} \ .
\end{aligned} \tag{7.2.8}$$

The requirement $\nabla \times \bar{B^Z} \propto \bar{B^Z}$ implies the condition

$$\frac{\partial_\rho B^Z_z}{\partial_\rho B^Z_\phi} = -\frac{B^Z_\phi}{\rho^2 B^Z_z} \ . \tag{7.2.9}$$

Using the explicit representation as an induced gauge field one obtains the differential equation

$$\begin{aligned}
\partial_\rho Y &= \frac{(1-(\rho/\rho_1)^2)}{(1+(\rho/\rho_1)^2)\rho} Y \\
Y &= sin^2 X \partial_\rho u \ , \\
\rho_1 &= \frac{n_1}{k^1_z} \ ,
\end{aligned} \tag{7.2.10}$$

which gives

$$\begin{aligned}
\partial_\rho Y &= \frac{(1-(\rho/\rho_1)^2)}{\rho(1+(\rho/\rho_1)^2)}Y \ , \\
Y &= sin^2 X \partial_\rho u \ .
\end{aligned} \tag{7.2.11}$$

By integrating this equation, one obtains

$$\begin{aligned}
B_z^Z &= -\frac{3}{(3+p)}\frac{n_1}{[(1+(\rho/\rho_1)^2)\rho_0^2]} \ , \\
B_\phi^Z &= \frac{k_z^1}{n_1}\rho^2 B_z^Z \ ,
\end{aligned} \tag{7.2.12}$$

where ρ_0 is an integration constant possessing the dimension of length.

The magnitudes of the velocity components β_z and β_ϕ are

$$\begin{aligned}
\beta_z &= \frac{2k_z^1}{NK_Z\rho_0^2}\frac{p}{2(3+p)}\frac{1}{(1+(\frac{\rho}{\rho_1})^2)} \ , \\
\beta_\phi &= \frac{\rho}{\rho_1}\beta_z \ .
\end{aligned} \tag{7.2.13}$$

Stability requirements for helical vortices [20] suggest that the value of n_1/k_z^1 is of the same order as critical radius. Notice that the vortex rotates like a rigid body near the z-axis and that the longitudinal velocity is also approximately constant near the z-axis.

The above described imbedding of the helical Z^0 magnetic field fails at the critical radius $\rho = \rho_{cr}$, which corresponds to the value of $r = \infty$. The expression for the critical radius in present case is obtained from the condition $r = \infty$ and reads as

$$\begin{aligned}
\rho_{cr} &= \rho_1\{exp[4(\frac{\rho_0}{\rho_1})^2(u_0+k)exp(-\frac{2\pi m}{\epsilon})X_0]-1\}^{1/2} \ , \\
&\simeq 2\rho_0 exp(-\frac{m\pi}{\epsilon})[(u_0+k)X_0]^{1/2} \ , \\
X_0 &= \frac{(2+\epsilon^2)exp(\frac{\pi}{\epsilon})+\epsilon^2}{1+\epsilon^2} \ ,
\end{aligned} \tag{7.2.14}$$

where it has been assumed that the value of the exponent is small. It will shortly found that the assumption is physically well founded. Notice that the critical radius depends extremely sensitively on the value of the "fractal" quantum number m and that the critical radii are related by a power of a discrete scaling transformation in the approximation used.

If one requires that Z^0 magnetic flux is quantized with n_1 multiple of some integer n, one has simpler condition

$$\begin{aligned}
\frac{3}{3+p}2(u_0+k)exp(-2\pi m/\epsilon)X_0 &= \frac{1}{n} \ , \\
\rho_{cr} &= \rho_1\{exp[2\frac{\rho_0^2}{n\rho_1^2}]-1\}^{1/2} \ .
\end{aligned} \tag{7.2.15}$$

If one requires flux quantization without any conditions on n_1, one must assume $n = 1$.

Vortex carries also radial Z^0 electric field: the magnitude of this field is given by

$$|E^Z| = |B_\phi^Z|(\omega_1\rho/n_1) \ . \tag{7.2.16}$$

The parametrization $\omega_1 = \sqrt{\epsilon_Z}x$, $x \sim 1$ is expected to hold true for ω_1.

7.2.8 Estimates for the vacuum parameters of magnetic flux tube

Consider next the values of the various vacuum parameters appearing in the embedding of the helical vortex.

An estimate for the quantum number ω_1

From the requirement that gravitational interaction is stronger than Z^0 force in long length scales one obtains $\omega_1 \leq 1/R \sim 10^{-4} m_{Planck}$ and $\epsilon_Z > 10^{38}$. The other extreme correspond to the condensate level $n = n_Z$ with $\epsilon_Z(n_Z) \sim 10^{20}$. One must however remember that neutrinos are not expected to serve as the source of Z^0 magnetic field and therefore $\epsilon_Z(n-1)$ appears in the expression of the magnetic field at level n and at level n_Z the total unscreened nuclear charge serves therefore as the source of B_Z. Lorentz invariance implies that the value of k_z^1 is given by

$$k_z^1 \simeq \omega_1 \beta_z \ . \tag{7.2.17}$$

An estimate for the quantum number n_1

The requirement that angular momentum density is of correct order of magnitude gives an estimate for the value of the parameter n_1. The expression of the conserved angular momentum current in the z-direction is given by

$$J^\alpha = T^{\alpha\beta}\partial_\beta m^k m_{kl} j^l \ , \tag{7.2.18}$$

where j^k denotes the vector field associated with an infinitesimal rotation and $T^{\alpha\beta}$ denotes energy momentum tensor. For the angular momentum density one obtains in the cylindrical M^4 coordinates for X^4 the expression

$$\begin{aligned} J^t &= T^{t\phi}\rho^2 \ , \\ T^{\alpha\beta} &= \frac{1}{16\pi G} G^{\alpha\beta} \ , \end{aligned} \tag{7.2.19}$$

where the second equation is Einstein's equation.

Case a:

If the contribution of CP_2 curvature to the curvature tensor is not dominating the leading order contribution to $G^{t\phi} = R^{t\phi} - g^{t\phi}R/2$ comes from the non-vanishing of the metric component $g_{t\phi}$:

$$g_{t\phi} = s^{eff}_{\Phi\Phi}\omega_1 n_1 = -\frac{R^2}{4}(cos^2(X)(k+u)^2 + 1 - u^2)sin^2(X)\omega_1 n_1 \ , \tag{7.2.20}$$

and one obtains the order of magnitude estimate

$$J^t \simeq -T^{tt} g_{t\phi} \simeq \rho_m \frac{R^2}{4}\omega_1 n_1 \ . \tag{7.2.21}$$

In order to obtain a correct order of magnitude for the angular momentum density associated with rotational flow one must have

$$\frac{R^2}{4}\omega_1 n_1 \sim \rho\beta(\rho) \ , \tag{7.2.22}$$

which implies

$$\begin{aligned} n_1 &\simeq \frac{L}{R^2\omega_1}\beta \sim \frac{10^{19}}{\sqrt{\epsilon_Z}x}\frac{L}{R}\beta \ , \\ \omega_1 &\equiv x\sqrt{\epsilon_Z}m(proton) \ , \end{aligned} \tag{7.2.23}$$

where L and β are typical scale and velocity associated with the flow and $x \sim 1$ is expected to hold true. If L is taken to be the radius of the vortex ($L \sim 10^7\ m$) and $\beta_\phi \sim 10^{-5}$ the rotation velocity of the vortex, one obtains: $n_1 \sim \frac{10^{55}}{x\sqrt{\epsilon_Z}}$. If L is taken to be the radius of the Sun and β, the rotation velocity of the Sun the value of n_1 is about hundred times larger. The order of magnitude for E^Z is

$$E^Z \sim a\frac{B^Z}{\beta_{rot}} \ ,$$

with

$$a = x\sqrt{\epsilon_Z}Gm_p\omega_1 << 1 \ ,$$

and is consistent with the assumption that the density of Z^0 charge is much smaller than the density of the nucleons.

Case b:

If Z^0 field is strong as compared to the gravitational field, the dominating contribution to $G^{t\phi}$ comes from the contribution of the CP_2 curvature to $R^{t\phi}$ and is proportional to the quantity ${J^t}_\rho J^{\rho\phi}$: in this case the previous estimate doesn't hold anymore and one obtains the estimate

$$\frac{n_1}{\omega_1} \simeq \beta L \ . \tag{7.2.24}$$

Since Z^0 field is strong inside the Sunspots one must use this estimate for n_1/ω_1 and one obtains the estimate

$$E^Z \sim \frac{B^Z}{\beta_{rot}} \ .$$

The result would mean that the density of Z^0 charge is of same order of magnitude as the density of the nucleons and by the presence neutrino screening this is not possible. Therefore case 1) is closer to the actual physical situation.

An estimate for the radius ρ_0

An estimate for the radius ρ_0 is obtained by substituting the estimate of k_z to the general expression of β_z at z-axis and one obtains the condition

$$\begin{aligned} \rho_0 &\sim [10^{19}\frac{p}{(3+p)}\frac{1}{\sqrt{G}N\epsilon_1}]^{1/2} \\ &\sim (\frac{1}{\epsilon_1})^{1/2}10^{11}\ m \ , \\ \epsilon_1 &\equiv K_Z 10^{19} \ , \end{aligned} \tag{7.2.25}$$

where the estimate $N \sim 10^{30}/m^3$ for the nucleon density has been used.

An estimate for the fractal quantum number m

En estimate for the value of the fractal quantum number m is obtained from the condition that the exponent appearing in the expression of the critical radius is small:

$$4(\frac{\rho_0}{\rho_1})^2 exp(-2m\pi\epsilon)[(u_0+k)X_0] \ll 1 \ . \tag{7.2.26}$$

Since one has $\rho_0 \simeq \sqrt{1/\epsilon_1}10^{11}\ m$ and $\rho_1 \sim \rho_{cr} \sim 10^6\ m$, one obtains an order of magnitude estimate $exp(-2m\pi/\epsilon) \ll 10^{-10}\epsilon_1/(u_0+k)$ so that the value of m must be rather large unless the value of the parameter $u_0+k = u_0+n_2/n_1$ is very small or the value of ϵ_1 is sufficiently large: the value $\epsilon_1 \geq 10^5$ implies that m is of order 2: a rather natural looking value unlike the large values implied by $\epsilon - 1 \sim 1$.

Estimate for the magnetic field

If the magnetic field is generated by the change of n_1 so that the condition $\omega_1/\omega_2 = n_1/n_2$ ceases to hold true one obtains the following approximate expression for the magnetic field at the z-axis

$$B_z^{em} \simeq \frac{\Delta n_1(3+p)}{\rho_0^2} \ . \tag{7.2.27}$$

The requirement that the magnetic field is of the order of $B_{em} = 10^3\ Gauss$ gives the estimate $\delta n_1 \simeq 10^{36}/\epsilon_1$ so that the relative change of n_1 is given by $\Delta n_1/n_1 = 10^{-19}x\sqrt{\epsilon_Z}/\epsilon_1 << 1$ for alternative 1) in which n_1 is very large. The argument related to the destruction of the super fluidity by the generation of Z^0 magnetic fields suggests the range $\epsilon_Z \in (10^{20} - 10^{22})$ at the condensation level level n_Z, at which elementary particles feed their Z^0 gauge fluxes for ϵ_Z (recall that $1/\sqrt{\epsilon_Z(n)}$ tells which fraction of total nuclear Z^0 charge the unscreened Z^0 charge is at the condensate level n and therefore flows to level $n+1$ via the # throats located near the boundaries of level n surface). This number corresponds to $\epsilon_1(n_Z) = 10^{19}g_Z/\sqrt{\epsilon_Z} \in (10^8 - 10^9)$. Quite strong Z^0 magnetic fields are possible: the strength of the Z^0 magnetic field at the level $n = n_Z + 1$ is below $10^4\ Tesla$ for $\epsilon_Z(n_Z) = 10^{22}$ and $\rho_{cr} \sim 10^6\ m$!

7.3 Explanation for the high temperature of solar corona

The mysterious feature of the solar corona is its high temperature $T \sim 10^6\ K$, as compared with the temperature of the chromosphere of order $10^4\ K$ [19] (the book of Zirin provides excellent introduction to the physics of Sun). The temperature rises very rapidly to $10^6\ K$ at height $h \sim 2\cdot 10^6\ m$ from the surface of Sun. The problem is to identify the mechanism leading to the heating of the particles of the solar wind after leaving solar surface: no convincing mechanism has been identified and this suggests that many-sheeted space-time concept might be involved in an essential manner. Indeed, the high temperature matter in the solar corona can be interpreted as a dark matter leaked from the highly curved portions of magnetic flux tubes to the space-time sheets where it becomes visible.

7.3.1 Topological model for the magnetic field of Sun

The basic observation is that solar corona cannot behave like single homogenous object possessing high temperature $T \sim 10^6$ K: the effective black body temperature deduced from the net radiation flux is not larger than 7000 K [19] corresponding energy density is more than 10^{-9} times smaller than the energy density associated with T. This suggests the existence of local high temperature regions giving rise to characteristic spectral lines in X ray region serving as a signature of the high temperature.

It is also known that the dynamics of the solar atmosphere and convective zone is very strongly correlated with magnetic fields, which from Zeeman splitting are known to have typical magnitudes of order .3 Tesla [19]. Furthermore, only those stars which have convective zone, possess corona and the size and shape of corona varies during the sunspot cycle.

Also solar constant is found to vary during sunspot cycle, which is difficult to understand in the standard picture about solar energy transfer. Solar wind is known to be associated with the non-closed magnetic fields lines and with the coronal holes in which temperature is lower than in the surroundings. High temperature regions in corona in turn correspond to regions at which field lines tend to be tangential to the surface and temperature. This suggests that magnetic fields provide the basic mechanism of convective energy transfer and that magnetic fields somehow make it possible to heat the solar corona locally.

These considerations suggests that magnetic flux tubes realized as tube like space-time sheets having radius $\rho \geq \rho_0 = \sqrt{1/eB}$ provide a TGD based topological realization for the convective energy transfer. This hypothesis reduces the problem to microscopic level and rather precise quantitative predictions should become possible. Protons and electrons can topologically condense at the magnetic flux tubes and move along them. It is assumed that in good approximation all protons, electrons and also heavier elements are condensed at the magnetic flux tubes.

The magnetic field of the flux tube confines charged particles and in transversal degrees of freedom they behave quantum mechanically like 2-dimensional harmonic oscillators with wave functions localized around Landau orbits with radius of order $\sqrt{n}\rho_0$, $n = 0, 1, 2..$ whereas in longitudinal degrees of freedom they behave like free particles locally. If n is sufficiently large, classical description as continuous matter should become possible. In the classical description charged particles are confined around magnetic lines of force and rotate with frequency $\omega = eB/E$, where E is total relativistic energy. The radius of the orbit is $\rho = \beta/\omega$, where β is rotational velocity. For sufficiently small values of β the radius of orbit is so small that particle is confined inside the flux tube. The dominant component of velocity is along the direction of flux tube.

In magneto-hydrodynamical description the basic equations state the conservation of magnetic flux, of various particle numbers (electron and proton numbers for magnetic flux tubes and neutron and neutrino numbers for Z^0 magnetic flux tubes) and conservation of momentum and energy along the flow lines. Energy density contains the energy density σT^4 of from black body radiation, kinetic energy density $\rho v^2/2$ of the macroscopic motion, pressure contribution p and the density $B^2/2$ of the magnetic energy. Gravitation is assumed to couple to the size and shape of the flux tube rather than to individual particles inside the flux tube so that gravitational energy density does not contribute to energy conservation conditions. If the particles slow down somewhat as they approach to the highly curved portions of the flux tubes, the increase of the temperature along the flux tube is implied by the conservation of energy $\sigma T^4 + \rho v^2/2 \simeq constant$. This explains why the local temperature of the corona is higher than the temperature at the surface of Sun and why the temperature is lowest and streaming velocity highest at the coronal holes with non-closed magnetic field lines extending to interplanetary space. The leakage of the particles to other space-time sheets at the highly curved portions of the flux tubes could in turn cause local heating of the matter.

Since the particles entering the closed flux tubes have some kinetic energy and since most of them return to the convective zone, there must be a momentum transfer from particles to the flux tube and flux tube must receive momentum. In equilibrium this force and gravitational force affecting the shape and size of the entire flux tube cancel each other. This is nothing but a topological representation for the freezing of magnetic field lines to moving matter. In this picture it is possible to understand the mysterious looking ability of the solar prominences to defy the force of gravity. Solar wind corresponds to particles glued to open flux tubes or closed flux tubes formed via the recombination of flux lines in solar atmosphere and having velocity larger than the escape velocity.

The model predicts correctly the basic qualitative properties of the solar wind [19].

1. The highest velocity streams come from the coolest part of corona, coronal holes: these regions correspond to open magnetic field lines extending into interplanetary space. This follows from the energy conservation and from the fact that temperature is lower for coronal holes so that kinetic energy must be larger.

2. The velocity of the solar wind protons is found to decrease with the increasing density of electrons at the base of Corona [19]. By charge neutrality inside flux tubes also proton density is reduced and conservation law for energy requires the increase of the velocity of protons. Streaming velocity is also found to increase with the electron temperature at the base of the corona [19]. Assuming thermal equilibrium this means that the radiative contribution to energy is reduced so that kinetic energy density must increase.

If flux tube is closed, particles return to the convective zone and one can indeed speak about convective motion also in solar atmosphere. The confinement of radiative energy to the closed magnetic flux tubes (space-time sheets actually!) might explain why solar constant depends on the phase of the sunspot cycle being smallest at sunspot maximum when the number of closed field lines is maximum. Neutrinos and neutrons are expected to suffer topological condensation on Z^0 magnetic flux tubes and the obvious explanation for the solar neutrino deficit is that some fraction of neutrinos is confined to these tubes returns back to Sun. The reduction of the neutrino flux is possible even without absolute confinement inside flux tubes: already the dispersion of the neutrino flux caused by the change in the direction of motion during the travel inside the flux tube reduces neutrino flux from the solar core.

7.3.2 Quantitative formulation

Magnetic flux tubes are assumed to have fractal 'flux tubes inside flux tubes' structure and decompose ultimately into microscopically thin flux tubes. Furthermore that protons and electrons are assumed to suffer magnetic confinement inside these flux tubes. Classical rotational motion around field lines occurs with frequency $\omega = eB/m$ and the rotational velocity satisfies $\beta = \omega\rho$. For small values of rotational velocity the particle remains confined inside the flux tube. The observed Zeeman splitting suggests that B is of order .1 Tesla. Quantum mechanically the confined particle is essentially equivalent with a harmonic oscillator with frequency ω in transversal degrees of freedom and behaves like free particle in longitudinal degrees of freedom. $B \simeq .3$ Tesla gives in case of proton the estimate $\omega \sim 10^{-7}$ eV for the frequency ω serving as the energy unit of the harmonic oscillator in question. Clearly, quasi-continuous spectrum is in question. The width of the ground state Gaussian wave function is $\rho_0 = \sqrt{\frac{1}{eB}}$ giving $\rho_0 \sim 10^{-8}$ meters for $B \sim .3$ Tesla. This gives the constraint $\rho > \rho_0$ to the thickness of the flux tube.

Higher Landau levels correspond to the radii $\rho_n = \sqrt{n}\rho_0$, $n = 1, 2, ...$ with energy spectrum given by $E_{n,m} = (n + m/2)\omega$, with angular momentum quantum number m varying in the range $-2n \leq m \leq 2n$. Transversal excitations with energies up to thermal energy must be allowed and this allows excitations up to $n = 10^7$ and thermal stability against the transfer of proton to larger space-time sheets requires $\rho > 10^{-5}$ meters. Since rather large values of n are excited thermally, it is possible to treat the matter inside flux tubes as continuous matter obeying hydrodynamic equations and ordinary Boltzmann statistics (rather than behaving as degenerate Fermi gas). The dominant component of the velocity is along the flux tube. The requirement that the Compton wavelength of the thermal photon is smaller than ρ gives $\rho > 10^{-8}$ meters for $T \sim 10^2\ eV$.

The effective black body temperature for the radiation from corona determined from the entire energy flux is not larger than 7000 K and corresponding energy density is roughly a fraction 10^{-9} of black body radiation temperature associated with the real temperature of order $T \sim 10^6$ K. Near the solar surface the density of matter is roughly 10^9 times that in corona [19]. In the approximation that the matter density inside flux tubes is same in the corona and at the solar surface these observations suggest that the matter inside the magnetic flux tubes behaves as a dark matter and that the matter visible in the corona corresponds to a fraction 10^{-9} of dark matter leaked out from the magnetic flux tubes to space-time sheets where it becomes visible. This interpretation is consistent with the TGD based explanation of dark energy and dark matter in terms of magnetic energy of magnetic and Z^0 magnetic flux tubes and particles residing inside them (see the chapter "Cosmic Strings").

The particle density in the corona is of order $10^{14}/m^3$ particles [19]. This implies a density of order $10^{23}/m^3$ particles (protons dominate in the mass density) inside flux tubes in corona. The density of solar wind particles is roughly $10^6/m^3$ at the solar surface [19] and forms a fraction of order 10^{-17} of the density of matter at solar surface. If all solar wind particles are condensed at magnetic flux tubes, this means that only a fraction 10^{-17} of all magnetic flux tubes runs out of Sun! If flux tube structure is described as ordinary classical magnetic field one would say that most of magnetic energy resides in turbulent magnetic fields.

The basic equations of the model state the conservation of magnetic flux, particle number, energy and momentum. The requirement that the magnetic flux is conserved implies that the magnitude of BS, where S is the transverse area of the flux tube, is constant along the flux tube. Together with the conservation of particle number this gives the conditions

$$\begin{aligned} BS &= B_0 S_0 \ , \\ n_p v S &= n_p^0 v_0 S_0 \ . \end{aligned} \qquad (7.3.1)$$

Since the flux tubes turns back to the solar surface in corona, the vertical component of v is reduced at the corona whereas the tangential component increases by energy conservation. If the particle density inside the flux tubes were much smaller at the solar surface than in corona, the fraction of volume occupied by the magnetic flux tubes at solar surface would be larger than one so that the changes of ρ and v must be rather small.

The conservation of energy, assuming that gravitational force couples to the flux tube geometry rather than the matter inside flux tube, gives

$$\sigma T^4 + \frac{1}{2}\rho v^2 + \frac{1}{2}B^2 + p = constant \ . \tag{7.3.2}$$

Here one has $\sigma \simeq 51.95/2\pi^2 \sim 3$. The pressure term associated with matter is in a good approximation negligible as compared to the energy density of the kinetic energy since the thermal velocity of proton at corona is about $10^{-3-1/2}$. The dominating part in the energy density at solar surface corresponds to the density of kinetic energy which is roughly 10^2 times larger than the thermal energy density of photons at corona and 10^4 times larger than the density of the magnetic energy. If one assumes that the thickness of the flux tubes does not change, magnetic energy remains constant and one has $\rho v = \rho_0 v_0$, and energy conservation gives

$$\sigma\Delta(T^4) = -\frac{1}{2}\rho_0 v_0 \Delta v \ ,$$

which gives

$$\frac{\Delta v}{v_0} = -\frac{2\sigma\Delta(T^4)}{\rho_0 v_0^2} \ . \tag{7.3.3}$$

For $T = 10^2$ eV and $v_0 = 10^{-2}$ [19] and $\rho_0 = 10^{23} m_p/m^3$ this gives $|\Delta\rho/\rho| = |\Delta v/v_0| = 6 \cdot 10^{-2} \ll 1$ so that the scenario is internally consistent. The slowing down of the particles as they approach the highly curved portion of the flux tube inside corona is natural.

As such the matter inside flux tubes is invisible and the high temperature matter in the corona results from a partial leakage of the particles from the magnetic flux tubes to other space-time sheets. The leakage of a fraction 10^{-9} would be caused by the large centrifugal acceleration at the highly curved portion of the flux tube. This would also explain why coronal holes are cooler than other regions of the corona.

The conservation of momentum together with the assumption that (most) matter flowing around flux tube returns back to the Sun implies that the matter topologically condensed at the flux tube feeds momentum in the degrees of freedom characterizing the size and shape of the flux tube and this must give rise to over all cm motion of the flux tube. The net force acting on the flux tube is obtained by integrating the divergence of the energy momentum tensor over the entire flux tube. Assuming that the velocity of matter at the return end is not considerably reduced, the contributions from the two ends are roughly identical and the expression for the resulting force acting on the cm of the flux tube reads as

$$F \simeq 2\rho_0 v_0^2 A \ , \tag{7.3.4}$$

where A is the transverse area of the flux tube. Also gravitational force acts on the cm motion of the flux tube and in equilibrium the two forces must cancel each other.

$$GM(Sun)L\langle\frac{\rho}{(R(Sun)+h)^2}\rangle = \rho_0 v_0^2 \ , \tag{7.3.5}$$

where h is the height from the surface of Sun and brackets denote averaging along the length of the flux tube of length L.

It can quite well happen that the momentum feed is so large that equilibrium is not possible and flux tube rises gradually and, if recombination of the flux tube ends giving rise to a closed flux tube occurs, runs away. This effect is enhanced by the fact that at large values of distance from Sun, where gravitational force is weakest, the mass density of the flux tube is largest. From the dependence of the gravitational force on height h it is clear that the eruption should occur when the height of prominence is same order of magnitude as solar radius: solar prominences have indeed the mysterious looking property of being unstable against upwards rather than downwards perturbations.

7.4 A quantum model for the formation of astrophysical structures and dark matter?

D. Da Rocha and Laurent Nottale, the developer of Scale Relativity, have ended up with an highly interesting quantum theory like model for the evolution of astrophysical systems [30] (I am grateful for Victor Christianito for informing me about the article). In particular, this model applies to planetary orbits. I learned later that also A. Rubric and J. Rubric have proposed a Bohr model for planetary orbits [37] already 1998.

The model is simply Schrödinger equation with Planck constant $\hbar$ replaced with what might be called gravitational Planck constant

$$\hbar \quad \rightarrow \quad \hbar_{gr} = \frac{GmM}{v_0} \quad . \tag{7.4.1}$$

Here I have used units $\hbar = c = 1$. v_0 is a velocity parameter having the value $v_0 = 144.7 \pm .7$ km/s giving $v_0/c = 4.6 \times 10^{-4}$. The peak orbital velocity of stars in galactic halos is 142 ± 2 km/s whereas the average velocity is 156 ± 2 km/s. Also sub-harmonics and harmonics of v_0 seem to appear.

The model makes fascinating predictions which hold true. For instance, the radii of planetary orbits fit nicely with the prediction of the hydrogen atom like model. The inner solar system (planets up to Mars) corresponds to v_0 and outer solar system to $v_0/5$.

The predictions for the distribution of major axis and eccentrities have been tested successfully also for exoplanets. Also the periods of 3 planets around pulsar PSR B1257+12 fit with the predictions with a relative accuracy of few hours/per several months. Also predictions for the distribution of stars in the regions where morphogenesis occurs follow from the gravitational Schödinger equation.

What is important is that there are no free parameters besides v_0. In [30] a wide variety of astrophysical data is discussed and it seem that the model works and has already now made predictions which have been later verified. In the following I shall discuss Nottale's model from the point of view of TGD.

7.4.1 TGD prediction for the parameter v_0

One of the basic questions is the origin of the parameter v_0, which according to a rich amount of experimental data discussed in [30] seems to play a role of a constant of Nature. One of the first applications of cosmic strings in TGD sense was an explanation of the velocity spectrum of stars in the galactic halo in terms of dark matter which could consists of cosmic strings. Cosmic strings could be orthogonal to the galactic plane going through the nucleus (jets) or they could be in galactic plane in which case the strings and their decay products would explain dark matter assuming that the length of cosmic string inside a sphere of radius R is or has been roughly R [D4]. The predicted value of the string tension is determined by the CP_2 radius whose ratio to Planck length is fixed by electron mass via p-adic mass calculations. The resulting prediction for the v_0 is correct and provides a working model for the constant orbital velocity of stars in the galactic halo.

The parameter $v_0 \simeq 2^{-11}$, which has actually the dimension of velocity unless on puts $c = 1$, and also its harmonics and sub-harmonics appear in the scaling of $\hbar$. v_0 corresponds to the velocity of distant stars in the model of galactic dark matter. TGD allows to identify this parameter as the parameter

$$\begin{aligned} v_0 &= 2\sqrt{TG} = \sqrt{\frac{1}{2\alpha_K}}\sqrt{\frac{G}{R^2}} \ , \\ T &= \frac{1}{8\alpha_K}\frac{\hbar_0}{R^2} \ . \end{aligned} \tag{7.4.2}$$

Here T is the string tension of cosmic strings, R denotes the "radius" of CP_2 ($2R$ is the radius of geodesic sphere of CP_2). α_K is Kähler coupling strength, the basic coupling constant strength of TGD, whose evolution as a function of p-adic length scale is fixed by quantum criticality. The condition that G is invariant in the p-adic coupling constant evolution and number theoretical arguments predict

$$\begin{aligned} \alpha_K(p) &= k\frac{1}{log(p)+log(K)} \ , \\ K &= \frac{R^2}{\hbar_0 G} = 2\times 3\times 5\times 7\times 11\times 13\times 17\times 19\times 23 \ , \ k\simeq \pi/4 \ . \end{aligned} \tag{7.4.3}$$

The predicted value of v_0 depends logarithmically on the p-adic length scale and for $p \simeq 2^{127}-1$ (electron's p-adic length scale) one has $v_0 \simeq 2^{-11}$.

7.4.2 Model for planetary orbits without $v_0 \rightarrow v_0/5$ scaling

Also harmonics and sub-harmonics of v_0 appear in the model of Nottale and Da Rocha. For instance, the outer planets (Jupiter, Saturn,...) correspond to $v_0/5$ whereas inner planets correspond to v_0. Quite generally, it is found that the values seem to come as harmonics and sub-harmonics of v_0: $v_n = nv_0$ and v_0/n, and the argument [30] is that the different values of n relate to fractality. This scaling is not necessary for the planetary orbits in TGD based model.

Effectively a multiplication $n \rightarrow 5n$ of the principal quantum number is in question in the case of outer planets. If one accepts the interpretation that visible matter has concentrated around dark matter, which is in macroscopic quantum phase around Bohr orbits, this allows to consider also the possibility that $\hbar_{gr}$ has the same value for all planets.

1. Some gravitational perturbation has kicked dark matter from the region of the asteroid belt to $n \simeq 5k$, $k = 2,..,6$, orbits. The best fit is obtained by using values of n deviating somewhat from multiples of 5 which suggests that the scaling of v_0 is not needed. Gravitational perturbations might have caused the same for the visible matter. The fact that the tilt angles of Earth and outer planets other than Pluto are nearly the same suggests that the orbits of these planets might be an outcome of some violent quantum process for dark matter preserving the orbital plane in a good approximation. Pluto might in turn have experienced some violent collision changing its orbital plane.

2. There could exist at least small amounts of dark matter at all orbits but visible matter is concentrated only around orbits containing some critical amount of dark matter.

	Exp.	T-B	Bohr_1	Bohr_2
Planet	R/R_M	R/R_M	$[n, R/R_M]$	$[n, R/R_M]$
Mercury	1	1	[3, 1]	
Venus	1.89	1.75	[4, 1.8]	
Earth	2.6	2.5	[5, 2.8]	
Mars	3.9	4	[6, 4]	
Asteroids	6.1-8.7	7	[(7, 8, 9), (5.4, 7.1, 9)]	
Jupiter	13.7	13	[11, 13.4]	[2×5,11.1]
Saturn	25.0	25	[3×5, 25]	[3×5, 25]
Uranus	51.5	49	[22, 53.8]	[4×5,44.4]
Neptune	78.9	97	[27 , 81]	[5×5, 69.4]
Pluto	105.2	97	[31, 106.7]	[6×5,100]

Table 1. The table represents the experimental average orbital radii of planets, the predictions of Titius-Bode law (note the failure for Neptune), and the predictions of Bohr orbit model assuming a) that the principal quantum number n corresponds to best possible fit, b) the scaling $v_0 \rightarrow v_0/5$ for outer planets. Option a) gives the best fit with errors being considerably smaller than the maximal error $|\Delta R|/R \simeq 1/n$ except for Uranus. R_M denotes the orbital radius of Mercury. T-B refers to Titius-Bode law.

How to understand the harmonics and sub-harmonics of v_0 in TGD framework?

Also harmonics and sub-harmonics of v_0 appear in the model of Nottale and Da Rocha. In particular, the outer planets (Jupiter, Saturn,...) correspond to $v_0/5$ whereas inner planets correspond to v_0 in this model. As already found, TGD allows also an alternative explanation.

Quite generally, it is found that the values seem to come as harmonics and sub-harmonics of v_0: $v_n = nv_0$ and v_0/n, and the argument [30] is that the different values of n relate to fractality. This quantization is a challenge for TGD since v_0 certainly defines a fundamental constant in TGD Universe.

1. Consider first the harmonics of v_0. Besides cosmic strings of type $X^2 \times S^2 \subset M^4 \times CP_2$ one can consider also deformations of these strings defining their multiple coverings so that the deformation is n-valued as a function of S^2-coordinates (Θ, Φ) and the projection to S^2 is thus an $n \rightarrow 1$ map. The solutions are higher dimensional analogs of originally closed orbits which after perturbation close only after n turns. This kind of surfaces emerge in the TGD inspired model of quantum Hall effect naturally [E9] and $n \rightarrow \infty$ limit has an interpretation as an approach to chaos [G2].

   Using the coordinates (x, y, θ, ϕ) of $X^2 \times S^2$ and coordinates m^k for M^4 of the unperturbed solution the space-time surface the deformation can be expressed as

$$\begin{aligned} m^k &= m^k(x,y,\theta,\phi) \ , \\ (\Theta,\Phi) &= (\theta, n\phi) \ . \end{aligned} \tag{7.4.4}$$

   The value of the string tension would be indeed n^2-fold in the first approximation since the induced Kähler form defining the Kähler magnetic field would be $J_{\theta\phi} = nsin(\Theta)$ and one would have $v_n = nv_0$. At the limit $m^k = m^k(x, y)$ different branches for these solutions collapse together.

2. Consider next how sub-harmonics appear in TGD framework. Cosmic strings are predicted to decay to magnetic flux tube structures by absolute minimization of Kähler action. The Kähler magnetic flux $\Phi = BS$ is conserved in the process but the thickness of the M^4 projection of the cosmic string increases field strength is reduced. This means that string tension, which is proportional to B^2S, is reduced (so that also Kähler action is reduced). The fact that space-time surface is Bohr orbit in generalized sense means that the reduced string tension (magnetic energy per unit length) is quantized.

The task is to guess how the quantization occurs. There are two options.

1. The simplest explanation for the reduction of v_0 is based on the decay of a flux tube resembling a disk with a hole to n identical flux tubes so that $v_0 \rightarrow v_0/n$ results for the resulting flux tubes. It turns out that this mechanism is favored and explains elegantly the value of $\hbar_{gr}$ for outer planetary system. One can also consider small-p p-adicity so that n would be prime.

2. Second explanation is more intricate. Consider a magnetic flux tube. Since magnetic flux is quantized, the magnetic field strengths are quantized in integer multiples of basic strength: $B = nB_0$ and would rather naturally correspond to the multiple coverings of the original magnetic flux tube with magnetic energy quantized in multiples of n^2. The idea is to require internal consistency in the sense that the allowed reduced field strengths are such that the spectrum associated with B_0 is contained to the spectrum associated with the quantized field strengths $B_1 > B_0$. This would allow only field strengths $B = B_S/n^2$, where B_S denotes the field strength of the fundamental cosmic string and one would have $v_n = v_0/n$. Flux conservation requires that the area of the flux tube scales as n^2.

Sub-harmonics might appear in the outer planetary system and there are indications for the higher harmonics below the inner planetary system [30]: for instance, solar radius corresponds to $n = 1$ orbital for $v_3 = 3v_0$. This would suggest that Sun and also planets have an onion like structure with highest harmonics of v_0 and strongest string tensions appearing in the solar core and highest sub-harmonics appearing in the outer regions. If the matter results as decay remnants of cosmic strings this means that the mass density inside Sun should correlate strongly with the local value of n characterizing the multiple covering of cosmic strings.

One can ask whether the very process of the formation of the structures could have excited the higher values of n just like closed orbits in a perturbed system become closed only after n turns. The energy density of the cosmic string is about one Planck mass per $\sim 10^7$ Planck lengths so that $n > 1$ excitation increasing this density by a factor of n^2 is obviously impossible except under the primordial cosmic string dominated period of cosmology during which the net inertial energy density must have vanished. The structure of the future solar system would have been dictated already during the primordial phase of cosmology when negative energy cosmic string suffered a time reflection to positive energy cosmic strings.

Nottale equation is consistent with the TGD based model for dark matter

TGD allows two models of dark matter. The first one is spherically symmetric and the second one cylindrically symmetric. The first thing to do is to check whether these models are consistent with the gravitational Schödinger equation/Bohr quantization.

1. Spherically symmetric model for the dark matter

The following argument based on Bohr orbit quantization demonstrates that this is indeed the case for the spherically symmetric model for dark matter. The argument generalizes in a trivial manner to the cylindrically symmetric case.

1. The gravitational potential energy $V(r)$ for a mass distribution $M(r) = xTr$ (T denotes string tension) is given by

$$V(r) = Gm\int_r^{R_0} \frac{M(r)}{r^2}dr = GmxTlog(\frac{r}{R_0}) \ . \tag{7.4.5}$$

   Here R_0 corresponds to a large radius so that the potential is negative as it should in the region where binding energy is negative.

2. The Newton equation $\frac{mv^2}{r} = \frac{GmxT}{r}$ for circular orbits gives

$$v = xGT \ . \tag{7.4.6}$$

3. Bohr quantization condition for angular momentum by replacing $\hbar$ with $\hbar_{gr}$ reads as $mvr = n\hbar_{gr}$ and gives

$$\begin{aligned} r_n &= \frac{n\hbar_{gr}}{mv} = nr_1 \ , \\ r_1 &= \frac{GM}{vv_0} \ . \end{aligned} \tag{7.4.7}$$

   Here v is rather near to v_0.

4. Bound state energies are given by

$$E_n = \frac{mv^2}{2} - xTlog(\frac{r_1}{R_0}) + xTlog(n) \ . \tag{7.4.8}$$

   The energies depend only weakly on the radius of the orbit.

5. The centrifugal potential $l(l+1)/r^2$ in the Schrödinger equation is negligible as compared to the potential term at large distances so that one expects that degeneracies of orbits with small values of l do not depend on the radius. This would mean that each orbit is occupied with same probability irrespective of value of its radius. If the mass distribution for the starts does not depend on r, the number of stars rotating around galactic nucleus is simply the number of orbits inside sphere of radius R and thus given by $N(R) \propto R/r_0$ so that one has $M(R) \propto R$. Hence the model is self consistent in the sense that one can regard the orbiting stars as remnants of cosmic strings and thus obeying same mass distribution.

2. Cylindrically symmetric model for the galactic dark matter

TGD allows also a model of the dark matter based on cylindrical symmetry. In this case the dark matter would correspond to the mass of a cosmic string orthogonal to the galactic plane and traversing through the galactic nucleus. The string tension would the one predicted by TGD. In the directions orthogonal to the plane of galaxy the motion would be free motion so that the orbits would be helical, and this should make it possible to test the model. The quantization of radii of the orbits would be exactly the same as in the spherically symmetric model. Also the quantization of inclinations predicted by the spherically symmetric model could serve as a sensitive test. In this kind of situation general theory of relativity would predict only an angle deficit giving rise to a lens effect. TGD predicts a Newtonian $1/\rho$ potential in a good approximation.

Spiral galaxies are accompanied by jets orthogonal to the galactic plane and a good guess is that they are associated with the cosmic strings. The two models need not exclude each other. The vision about astrophysical structures as pearls of a fractal necklace would suggest that the visible matter has resulted in the decay of cosmic strings originally linked around the cosmic string going through the galactic plane and creating $M(R) \propto R$ for the density of the visible matter in the galactic bulge. The finding that galaxies are organized along linear structures [22] fits nicely with this picture.

3. MOND and TGD

TGD based model explains also the MOND (Modified Newton Dynamics) model of Milgrom [38] for the dark matter. Instead of dark matter the model assumes a modification of Newton's laws. The model is based on the observation that the transition to a constant velocity spectrum seems in the galactic halos seems to occur at a constant value of the stellar acceleration equal to $a_0 \simeq 10^{-11}g$, where g is the gravitational acceleration at the Earth. MOND theory assumes that Newtonian laws are modified below a_0.

The explanation relies on Bohr quantization. Since the stellar radii in the halo are quantized in integer multiples of a basic radius and since also rotation velocity v_0 is constant, the values of the acceleration are quantized as $a(n) = v_0^2/r(n)$ and a_0 correspond to the radius $r(n)$ of the smallest Bohr orbit for which the velocity is still constant. For larger orbital radii the acceleration would indeed be below a_0. a_0 would correspond to the distance above which the density of the visible matter does not appreciably perturb the gravitational potential of the straight string. This of course requires that gravitational potential is that given by Newton's theory and is indeed allowed by TGD.

7.4.3 The interpretation of $\hbar_{gr}$ and pre-planetary period

$\hbar_{gr}$ could corresponds to a unit of angular momentum for quantum coherent states at magnetic flux tubes or walls containing macroscopic quantum states. Quantitative estimate demonstrates that $\hbar_{gr}$ for astrophysical objects cannot correspond to spin angular momentum. For Sun-Earth system one would have $\hbar_{gr} \simeq 10^{77}\hbar$. This amount of angular momentum realized as a mere spin would require 10^{77} particles! Hence the only possible interpretation is as a unit of orbital angular momentum. The linear dependence of $\hbar_{gr}$ on m is consistent with the additivity of angular momenta in the fusion of magnetic flux tubes to larger units if the angular momentum associated with the tubes is proportional to both m and M.

Just as the gravitational acceleration is a more natural concept than gravitational force, also $\hbar_{gr}/m = GM/v_0$ could be more natural unit than $\hbar_{gr}$. It would define a universal unit for the circulation $\oint v \cdot dl$, which is apart from $1/m$-factor equal to the phase integral $\oint p_\phi d\phi$ appearing in Bohr rules for angular momentum. The circulation could be associated with the flow associated with outer boundaries of magnetic flux tubes surrounding the orbit of mass m around the central mass $M \gg m$ and defining light like 3-D CDs analogous to black hole horizons.

The expression of $\hbar_{gr}$ depends on masses M and m and can apply only in space-time regions carrying information about the space-time sheets of M and and the orbit of m. Quantum gravitational holography suggests that the formula applies at 3-D light like causal determinant (CD) X_l^3 defined by the wormhole contacts gluing the space-time sheet X_l^3 of the planet to that of Sun. More generally, X_l^3 could be the space-time sheet containing the planet, most naturally the magnetic flux tube surrounding the orbit of the planet and possibly containing dark matter in super-conducting state. This would give a precise meaning for $\hbar_{gr}$ and explain why $\hbar_{gr}$ does not depend on the masses of other planets.

The simplest option consistent with the quantization rules and with the explanatory role of magnetic flux structures is perhaps the following one.

1. X_l^3 is a torus like surface around the orbit of the planet containing delocalized dark matter. The key role of magnetic flux quantization in understanding the values of v_0 suggests the interpretation of the torus as a magnetic or Z^0 magnetic flux tube. At pre-planetary period the dark matter formed a torus like quantum object. The conditions defining the radii of Bohr orbits follow from the requirement that the torus-like object is in an eigen state of angular momentum in the center of mass rotational degrees of freedom. The requirement that rotations do not leave the torus-like object invariant is obviously satisfied. Newton's law required by the quantum-classical correspondence stating that the orbit corresponds to a geodesic line in general relativistic framework gives the additional condition implying Bohr quantization.

2. A simple mechanism leading to the localization of the matter would have been the pinching of the torus causing kind of a traffic jam leading to the formation of the planet. This process could quite well have involved a flow of matter to a smaller planet space-time sheet Y_l^3 topologically condensed at X_l^3. Most of the angular momentum associated with torus like object would have transformed to that of planet and situation would have become effectively classical.

3. The conservation of magnetic flux means that the splitting of the orbital torus would generate a pair of Kähler magnetic charges. It is not clear whether this is possible dynamically and hence the torus could still be there. In fact, TGD explanation for the tritium beta decay anomaly citeTroitsk,Mainz in terms of classical Z^0 force [F8] requires the existence of this kind of torus containing neutrino cloud whose density varies along the torus. This picture suggests that the lacking $n = 1$ and $n = 2$ orbits in the region between Sun and Mercury are still in magnetic flux tube state containing mostly dark matter.

4. The fact that $\hbar_{gr}$ is proportional to m means that it could have varied continuously during the accumulation of the planetary mass without any effect in the planetary motion: this is of course nothing but a manifestation of Equivalence Principle.

5. It is interesting to look for the scaled up versions of Planck mass $m_{Pl} = \sqrt{\hbar_{gr}/\hbar} \times \sqrt{\hbar/G} = \sqrt{M_1 M_2/v_0}$ and Planck length $L_{Pl} = \sqrt{\hbar_{gr}/\hbar} \times \sqrt{\hbar/G} = G\sqrt{M_1 M_2/v_0}$. For $M_1 = M_2 = M$ this gives $m_{Pl} = M/\sqrt{v_0} \simeq 45.6 \times M$ and $L_{Pl} = r_S/2\sqrt{v_0} \simeq 22.8 \times r_S$, where r_S is Schwartshild radius. For Sun r_S is about 2.9 km so that one has $L_{Pl} \simeq 66$ km. For a few years ago it was found that Sun contains "inner-inner" core of radius about $R = 300$ km [21] which is about $4.5 \times L_{Pl}$.

7.4.4 Inclinations for the planetary orbits and the quantum evolution of the planetary system

The inclinations of planetary orbits provide a test bed for the theory. The semiclassical quantization of angular momentum gives the directions of angular momentum from the formula

$$cos(\theta) = \frac{m}{\sqrt{j(j+1)}} \quad , \quad |m| \leq j \ . \tag{7.4.9}$$

where θ is the angle between angular momentum and quantization axis and thus also that between orbital plane and (x,y)-plane. This angle defines the angle of tilt between the orbital plane and (x,y)-plane.

$m = j = n$ gives minimal value of angle of tilt for a given value of n of the principal quantum number as

$$cos(\theta) = \frac{n}{\sqrt{n(n+1)}} . \tag{7.4.10}$$

For $n = 3, 4, 5$ (Mercury, Venus, Earth) this gives $\theta = 30.0$, 26.6, and 24.0 degrees respectively.

Only the relative tilt angles can be compared with the experimental data. Taking as usual the Earth's orbital plane as the reference the relative tilt angles give what are known as inclinations. The predicted inclinations are 6 degrees for Mercury and 2.6 degrees for Venus. The observed values [39] are 7.0 and 3.4 degrees so that the agreement is satisfactory. If one allows half-odd integer spin the fit is improved. For $j = m = n - 1/2$ the predictions are 7.1 and 2.9 degrees for Mercury and Venus respectively. For Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto the inclinations are 1.9, 1.3, 2.5, 0.8, 1.8, 17.1 degrees. For Mars and outer planets the tilt angles are predicted to have wrong sign for $m = j$. In a good approximation the inclinations vanish for outer planets except Pluto and this would allow to determine m as $m \simeq \sqrt{5n(n+1)/6}$: the fit is not good.

The assumption that matter has condensed from a matter rotating in (x,y)-plane orthogonal to the quantization axis suggests that the directions of the planetary rotation axes are more or less the same and by angular momentum conservation have not changed appreciably. The prediction for the tilt of the rotation axis of the Earth is 24 degrees of freedom in the limit that the Earth's spin can be treated completely classically, that is for $m = j >> 1$ in the units used for the quantization of the Earth's angular momentum. What is the value of $\hbar_{gr}$ for Earth is not obvious (using the unit $\hbar_{gr} = GM^2/v_0$ the Earth's angular momentum would be much smaller than one). The tilt of the rotation axis of Earth with respect to the orbit plane is 23.5 degrees so that the agreement is again satisfactory. This prediction is essentially quantal: in purely classical theory the most natural guess for the tilt angle for planetary spins is 0 degrees.

The observation that the inner planets Mercury, Venus, and Earth have in a reasonable approximation the predicted inclinations suggest that they originate from a primordial period during which they formed spherical cells of dark matter and had thus full rotational degrees of freedom and were in eigen states of angular momentum corresponding to a full rotational symmetry. The subsequent $SO(3) \rightarrow SO(2)$ symmetry breaking leading to the formation of torus like configurations did not destroy the information about this period since the information about the value of j and m was coded by the inclination of the planetary orbit.

In contrast to this, the dark matter associated with Earth and outer planets up to Neptune formed a flattened magnetic or Z^0 magnetic flux tube resembling a disk with a hole and the subsequent symmetry breaking broke it to separate flux tubes. Earth's spherical disk was joined to the disk formed by the outer planets. The spherical disk could be still present and contain super-conducting dark matter. The presence of this "heavenly sphere" might closely relate to the fact that Earth is a living planet. The time scale $T = 2\pi R/c$ is very nearly equal to 5 minutes and defines a candidate for a bio-rhythm.

If this flux tube carried the same magnetic flux as the flux tubes associated with the inner planets, the decomposition of the disk with a hole to 5 flux tubes corresponding to Earth and to the outer planets Mars, Jupiter, Saturn and Neptune, would explain the value of v_0 correctly and also the small inclinations of outer planets. That Pluto would not originate from this structure, is consistent with its anomalously large values of inclination $i = 17.1$ degrees, small value of eccentricity $e = .248$, and anomalously large value of inclination of equator to orbit about 122 degrees as compared to 23.5 degrees in the case of Earth [39].

7.4.5 Eccentricities and comets

Bohr-Sommerfeld quantization allows also to deduce the eccentricities of the planetary and comet orbits. One can write the quantization of energy as

$$\begin{aligned} \frac{p_r^2}{2m_1} + \frac{p_\theta^2}{2m_1 r^2} + \frac{p_\phi^2}{2m_1 r^2 sin^2(\theta)} - \frac{k}{r} &= -\frac{E_1}{n^2} , \\ E_1 = \frac{k^2}{2\hbar_{gr}^2} \times m_1 &= \frac{v_0^2}{2} \times m_1 . \end{aligned} \tag{7.4.11}$$

Here one has $k = GMm_1$. E_1 is the binding energy of $n = 1$ state. In the orbital plane ($\theta = \pi/2, p_\theta = 0$) the conditions are simplified. Bohr quantization gives $p_\phi = m\hbar_{gr}$ implying

$$\frac{p_r^2}{2m_1} + \frac{k^2\hbar_{gr}^2}{2m_1 r^2} - \frac{k}{r} = -\frac{E_1}{n^2} \ . \tag{7.4.12}$$

For $p_r = 0$ the formula gives maximum and minimum radii $r_\pm$ and eccentricity is given by

$$e^2 = \frac{r_+ - r_-}{r_+} = \frac{2\sqrt{1 - \frac{m^2}{n^2}}}{1 + \sqrt{1 - \frac{m^2}{n^2}}} \ . \tag{7.4.13}$$

For small values of n the eccentricities are very large except for $m = n$. For instance, for $(m = n-1, n)$ for $n = 3, 4, 5$ gives $e = (.93, .89, .86)$ to be compared with the experimental values (.206, .007, .0167). Thus the planetary eccentricities with Pluto included ($e = .248$) must vanish in the lowest order approximation and must result as a perturbation of the magnetic flux tube.

The large eccentricities of comet orbits might however have an interpretation in terms of $m < n$ states. The prediction is that comets with small eccentricities have very large orbital radius. Oort's cloud is a system weakly bound to a solar system extending up to 3 light years. This gives the upper bound $n \leq 700$ if the comets of the cloud belong to the same family as Mercury, otherwise the bound is smaller. This gives a lower bound to the eccentricity of not nearly circular orbits in the Oort cloud as $e > .32$.

7.4.6 Why the quantum coherent dark matter is not visible?

The obvious objection against quantal astrophysics is that astrophysical systems look extremely classical. Quantal dark matter in many-sheeted space-time resolves this counter argument. As already explained, the sequence of symmetry breakings of the rotational symmetry would explain nicely why astral Bohr rules work. The prediction is however that delocalized quantal dark matter is probably still present at (the boundaries of) magnetic flux tubes and spherical shells. It is however the entire structure defined by the orbit which behaves like a single extended particle so that the localization in quantum measurement does not mean a localization to a point of the orbit. Planet itself corresponds to a smaller localized space-time sheet condensed at the flux tube.

One should however understand why this dark matter with a gigantic Planck constant is not visible. The simplest explanation is that there cannot be any direct quantum interactions between ordinary and dark matter in the sense that particles with different values of Planck constant could appear in the same particle vertex. This would allow also a fractal hierarchy copies of standard model physics to exist with different p-adic mass scales.

There is also second argument. The inability to observe dark matter could mean inability to perform state function reduction localizing the dark matter. The probability for this should be proportional to the strength of the measurement interaction. For photons the strength of the interaction is characterized by the fine structure constant. In the case of dark matter the fine structure constant is replaced with

$$\alpha_{em,gr} = \alpha_{em} \times \frac{\hbar}{\hbar_{gr}} = \alpha_{em} \times \frac{v_0}{GMm} \ . \tag{7.4.14}$$

For $M = m = m_{Pl} \simeq 10^{-8}$ kg the value of the fine structure constant is smaller than $\alpha_{em}v_0$ and completely negligible for astrophysical masses. However, for processes for which the lowest order classical rates are non-vanishing, rates are not affected in the lowest order since the increase of the Compton length compensates the reduction of α. Higher order corrections become however small. What makes dark matter invisible is not the smallness of α_{em} but the fact that the binding energies of say hydrogen atom proportional to $\alpha^2 m_e$ are scaled as $1/\hbar^2$ so that the spectrum is scaled down.

7.4.7 Quantum interpretation of gravitational Schrödinger equation

Schrödinger equation in astrophysical length scales with a gigantic value of Planck constant looks sheer madness idea from the standard physics point of view. In TGD Universe situation might be different.

1. In TGD inertial four-momentum (or conserved four-momentum) is not positive definite and the net four-momentum of the Universe vanishes. Already in cosmological length scales the density of inertial mass vanishes. Gravitational masses and inertial masses can be identified only at the limit when one can neglect the interaction between positive and negative energy matter. The masses appearing in the gravitational Schrödinger equation are gravitational masses and one can ask whether inertial and gravitational Planck constants are different.

2. The fractality of the many-sheeted space-time predicts that quantum effects appear in all length and time scales. In particular, dark matter is at larger space-time sheets and hence almost invisible.

3. An even more weirder looks the idea that Planck constant could have a gigantic value in astrophysical length scales being of order of magnitude of product of masses using Planck mass as a unit for $\hbar = c = 1$. This would mean that gravitation at space-time sheets of astrophysical size would have super quantal character! But even the gigantic value of Planck constant might be understood in TGD framework.

Jones inclusions and quantization of Planck constants

Quantum TGD emerges from infinite-dimensional Clifford algebra defined as infinite power of 8-dimensional Clifford algebra $C(8)$ generalized to a local algebra by constructing power series of quantum octonionic variable having the elements of this Clifford algebra as coefficients. The eigenstates for the commuting hermitian coordinates assignable to this octonionic variable have M^8 as spectrum and extremely general arguments imply both classical and quantum TGD. The construction works only for $D = 8$ (by non-associativity of the octonionic units) since for other dimensions the local field defined by algebra could not be distinguished from algebra itself.

Perhaps the most important outcome is a general master formula for S-matrix with interactions described as a deformation of ordinary tensor product to Connes tensor products and new view theory of quantum measurement. Further outcomes are prediction the spectra of the quantized values of M^4 and CP_2 Planck constants as characterizers of Jones inclusions associated with quantum phases $q = exp(i\pi/n)$.

1. Some background

It has been for few years clear that TGD could emerge from the mere infinite-dimensionality of the Clifford algebra of infinite-dimensional "world of classical worlds" and from number theoretical vision in which classical number fields play a key role and determine imbedding space and space-time dimensions. This would fix completely the "world of classical worlds".

Infinite-dimensional Clifford algebra is a standard representation for von Neumann algebra known as a hyper-finite factor of type II_1. In TGD framework the infinite tensor power of C(8), Clifford algebra of 8-D space would be the natural representation of this algebra.

2. How to localize infinite-dimensional Clifford algebra?

The basic new idea is to make this algebra *local*: local Clifford algebra as a generalization of gamma field of string models.

1. Represent Minkowski coordinate of M^d as linear combination of gamma matrices of D-dimensional space. This is the first guess. One fascinating finding is that this notion can be quantized and classical M^d is genuine quantum M^d with coordinate values eigenvalues of quantal commuting Hermitian operators built from matrix elements. Euclidian space is not obtained in this manner. Minkowski signature is something quantal and the standard quantum group $Gl_(2,q)(C)$ with (non-Hermitian matrix elements) gives M^4.

2. Form power series of the M^d coordinate represented as linear combination of gamma matrices with coefficients in corresponding infinite-D Clifford algebra. One would get tensor product of two algebra.

3. There is however a problem: one cannot distinguish the tensor product from the original infinite-D Clifford algebra. $D = 8$ is however an exception! One can replace gammas in the expansion of M^8 coordinate by hyper-octonionic units which are non-associative (or octonionic units in quantum complexified-octonionic case). Now one cannot anymore absorb the tensor factor to the Clifford algebra and one gets a genuine M^8-localized factor of type II_1. Everything is determined by infinite-dimensional gamma matrix fields analogous to conformal super fields with z replaced by hyperoctonion.

4. Octonionic non-associativity actually reproduces whole classical and quantum TGD: space-time surface must be associative sub-manifolds hence hyper-quaternionic surfaces of M^8. Representability as surfaces in $M^4 \times CP_2$ follows naturally, the notion of configuration space of 3-surfaces, etc....

3. Connes tensor product for free fields as a universal definition of interaction quantum field theory

This picture has profound implications. Consider first the construction of S-matrix.

1. A non-perturbative construction of S-matrix emerges. The deep principle is simple. The canonical outer automorphism for von Neumann algebras defines a natural candidate unitary transformation giving rise to propagator. This outer automorphism is trivial for II_1 factors meaning that all lines appearing in Feynman diagrams must be on mass shell states satisfying Super Virasoro conditions. One can allow all possible diagrams: all on mass shell loop corrections vanish by unitarity and what remains are diagrams with single N-vertex.

2. At 2-surface representing N-vertex space-time sheets representing generalized Bohr orbits of incoming and outgoing particles meet. This vertex involves von Neumann trace (finite!) of localized gamma matrices expressible in terms of fermionic oscillator operators and defining free fields satisfying Super Virasoro conditions.

3. For free fields ordinary tensor product would not give interacting theory. What makes S-matrix non-trivial is that *Connes tensor product* is used instead of the ordinary one. This tensor product is a universal description for interactions and we can forget perturbation theory! Interactions result as a deformation of tensor product. Unitarity of resulting S-matrix is unproven but I dare believe that it holds true.

4. The subfactor $\mathcal{N}$ defining the Connes tensor product has interpretation in terms of the interaction between experimenter and measured system and each interaction type defines its own Connes tensor product. Basically $\mathcal{N}$ represents the limitations of the experimenter. For instance, IR and UV cutoffs could be seen as primitive manners to describe what $\mathcal{N}$ describes much more elegantly. At the limit when $\mathcal{N}$ contains only single element, theory would become free field theory but this is ideal situation never achievable.

4. The quantization of Planck constant and ADE hierarchies

The quantization of Planck constant has been the basic them of TGD for more than one and half years and leads also the understanding of ADE correspondences (index $\beta \leq 4$ and $\beta = 4$) from the point of view of Jones inclusions.

1. The new view allows to understand how and why Planck constant is quantized and gives an amazingly simple formula for the separate Planck constants assignable to M^4 and CP_2 and appearing as scaling constants of their metrics. This in terms of a mild generalizations of standard Jones inclusions. The emergence of imbedding space means only that the scaling of these metrics have spectrum: no landscape.

2. In ordinary phase Planck constants $\hbar(M^4)$ and $\hbar(CP_2)$ are same and have their standard values. Large Planck constant phases correspond to situations in which a transition to a phase in which quantum groups occurs. These situations correspond to standard Jones inclusions in which Clifford algebra is replaced with a sub-algebra of its G-invariant elements. G is product $G_a \times G_b$ of subgroups of $SL(2,C)$ and $SU(2)_L \times \times U(1)$ which also acts as a subgroup of SU(3). Space-time sheets are $n(G_b)$-fold coverings of M^4 and $n(G_a)$-fold coverings of CP_2 generalizing the picture which has emerged already. An elementary study of these coverings fixes the values of scaling factors of M^4 and CP_2 Planck constants to orders of the maximal cyclic sub-groups. Mass spectrum is invariant under these scalings. The values of Planck constants are $\hbar(M^4) = n_a\hbar_0$ and $\hbar(CP_2) = n_b\hbar_0$ and scaling factor of M^4 covariant metric is n_b and that of CP_2 metric n_a. In Kähler action only the ratio n_a/n_b occurs and the Planck constant $\hbar_{eff}$ occurring in Schrödinger equation is by quantum classical correspondence $\hbar_{eff}/\hbar_0 = n_a/n_b$.

3. This predicts automatically arbitrarily large and also small values of Planck constant depending in the value of the ratio n_a/n_b and assigns the preferred values of Planck constant to quantum phases $q = exp(i\pi/n_i)$, $i = a, b$ expressible in terms of iterated square roots of rationals: these correspond to polygons obtainable by compass and ruler construction. In particular, experimentally favored values of $\hbar$ in living matter correspond to these special values of Planck constant. This model reproduces also the other aspects of the general vision. The subgroups of $SL(2,C)$ in turn can give rise to re-scaling of $SU(3)$ Planck constant. The most general situation can be described in terms of Jones inclusions for fixed point subalgebras of number theoretic Clifford algebras defined by $G_a \times G_b \subset SL(2,C) \times SU(2)$.

4. These inclusions (apart from those for which G_a contains infinite number of elements) are represented by ADE or extended ADE diagrams depending on the value of index. The group algebras of these groups give rise to additional degrees of freedom which make possible to construct the multiplets of the corresponding gauge groups. For $\beta \leq 4$ the gauge groups A_n, D_2n, E_6, E_8 are possible so that TGD seems to be able to mimick these gauge theories. For $\beta = 4$ all ADE Kac Moody groups are possible and again mimicry becomes possible: TGD would be kind of universal physics emulator but it would be anyonic dark matter which would perform this emulation.

Bohr quantization of planetary orbits and prediction for Planck constant

The predictions of the generalization of the p-adic length scale hypothesis are consistent with the TGD based model for the Bohr quantization of planetary orbits and some new non-trivial predictions follow.

1. Generalization of the p-adic length scale hypothesis

The evolution in phase resolution in p-adic degrees of freedom corresponds to emergence of algebraic extensions allowing increasing variety of phases $exp(i\pi/n)$ expressible p-adically. This evolution can be assigned to the emergence of increasingly complex quantum phases and the increase of Planck constant.

One expects that quantum phases $q = exp(i\pi/n)$ which are expressible using only square roots of rationals are number theoretically very special since they correspond to algebraic extensions of p-adic numbers involving only square roots which should emerge first and therefore systems involving these values of q should be especially abundant in Nature.

These polygons are obtained by ruler and compass construction and Gauss showed that these polygons, which could be called Fermat polygons, have $n_F = 2^k \prod_s F_{n_s}$ sides/vertices: all Fermat primes F_{n_s} in this expression must be different. The analog of the p-adic length scale hypothesis emerges since larger Fermat primes are near a power of 2. The known Fermat primes $F_n = 2^{2^n} + 1$ correspond to $n = 0, 1, 2, 3, 4$ with $F_0 = 3$, $F_1 = 5$, $F_2 = 17$, $F_3 = 257$, $F_4 = 65537$. It is not known whether there are higher Fermat primes. $n = 3, 5, 15$-multiples of p-adic length scales clearly distinguishable from them are also predicted and this prediction is testable in living matter. I have already earlier considered the possibility that Fermat polygons could be of special importance for cognition and for biological information processing [H8].

This condition could be interpreted as a kind of resonance condition guaranteeing that scaled up sizes for space-time sheets have sizes given by p-adic length scales. The numbers n_F could take the same role in the evolution of Planck constants assignable with the phase resolution as Mersenne primes have in the evolution assignable to the p-adic length scale resolution.

2. Do the values of gravitational Planck constant correspond to polygons obtained by ruler and compass construction?

Since the macroscopic quantum phases with minimum dimension of algebraic extension should be especially abundant in the universe, the natural guess is that the values of the gravitational Planck constant correspond to n_F-multiples of ordinary Planck constant.

1. The model can explain the enormous values of gravitational Planck constant $\hbar_{gr}/\hbar_0 =\simeq GMm/v_0) = n_a/n_b$. The favored values of this parameter should correspond to n_{F_a}/n_{F_b} so that the mass ratios $m_1/m_2 = n_{F_{a,1}}n_{F_{b,2}}/n_{F_{b,1}}n_{F_{a,2}}$ for planetary masses should be preferred. The general prediction $GMm/v_0 = n_a/n_b$ is of course not testable.
2. Nottale [30] has suggested that also the harmonics and subharmonics of λ are possible and in fact required by the model for planetary Bohr orbits (in TGD framework this is not absolutely necessary). The prediction is that favored values of n should be of form $n_F = 2^k \prod F_i$ such that F_i appears at most once. In Nottale's model for planetary orbits as Bohr orbits in solar system $n = 5$ harmonics appear and are consistent with either $n_{F,a} \rightarrow F_1 n_{F_a}$ or with $n_{F,b} \rightarrow n_{F_b}/F_1$ if possible.

The prediction for the ratios of planetary masses can be tested. In the table below are the experimental mass ratios $r_{exp} = m(pl)/m(E)$, the best choice of $r_R = [n_{F,a}/n_{F,b}] * X$, X common factor for all planets, and the ratios $r_{pred}/r_{exp} = n_{F,a}(planet)n_{F,b}(Earth)/n_{F,a}(Earth)n_{F,b}(planet)$. The deviations are at most 2 per cent.

$planet$	Me	V	E	M	J
y	$\frac{2^{13}\times 5}{17}$	$2^{11}\times 17$	$2^9\times 5\times 17$	$2^8\times 17$	$\frac{2^{23}\times 5}{7}$
y/x	1.01	.98	1.00	.98	1.01
$planet$	S	U	N	P	
y	$2^{14}\times 3\times 5\times 17$	$\frac{2^{21}\times 5}{17}$	$\frac{2^{17}\times 17}{3}$	$\frac{2^{4}\times 17}{3}$	
y/x	1.01	.98	.99	.99	

Table 1. The table compares the ratios $x = m(pl)/(m(E)$ of planetary mass to the mass of Earth to prediction for these ratios in terms of integers n_F associated with Fermat polygons. y gives the best fit for the allowed factors of the known part y of the rational $n_{F,a}/n_{F,b} = yX$ characterizing planet, and the ratios y/x. Errors are at most 2 per cent.

A stronger prediction comes from the requirement that GMm/v_0 equals to $n = n_{F_a}/n_{F,b}$ $n_F = 2^k \prod_k F_{n_k}$, where $F_i = 2^{2^i}+1$, $i = 0,1,2,3,4$ is Fibonacci prime. The fit using solar mass and Earth mass gives $n_F = 2^{254}\times 5\times 17$ for $1/v_0 = 2044$, which within the experimental accuracy equals to the value $2^{11} = 2048$ whose powers appear as scaling factors of Planck constant in the model for living matter [M3]. For $v_0 = 4.6\times 10^{-4}$ reported by Nottale the prediction is by a factor 16/17.01 too small (6 per cent discrepancy).

A possible solution of the discrepancy is that the empirical estimate for the factor GMm/v_0 is too large since m contains also the the visible mass not actually contributing to the gravitational force between dark matter objects whereas M is known correctly. The assumption that the dark mass is a fraction $1/(1+\epsilon)$ of the total mass for Earth gives

$$1+\epsilon = \frac{17}{16} \quad (7.4.15)$$

in an excellent approximation. This gives for the fraction of the visible matter the estimate $\epsilon = 1/16 \simeq 6$ per cent. The estimate for the fraction of visible matter in cosmos is about 4 per cent so that estimate is reasonable and would mean that most of planetary and solar mass would be also dark (as a matter dark energy would be in question).

That $v_0(eff) = v_0/(1-\epsilon) \simeq 4.6 \times 10^{-4}$ equals with $v_0(eff) = 1/(2^7 \times F_2) = 4.5956 \times 10^{-4}$ within the experimental accuracy suggests a number theoretical explanation for the visible-to-dark fraction.

3. Can one really identify gravitational and inertial Planck constants?

The original unconsciously performed identification of the gravitational and inertial Planck constants leads to some confusing conclusions but it seems that the new view about the quantization of Planck constants resolves these problems and allows to see $\hbar_{gr}$ as a special case of $\hbar_I$.

1. $\hbar_{gr}$ is proportional to the product of masses of interacting systems and not a universal constant like $\hbar$. One can however express the gravitational Bohr conditions as a quantization of circulation $\oint v \cdot dl = n(GM/v_0)\hbar_0$ so that the dependence on the planet mass disappears as required by Equivalence Principle. This suggests that gravitational Bohr rules relate to velocity rather than inertial momentum as is indeed natural. The quantization of circulation is consistent with the basic prediction that space-time surfaces are analogous to Bohr orbits.

2. $\hbar_{gr}$ seems to characterize a relationship between planet and central mass and quite generally between two systems with the property that smaller system is topologically condensed at the space-time sheet of the larger system. Thus it would seem that $\hbar_{gr}$ is not a universal constant and cannot correspond to a special value of ordinary Planck constant. Certainly this would be the case if $\hbar_I$ is quantized as λ^k-multiplet of ordinary Planck constant with $\lambda \simeq 2^{11}$.

The recent view about the quantization of Planck constant in terms of coverings of M^4 seems to resolve these problems.

1. The integer quantization of Planck constants is consistent with the huge values of gravitational Planck constant within experimental resolution and the killer test for $\hbar = \hbar_{gr}$ emerges if one takes seriously the stronger prediction $\hbar_{gr} = n_{F,a}/n_{F,b}$.

2. One can also regard $\hbar_{gr}$ as ordinary Planck constant $\hbar_{eff}$ associated with the space-time sheet along which the masses interact provided each pair (M, m_i) of masses is characterized by its own sheets. These sheets could correspond to flux tube like structures carrying the gravitational flux of dark matter. If these sheets corresponds to n_{F_a}-fold covering of M^4, one can understand $\hbar_{gr}$ as a particular instance of the $\hbar_{eff}$.

Quantization as a means of avoiding gravitational collapse

Schrödinger equation provided a solution to the infrared catastrophe of the classical model of atom: the classical prediction was that electron would radiate its energy as brehmstrahlung and would be captured by the nucleus. The gravitational variant of this process would be the capture of the planet by a black hole, and more generally, a collapse of the star to a black hole. Gravitational Schrödinger equation could obviously prevent the catastrophe.

For $1/r$ gravitation potential the Bohr radius is given by $a_{gr} = GM/v_0^2 = r_S/2v_0^2$, where $r_S = 2GM$ is the Schwartchild radius of the mass creating the gravitational potential: obviously Bohr radius is much larger than the Schwartschild radius. That the gravitational Bohr radius does not depend on m conforms with Equivalence Principle, and the proportionality $\hbar_{gr} \propto Mm$ can be deduced from it. Gravitational Bohr radius is by a factor $1/2v_0^2$ larger than black hole radius so that black hole can swallow the piece of matter with a considerable rate only if it is in the ground state and also in this state the rate is proportional to the black hole volume to the volume defined by the black hole radius given by $2^3 v_0^6 \sim 10^{-20}$.

The $\hbar_{gr} \to \infty$ limit for $1/r$ gravitational potential means that the exponential factor $exp(-r/a_0)$ of the wave function becomes constant: on the other hand, also Schwartshild and Bohr radii become infinite at this limit. The gravitational Compton length associated with mass m does not depend on m and is given by GM/v_0 and the time $T = E_{gr}/\hbar_{gr}$ defined by the gravitational binding energy is twice the time taken to travel a distance defined by the radius of the orbit with velocity v_0 which suggests that signals travelling with a maximal velocity v_0 are involved with the quantum dynamics.

In the case of planetary system the proportionality $\hbar_{gr} \propto mM$ creates problems of principle since the influence of the other planets is not taken account. One might argue that the generalization of the formula should be such that M is determined by the gravitational field experienced by mass m and thus contains also the effect of other planets. The problem is that this field depends on the position of m which would mean that $\hbar_{gr}$ itself would become kind of field quantity.

Does the transition to non-perturbative phase correspond to a change in the value of $\hbar$?

Nature is populated by systems for which perturbative quantum theory does not work. Examples are atoms with $Z_1Z_2e^2/4\pi\hbar > 1$ for which the binding energy becomes larger than rest mass, non-perturbative QCD resulting for $Q_{s,1}Q_{s,2}g_s^2/4\pi\hbar > 1$, and gravitational systems satisfying $GM_1M_2/4\pi\hbar > 1$. Quite generally, the condition guaranteing troubles is of the form $Q_1Q_2g^2/4\pi\hbar > 1$. There is no general mathematical approach for solving the quantum physics of these systems but it is believed that a phase transition to a new phase of some kind occurs.

The gravitational Schrödinger equation forces to ask whether Nature herself takes care of the problem so that this phase transition would involve a change of the value of the Planck constant to guarantee that the perturbative approach works. The values of $\hbar$ would vary in a stepwise manner from $\hbar(\infty)$ to $\hbar(3) = \hbar(\infty)/4$. The non-perturbative phase transition would correspond to transition to the value of

$$\frac{\hbar}{\hbar_0} \rightarrow \left[\frac{Q_1Q_2g^2}{v}\right] \tag{7.4.16}$$

where $[x]$ is the integer nearest to x, inducing

$$\frac{Q_1Q_2g^2}{4\pi\hbar} \rightarrow \frac{v}{4\pi} \ . \tag{7.4.17}$$

The simplest (and of course ad hoc) assumption making sense in TGD Universe is that v is a harmonic or subharmonic of v_0 appearing in the gravitational Schrödinger equation. For instance, for the Kepler problem the spectrum of binding energies would be universal (independent of the values of charges) and given by $E_n = v^2m/2n^2$ with v playing the role of small coupling. Bohr radius would be g^2Q_2/v^2 for $Q_2 \gg Q_1$.

This provides a new insight to the problems encountered in quantizing gravity. QED started from the model of atom solving the infrared catastrophe. In quantum gravity theories one has started directly from the quantum field theory level and the recent decline of the M-theory shows that we are still practically where we started. If the gravitational Schrödinger equation indeed allows quantum interpretation, one could be more modest and start from the solution of the gravitational IR catastrophe by assuming a dynamical spectrum of $\hbar$ determined by Beraha numbers. The implications would be profound: the whole program of quantum gravity would have been misled as far as the quantization of systems with $GM_1M_2/\hbar > 1$ is considered. In practice, these systems are the most interesting ones and the prejudice that their quantization is a mere academic exercise would have been completely wrong.

An alternative formulation for the occurrence of a transition increasing the value of $\hbar$ could rely on the requirement that classical bound states have reasonable quantum counterparts. In the gravitational case one would have $r_n = n^2\hbar_{gr}^2/GM_1^2M$, for $M_1 \ll M$, which is extremely small distance for $\hbar_{gr} = \hbar$ and reasonable values of n. Hence, either n is so large that the system is classical or $\hbar_{gr}/\hbar$ is very large. Equivalence Principle requires the independence of r_n on M_1, which gives $\hbar = kGM_1M_2$ giving $r_n = n^2kGM$. The requirement that the radius is above Schwartshild radius gives $k \geq 2$. In the case of Dirac equation the solutions cease to exist for $Z \geq 137$ and which suggests that $\hbar$ is large for hypothetical atoms having $Z \geq 137$.

7.4.8 How do the magnetic flux tube structures and quantum gravitational bound states relate?

In the case of stars in galactic halo the appearance of the parameter v_0 characterizing cosmic strings as orbital rotation velocity can be understood classically. That v_0 appears also in the gravitational dynamics of planetary orbits could relate to the dark matter at magnetic flux tubes. The argument explaining the harmonics and sub-harmonics of v_0 in terms of properties of cosmic strings and magnetic flux tubes identifiable as their descendants strengthens this expectation.

The notion of magnetic body

In TGD inspired theory of consciousness the notion of magnetic body plays a key role: magnetic body is the ultimate intentional agent, experiencer, and performer of bio-control and can have astrophysical size: this does not sound so counter-intuitive if one takes seriously the idea that cognition has p-adic space-time sheets as space-time correlates and that rational points are common to real and p-adic number fields. The point is that infinitesimal in p-adic topology corresponds to infinite in real sense so that cognitive and intentional structures would have literally infinite size.

The magnetic flux tubes carrying various supra phases can be interpreted as special instance of dark energy and dark matter. This suggests a correlation between gravitational self-organization and quantum phases at the magnetic flux tubes and that the gravitational Schrödinger equation somehow relates to the ordinary Schrödinger equation satisfied by the macroscopic quantum phases at magnetic flux tubes. Interestingly, the transition to large Planck constant phase should occur when the masses of interacting is above Planck mass since gravitational self-interaction energy is $V \sim GM^2/R$. For the density of water about 10^3 kg/m^3 the volume carrying a Planck mass correspond to a cube with side 2.8×10^{-4} meters. This corresponds to a volume of a large neuron, which suggests that this phase transition might play an important role in neuronal dynamics.

Could gravitational Schrödinger equation relate to a quantum control at magnetic flux tubes?

An infinite self hierarchy is the basic prediction of TGD inspired theory of consciousness ("everything is conscious and consciousness can be only lost"). Topological quantization allows to assign to any material system a field body as the topologically quantized field pattern created by the system [L5, K1]. This field body can have an astrophysical size and would utilize the material body as a sensory receptor and motor instrument.

Magnetic flux tube and flux wall structures are natural candidates for the field bodies. Various empirical inputs have led to the hypothesis that the magnetic flux tube structures define a hierarchy of magnetic bodies, and that even Earth and larger astrophysical systems possess magnetic body which makes them conscious self-organizing living systems. In particular, life at Earth would have developed first as a self-organization of the super-conducting dark matter at magnetic flux tubes [L5].

For instance, EEG frequencies corresponds to wavelengths of order Earth size scale and the strange findings of Libet about time delays of conscious experience [68, 69] find an elegant explanation in terms of time taken for signals propagate from brain to the magnetic body [K1]. Cyclotron frequencies, various cavity frequencies, and the frequencies associated with various p-adic frequency scales are in a key role in the model of bio-control performed by the magnetic body. The cyclotron frequency scale is given by $f = eB/m$ and rather low as are also cavity frequencies such as Schumann frequencies: the lowest Schumann frequency is in a good approximation given by $f = 1/2\pi R$ for Earth and equals to 7.8 Hz.

1. Quantum time scales as "bio-rhythms" in solar system?

To get some idea about the possible connection of the quantum control possibly performed by the dark matter with gravitational Schrödinger equation, it is useful to look for the values of the periods defined by the gravitational binding energies of test particles in the fields of Sun and Earth and look whether they correspond to some natural time scales. For instance, the period $T = 2GM_S n^2/v_0^3$ defined by the energy of n^{th} planetary orbit depends only on the mass of Sun and defines thus an ideal candidate for a universal "bio-rhytm".

For Sun black hole radius is about 2.9 km. The period defined by the binding energy of lowest state in the gravitational field of Sun is given $T_S = 2GM_S/v_0^3$ and equals to 23.979 hours for $v_0/c = 4.8233 \times 10^{-4}$. Within experimental limits for v_0/c the prediction is consistent with 24 hours! The value of v_0 corresponding to exactly 24 hours would be $v_0 = 144.6578$ km/s (as a matter fact, the rotational period of Earth is 23.9345 hours). As if as the frequency defined by the lowest energy state would define a "biological" clock at Earth! Mars is now a strong candidate for a seat of life and the day in Mars lasts 24hr 37m 23s! $n = 1$ and $n = 2$ are orbitals are not realized in solar system as planets but there is evidence for the $n = 1$ orbital as being realized as a peak in the density of IR-dust [30]. One can of course consider the possibility that these levels are populated by small dark matter planets with matter at larger space-time sheets. Bet as it may, the result supports the notion of quantum gravitational entrainment in the solar system.

The slower rhythms would become as n^2 sub-harmonics of this time scale. Earth itself corresponds to $n = 5$ state and to a rhythm of .96 hours: perhaps the choice of 1 hour to serve as a fundamental time unit is not merely accidental. The magnetic field with a typical ionic cyclotron frequency around 24 hours would be very weak: for 10 Hz cyclotron frequency in Earth's magnetic field the field strength would about 10^{-11} T. However, $T = 24$ hours corresponds with 6 per cent accuracy to the p-adic time scale $T(k = 280) = 2^{13}T(2, 127)$, where $T(2, 127)$ corresponds to the secondary p-adic time scale of .1 s associated with the Mersenne prime $M_{127} = 2^{127} - 1$ characterizing electron and defining a fundamental bio-rhytm and the duration of memetic codon [TGDgeme].

Comorosan effect [28, 67, J5] demonstrates rather peculiar looking facts about the interaction of organic molecules with visible laser light at wavelength $\lambda = 546\ nm$. As a result of irradiation molecules seem to undergo a transition $S \rightarrow S^*$. S^* state has anomalously long lifetime and stability in solution. $S \rightarrow S^*$ transition has been detected through the interaction of S^* molecules with different biological macromolecules, like enzymes and cellular receptors. Later Comorosan found that the effect occurs also in non-living matter. The basic time scale is $\tau = 5$ seconds. p-Adic length scale hypothesis does not explain τ, and it does not correspond to any obvious astrophysical time scale and has remained a mystery.

The idea about astro-quantal dark matter as a fundamental bio-controller inspires the guess that τ could correspond to some Bohr radius R for a solar system via the correspondence $\tau = R/c$. As observed by Nottale, $n = 1$ orbit for $v_0 \rightarrow 3v_0$ corresponds in a good approximation to the solar radius and to $\tau = 2.18$ seconds. For $v_0 \rightarrow 2v_0$ $n = 1$ orbit corresponds to $\tau = AU/(4 \times 25) = 4.992$ seconds: here $R = AU$ is the astronomical unit equal to the average distance of Earth from Sun. The deviation from τ_C is only one per cent and of the same order of magnitude as the variation of the radius for the orbit due to orbital eccentricity $(a - b)/a = .0167$ [39].

2. Earth-Moon system

For Earth serving as the central mass the Bohr radius is about 18.7 km, much smaller than Earth radius so that Moon would correspond to $n = 147.47$ for v_0 and $n = 1.02$ for the sub-harmonic $v_0/12$ of v_0. For an afficionado of cosmic jokes or a numerologist the presence of the number of months in this formula might be of some interest. Those knowing that the Mayan calendar had 11 months and that Moon is receding from Earth might rush to check whether a transition from $v/11$ to $v/12$ state has occurred after the Mayan culture ceased to exist: the increase of the orbital radius by about 3 per cent would be required! Returning to a more serious mode, an interesting question is whether light satellites of Earth consisting of dark matter at larger space-time sheets could be present. For instance, in [L5] I have discussed the possibility that the larger space-time sheets of Earth could carry some kind of intelligent life crucial for the bio-control in the Earth's length scale.

The period corresponding to the lowest energy state is from the ratio of the masses of Earth and Sun given by $M_E/M_S = (5.974/1.989) \times 10^{-6}$ given by $T_E = (M_E/M_S) \times T_S = .2595$ s. The corresponding frequency $f_E = 3.8535$ Hz frequency is at the lower end of the theta band in EEG and is by 10 per cent higher than the p-adic frequency $f(251) = 3.5355$ Hz associated with the p-adic prime $p \simeq 2^k$, $k = 251$. The corresponding wavelength is 2.02 times Earth's circumference. Note that the cyclotron frequencies of Nn, Fe, Co, Ni, and Cu are $5.5, 5.0, 5.2, 4.8$ Hz in the magnetic field of $.5 \times 10^{-4}$ Tesla, which is the nominal value of the Earth's magnetic field. In [M4] I have proposed that the cyclotron frequencies of Fe and Co could define biological rhythms important for brain functioning. For $v_0/12$ associated with Moon orbit the period would be 7.47 s: I do not know whether this corresponds to some bio-rhytm.

It is better to leave for the reader to decide whether these findings support the idea that the super conducting cold dark matter at the magnetic flux tubes could perform bio-control and whether the gravitational quantum states and ordinary quantum states associated with the magnetic flux tubes couple to each other and are synchronized.

7.4.9 p-Adic length scale hypothesis and $v_0 \rightarrow v_0/5$ transition at inner-outer border for planetary system

$v_0 \rightarrow v_0/5$ transition would allow to interpret the orbits of outer planets as $n \geq 1$ orbits. The obvious question is whether inner to outer zone as $v_0 \rightarrow v_0/5$ transition could be interpreted in terms of the p-adic length scale hierarchy.

1. The most important p-adic length scale are given by primary p-adic length scales $L(k) = 2^{(k-151)/2} \times 10$ nm and secondary p-adic length scales $L(2,k) = 2^{k-151} \times 10$ nm, k prime.
2. The p-adic scale $L(2,139) = 114$ Mkm is slightly above the orbital radius 109.4 Mkm of Venus. The p-adic length scale $L(2,137) \simeq 28.5$ Mkm is roughly one half of Mercury's orbital radius 57.9 Mkm. Thus strong form of p-adic length scale hypothesis could explain why the transition $v_0 \rightarrow v_0/5$ occurs in the region between Venus and Earth ($n = 5$ orbit for v_0 layer and $n = 1$ orbit for $v_0/5$ layer).
3. Interestingly, the *primary* p-adic length scales $L(137)$ and $L(139)$ correspond to fundamental atomic length scales which suggests that solar system be seen as a fractally scaled up "secondary" version of atomic system.
4. Planetary radii have been fitted also using Titius-Bode law predicting $r(n) = r_0 + r_1 \times 2^n$. Hence on can ask whether planets are in one-one correspondence with primary and secondary p-adic length scales $L(k)$. For the orbital radii $58, 110, 150, 228$ Mkm of Mercury, Venus, Earth, and Mars indeed correspond approximately to k= $276, 278, 279, 281$: note the special position of Earth with respect to its predecessor. For Jupiter, Saturn, Uranus, Neptune, and Pluto the radii are 52,95,191,301,395 Mkm and would correspond to p-adic length scales $L(280 + 2n))$, $n = 0, ..., 3$. Obviously the transition $v_0 \rightarrow v_0/5$ could occur in order to make the planet–p-adic length scale one-one correspondence possible.
5. It is interesting to look whether the p-adic length scale hierarchy applies also to the solar structure. In a good approximation solar radius .696 Mkm corresponds to $L(270)$, the lower radius .496 Mkm of the convective zone corresponds to $L(269)$, and the lower radius .174 Mkm of the radiative zone (radius of the solar core) corresponds to $L(266)$. This encourages the hypothesis that solar core has an onion like sub-structure corresponding to various p-adic length scales. In particular, $L(2,127)$ ($L(127)$ corresponds to electron) would correspond to 28 Mm. The core is believed to contain a structure with radius of about 10 km: this would correspond to $L(231)$. This picture would suggest universality of star structure in the sense that stars would differ basically by the number of the onion like shells having standard sizes.

Quite generally, in TGD Universe the formation of join along boundaries bonds is the space-time correlate for the formation of bound states. This encourages to think that (Z^0) magnetic flux tubes are involved with the formation of gravitational bound states and that for $v_0 \rightarrow v_0/k$ corresponds either to a splitting of a flux tube resembling a disk with a whole to k pieces, or to the scaling down $B \rightarrow B/k^2$ so that the magnetic energy for the flux tube thickened and stretched by the same factor k^2 would not change.

7.4.10 About the interpretation of the parameter v_0

The formula for the gravitational Planck constant contains the parameter $v_0/c = 2^{-11}$. This velocity defines the rotation velocities of distant stars around galaxies. The presence of a parameter with dimensions of velocity should carry some important information about the geometry of dark matter space-time sheets.

Velocity like parameters appear also in other contexts. There is evidence for the Tifft's quantization of cosmic redshifts in multiples of $v_0/c = 2.68 \times 10^{-5}/3$: also other units of quantization have been proposed but they are multiples of v_0 [64].

The strange behavior of graphene includes high conductivity with conduction electrons behaving like massless particles with light velocity replaced with $v_0/c = 1/300$. The TGD inspired model [J1] explains the high conductivity as being due to the Planck constant $\hbar(M^4) = 6\hbar_0$ increasing the delocalization length scale of electron pairs associated with hexagonal rings of mono-atomic graphene layer by a factor 6 and thus making possible overlap of electron orbitals. This explains also the anomalous conductivity of DNA containing 5- and 6-cycles [J1].

Is dark matter warped?

The reduced light velocity could be due to the warping of the space-time sheet associated with dark electrons. TGD predicts besides gravitational red-shift a non-gravitational red-shift due to the warping of space-time sheets possible because space-time is 4-surface rather than abstract 4-manifold. A simple example of everyday life is the warping of a paper sheet: it bends but is not stretched, which means that the induced metric remains flat although one of its component scales (distance becomes longer along direction of bending). For instance, empty Minkowski space represented canonically as a surface of $M^4 \times CP_2$ with constant CP_2 coordinates can become periodically warped in time direction because of the bending in CP_2 direction. As a consequence, the distance in time direction shortens and effective light-velocity decreases when determined from the comparison of the time taken for signal to propagate from A to B along warped space-time sheet with propagation time along a non-warped space-time sheet.

The simplest warped imbedding defined by the map $M^4 \rightarrow S^1$, S^1 a geodesic circle of CP_2. Let the angle coordinate of S^1 depend linearly on time: $\Phi = \omega t$. g_{tt} component of metric becomes $1 - R^2\omega^2$ so that the light velocity is reduced to $v_0/c = \sqrt{1 - R^2\omega^2}$. No gravitational field is present.

The fact that M^4 Planck constant $n_a\hbar_0$ defines the scaling factor n_a^2 of CP_2 metric could explain why dark matter resides around strongly warped imbeddings of M^4. The quantization of the scaling factor of CP_2 by $R^2 \rightarrow n_a^2 R^2$ implies that the initial small warping in the time direction given by $g_{tt} = 1 - \epsilon$, $\epsilon = R^2\omega^2$, will be amplified to $g_{tt} = 1 - n_a^2\epsilon$ if ω is not affected in the transition to dark matter phase. $n_a = 6$ in the case of graphene would give $1 - x \simeq 1 - 1/36$ so that only a one per cent reduction of light velocity is enough to explain the strong reduction of light velocity for dark matter.

Is c/v_0 quantized in terms of ruler and compass rationals?

The known cases suggests that c/v_0 is always a rational number expressible as a ratio of integers associated with n-polygons constructible using only ruler and compass.

1. $c/v_0 = 300$ would explain graphene. The nearest rational satisfying the ruler and compass constraint would be $q = 5 \times 2^{10}/17 \simeq 301.18$.

2. If dark matter space-time sheets are warped with $c_0/v = 2^{11}$ one can understand Nottale's quantization for the radii of the inner planets. For dark matter space-time sheets associated with outer planets one would have $c/v_0 = 5 \times 2^{11}$.

3. If Tifft's red-shifts relate to the warping of dark matter space-time sheets, warping would correspond to $v_0/c = 2.68 \times 10^{-5}/3$. $c/v_0 = 2^5 \times 17 \times 257/5$ holds true with an error smaller than .1 per cent.

Tifft's quantization and cosmic quantum coherence

An explanation for Tifft's quantization in terms of Jones inclusions could be that the subgroup G of Lorentz group defining the inclusion consists of boosts defined by multiples $\eta = n\eta_0$ of the hyperbolic angle $\eta_0 \simeq v_0/c$. This would give $v/c = sinh(n\eta_0) \simeq nv_0/c$. Thus the dark matter systems around which visible matter is condensed would be exact copies of each other in cosmic length scales since G would be an exact symmetry. The property of being an exact copy applies of course only in single level in the dark matter hierarchy. This would mean a delocalization of elementary particles in cosmological length scales made possible by the huge values of Planck constant. A precise cosmic analog for the delocalization of electron pairs in benzene ring would be in question.

Why then η_0 should be quantized as ruler and compass rationals? In the case of Planck constants the quantum phases $q = exp(im\pi/n_F)$ are number theoretically simple for n_F a ruler and compass integer. If the boost $exp(\eta)$ is represented as a unitary phase $exp(im\eta)$ at the level of discretely delocalized dark matter wave functions, the quantization $\eta_0 = n/n_F$ would give rise to number theoretically simple phases. Note that this quantization is more general than $\eta_0 = n_{F,1}/n_{F,2}$.

7.4.11 Further evidence for dark matter

The notion of many-sheeted space-time has been continually receiving qualitative support from various anomalies. In the following two latest anomalies are summarized briefly.

First dark matter galaxy found

The propose model for dark matter suggests an existence of dark matter planets and even dark matter galaxies. Therefore the news about finding of the first dark galaxy in New Scientist [47] came as a pleasant surprise. The galaxy is located at a distance of 10^7 light years. It contains 1 per cent hydrogen gas and and 99 per cent dark matter and is identified by 21 cm hydrogen line: hence the name VIRGOH21. The amount of dark matter counts as 10^8 average stars.

Anomalous chemical compositions at the surface of Sun as evidence for dark matter

Physics in Action, February 2005 contained the popular article "Chemical Controversy at the Solar Surface" by J. Bahcall in Physics in Action [48]. The article describes the problems created by results reported in the article "The Solar Chemical Decomposition" by M. Asplund, N. Grevesse, J. Sauval [49]. The abundances of C, N, O, Ne, Ar at the solar surface are about 30-40 per cent less than predicted by the standard solar model. If these abundances are feeded into the standard solar model as input the predictions change in the range $.45R - .73R$ of distances from solar interior (R is solar radius). In particular, sound velocity is predicted incorrectly. Interestingly, these abundances are consistent with the abundances in the gaseous medium in the neighborhood of our galaxy.

In TGD framework a possible solution of paradox comes from already old model of solar corona and solar magnetic field. Part of matter resides as dark matter at magnetic and Z^0 magnetic flux tubes of Sun (dark energy) and enters to the solar corona along these. That also gaseous medium in the neighborhood of our galaxy contains same abundances suggests that the formation of Sun has proceeded by a transformation of part of dark matter to a visible matter by leakage to space-time sheets visible to us. This is indeed what TGD inspired model for the formation of solar system based on quantal dark matter suggests.

Does Sun have a solid surface?

$n = 1$ Bohr orbit corresponds in a reasonable approximation to $L(276)/9 \simeq L(270)$ and thus to solar radius. This raises the question whether solar surface could contain spherical shell representing a topological condensate of dense matter around dark matter, kind of spherical preform of planet below the photosphere.

Recently new satellites have begun to provide information about what lurks beneath the photosphere. The pictures produced by Lockheed Martin's Trace Satellite and YOHKOH, TRACE and SOHO satellite programs are publicly available in the web. SERTS program for the spectral analysis suggest a new picture challenging the simple gas sphere picture [56]. The visual inspection of the pictures combined with spectral analysis has led Michael Moshina to suggests that Sun has a solid, conductive spherical surface layer consisting of calcium ferrite. The article of Moshina [56] provides impressive pictures, which in my humble non-specialist opinion support this view. Of course, I have not worked personally with the analysis of these pictures so that I do not have the competence to decide how compelling the conclusions of Moshina are. In any case, I think that his web article [56] deserves a summary.

Before SERTS people were familiar with hydrogen, helium, and calcium emissions from Sun. The careful analysis of SERTS spectrum however suggest the presence of a layer or layers containing ferrite and other heavy metals. Besides ferrite SERTS found silicon, magnesium, manganese, chromium, aluminum, and neon in solar emissions. Also elevated levels of sulphur and nickel were observed during more active cycles of Sun. In the gas sphere model these elements are expected to be present only in minor amounts. As many as 57 different types of emissions from 10 different kinds of elements had to be considered to construct a picture about the surface of the Sun.

Moshina has visually analyzed the pictures constructed from the surface of Sun using light at wave lengths corresponding to three lines of ferrite ions (171, 195, 284 Angstroms). On basis of his analysis he concludes that the spectrum originates from rigid and fixed surface structures, which can survive for days. A further analysis shows that these rigid structures rotate uniformly.

The existence of a rigid structure idealizable as spherical shell in the first approximation could by previous observation be interpreted as a spherical shell corresponding to $n = 1$ Bohr orbit of a planet not yet formed. This structure would already contain the germs of iron core and of crust containing Silicon, Ca and and other elements.

There is also another similar piece of evidence [58]. A new planet has been discovered orbiting around a star in a triple-star system in the constellation Cygnus. The planet is a so-called hot Jupiter but it orbits the parent star at distance of .05 AU, which much less that than allowed by current theories of planetary formation. Indeed, the so called migration theory predicts that the gravitational pull of the two stars should have stripped away the proto-planetary disk from the parent star. If an underlying dark matter structure serves as a condensation template for the visible matter, the planetary orbit is stabilized by Bohr quantization.

There is however a problem: ordinary iron and also ordinary iron topologically condensed at dark space-time sheets, becomes liquid at temperature 1811 K at atmospheric pressure. Using for the photospheric pressure p_{ph}, the ideal gas approximation $p_{ph} = n_{ph}T_{ph}$, the values of photospheric temperature $T_{ph} \sim 5800$ K and density $\rho_{ph} \sim 10^{-2}\rho_{atm}$, and idealizing photosphere as a plasma of hydrogen ions and atmosphere as a gas of O_2 molecules, one obtains $n_{ph} \sim .32n_{atm}$ giving $p_{ph} \sim 6.4p_{atm}$. This suggests that calcium ferrite cannot be solid at temperatures of order 5800 K prevailing in the photosphere (the material with highest known melting temperature is graphite with melting temperature of 3984 K at atmospheric pressure). Thus it would seem that dark calcium ferrite at the surface of the Sun cannot be just ordinary calcium ferrite at dark space-time sheets.

The following explanation for the solid surface is perhaps the simplest one found hitherto. Since the atomic energy spectrum is unaffected it seems that $n_a = n_b = 1$ holds true and the radii of Bohr orbitals are scaled up by the factor $n_a^2/n_b = n_a$. If the density of dark matter is roughly the same as that of ordinary matter, the larger size of atoms suggests that melting temperature must be higher than for ordinary matter. Ordinary photons would result via dark-visible phase transition from dark photons emitted by these atoms. Quite generally, spectral lines of molecules in environments in which they should not be thermally stable, would serve as a signature of dark matter with $n_a/n_b = 1$.

How to create dark matter in laboratory...

The creation of dark matter at laboratory is of course the crucial test. The hints for what to do come already from the findings of Tesla, which did not fit completely with Maxwell's electrodynamics (, which, using M-theory inspired jargon, had become "the only known classical theory of electromagnetism",) and were thus forgotten.

To transform visible matter to dark matter in laboratory one might try to generate conditions in which visible matter leaks to larger space-time sheets. What one could try is to generate pulsed current of electrons. For instance, current could flow to a circuit component acting as a charge reservoir. When the circuit is opened, and current cannot leave the charge reservoir, a situation analogous to a traffic jam occurs and some electrons might leak to larger space-time sheets via join along boundaries bonds generated in the process. Di-electric breakdown along larger space-time sheet would be in question. Recoil effects and zero point kinetic energy liberated as ionizing radiation would serve as a signature of the process. The production of dark matter might occur also in the usual di-electric breakdown and lead to the appearance of electrons in much larger volume after it partially re-enters original space-time sheets. The change of zero point kinetic energy would be liberated as radiation and would cause formation of plasma. Tesla detected dramatic effects of this kind in experiments utilizing sharp pulses.

..or has it already been done?

In their article "Investigation of high voltage discharges in low pressure gases through large ceramic super-conducting electrodes", Modanese and Podkletnov [50] report a fascinating discovery suggesting that some new form of radiation is generated in the di-electric breakdown of a capacitor at low temperature and having super-conductor as a second electrode. This radiation induces oscillatory motion of test penduli but, and this is very strange, its intensity is not reduced with distance.

The TGD based explanation [G3] would be in terms of either "topological light rays" or what I call in honor of Tesla "scalar wave pulses" (much like a capacitor moving with velocity of light predicted by TGD but not allowed by Maxwell's ED). This radiation would induce the formation of join along boundaries bonds between atomic and larger space-time sheets and part of electrons from penduli would leak to larger space-time sheets and their motion would result as a recoil effect. The radiation would have only the role of control signal and this would explain why its intensity is not weakened.

From the point of view of single sheeted space-time an over-unity device would be in question since the zero point kinetic energy would be transformed to kinetic energy. The transformation of visible matter to dark matter is in TGD Universe the basic mechanism of metabolism predicting universality of metabolic energy currencies and living matter in TGD Universe has developed a refined machinery to recycle the dropped charges back to the atomic space-time sheets to be used again. Combined with time mirror mechanism this makes, not a perpetuum mobile, but an extremely flexible mechanism of metabolism.

7.4.12 Anti-matter and dark matter

The usual view about matter anti-matter asymmetry is that during early cosmology matter-antimatter asymmetry characterized by the relative density difference of order $r = 10^{-9}$ was somehow generated and that the observed matter corresponds to what remained in the annihilation of quarks and leptons to bosons. A possible mechanism inducing the CP asymmetry is based on the CP breaking phase of CKM matrix.

The TGD based view about energy [D3, D5] forces the conclusion that all conserved quantum numbers including the conserved inertial energy have vanishing densities in cosmological length scales. Therefore fermion numbers associated with matter and antimatter must compensate each other. Therefore the standard option as such is definitely excluded in TGD framework although CKM matrix might well relate to the generation of matter antimatter asymmetry as discussed in [F6].

An early TGD based scenario explains matter antimatter asymmetry by assuming that antimatter is in topological vapor phase. This requires that matter and antimatter have slightly different topological evaporation rates with the relative difference of rates characterized by the parameter r. A more general scenario assumes that matter and antimatter reside at different space-time sheets.

The reader can easily guess the next step. The strict non-observability of antimatter finds an elegant explanation if matter and anti-matter are dark relative to each other. For instance, the masses of particles of antimatter could be scaled down so that antimatter could be practically everywhere without appreciably affecting the density of gravitational mass.

The matter antimatter asymmetry should be generated during cosmic evolution already before the formation of nucleons during the primordial synthesis of matter and antimatter. The number theoretical model for topological condensation based on formation of # contacts between space-time sheets of opposite time orientations (and thus opposite signs for energies) leads to a more detailed view about what might happen.

contacts can be modeled as CP_2 type extremals which simultaneously topologically condense to the two space-time sheets with Minkowskian signature of induced metric. The resulting two causal horizons are carriers of elementary particle quantum numbers and are identifiable as partons. The # contacts with vanishing net quantum numbers could be generated spontaneously and the splitting of # contact would create positive particle and negative energy particle at the two space-time sheets involved. The requirement that the net quantum numbers of Universe vanish is consistent with this kind of pairing of positive and negative energy space-time sheets.

Number theoretical vision [E3, F6] leads to a vision in which elementary particles correspond to infinite primes, perhaps also integers, or even rationals which in turn can be mapped to finite rationals. To infinite primes, integers, and rationals is is possible to associate a finite rational $q = m/n$ by a homomorphism. q defines an effective q-adic topology of space-time sheet consistent with p-adic topologies defined by the primes dividing m and n ($1/p$-adic topology is homeomorphic to p-adic topology).m and n are exchanged by super-symmetry and the primes dividing m (n) correspond to space-time sheets with positive (negative) time orientation. The largest prime dividing m (n) determines the mass scale of the space-time sheet in p-adic thermodynamics. Two space-time sheets characterized by rationals having common prime factors can be connected by a $\#_B$ contact and can interact by exchange of particles characterized by divisors of m or n. Thus fundamental topological selection rules would be coded by the hierarchy of infinite primes.

A possible interpretation is that particle (in extremely general sense that even entire universe can be regarded as a particle) corresponds to a pair of positive and negative energy space-time sheets labeled by m and n characterizing the p-adic topologies consistent with $m-$ and n-adicities. This looks natural since Universe has necessary vanishing net quantum numbers. Unless one allows the non-uniqueness due to $m/n = mr/nr$, positive and negative energy space-time sheets can be connected only by # contacts so that positive and negative energy space-time sheets cannot interact via the formation of $\#_B$ contacts and would be therefore dark relative to each other. Negative energy antiparticles would also have different p-adic mass scales. If the rate for the creation of # contacts and their CP conjugates are slightly different, say due to the presence of electric components of gauge fields, matter antimatter asymmetry could be generated primordially.

7.5 Explanations of some astrophysical and cosmological anomalies

In the sequel some astrophysical and cosmological anomalies such as the apparent shrinking of solar system observed by Masreliez, Pioneer anomaly, Flyby anomaly and new anomalies in cosmic microwave background.

7.5.1 Apparent shrinking of solar system

The findings of Masreliez

There are two means of determining the positions of planets in the solar system [40, 41, 42, 44]. The first method is based on optical measurements and determines the position of planets with respect to the distant stars. Already thirty years ago [44] came the first indications that the planetary positions determined in this manner drift from their predicted values as if planets were in accelerated motion. The second method determines the relative positions of planets using radar ranging: this method does not reveal any such acceleration.

C. J. Masreliez [41] has proposed that this acceleration could be due to a gradual scaling of the planetary system so that the sizes L of the planetary orbits are reduced by an over-all scale factor $L \rightarrow L/\lambda$, which implies the acceleration $\omega \rightarrow \lambda^{3/2}\omega$ in accordance with the Kepler's law $\omega \propto 1/L^{3/2}$. This scaling would exactly compensate the cosmological scaling $L \rightarrow (R(t)/R_0)\times L$ of the solar system size L, where $R(t)$ the curvature parameter of Robertson-Walker cosmology having the line element

$$ds^2 = dt^2 - R^2(t)\left(\frac{dr^2}{1+r^2} + r^2 d\Omega^2\right) \quad . \tag{7.5.1}$$

According to Masreliez, the model explains also some other anomalies in the solar system, such as angular momentum discrepancy between the lunar motion and the spin-down of the Earth [41]. The model also changes the rate for the estimated drift of the Moon away from the Earth so that the Moon could have very well formed together with Earth some five billion years ago.

Bohr quantization of planetary orbits predicts that orbital radii are constant in Minkowski coordinates. Hence solar system would not participate cosmic expansion and the radii of planets shrink in Robertson-Walker coordinates. This model is definitely the simplest one.

The basic coordinate systems

Consider now the previous argument in more detail. The first task is to identify the coordinates appearing in the equations of motion of the planetary system. Denote the standard spherical Minkowski coordinates by (m^0, r_M, θ, ϕ). The line element reads as

$$ds^2 = d(m^0)^2 - dr_M^2 - r_M^2 d\Omega^2 \quad . \tag{7.5.2}$$

Light cone coordinates are related to these coordinates by the relationship

$$a = \sqrt{m_0^2 - r_M^2} \quad , \quad r = r_M/a \quad . \tag{7.5.3}$$

Here a is the light cone proper time along radii from the tip of the light cone $a = constant$ surfaces are hyperboloids. The line element is given

$$ds^2 = da^2 - a^2\left(\frac{dr^2}{1+r^2} + r^2 d\Omega^2\right) \tag{7.5.4}$$

and is nothing but the empty space Minkowski metric.

The Robertson-Walker metric for the space-time sheet reads as

$$ds^2 = g_{aa} da^2 - a^2 (\frac{dr^2}{1+r^2} + r^2 d\Omega^2) \ . \tag{7.5.5}$$

The space-time sheet possessing this metric as induced metric is obtained as a map $M^4_+ \rightarrow CP_2$ having the form $s^k = s^k(a)$, where s^k denote CP_2 coordinates satisfying the constraint

$$g_{aa} = 1 - s_{kl}\partial_a s^k \partial_a s^l \ , \tag{7.5.6}$$

where s_{kl} denotes the metric tensor of CP_2.

One can introduce cosmic time as proper time coordinate t, or Hubble time as it is called, by the equation

$$\frac{dt}{da} = \sqrt{g_{aa}} \ . \tag{7.5.7}$$

For the matter-dominated cosmology one as

$$\frac{t}{t_0} = (\frac{a}{a_0})^{3/2} \ . \tag{7.5.8}$$

$t \simeq 1.5 \times 10^{10}$ ly is the value which explains the planetary acceleration in the model of Masreliez.

The basic question concerns the connection between cosmic coordinates and the radial and time coordinates (r_{PN}, t_{PN}) used in Post-Newtonian approximation. The correspondence $(t = t_{PN}, r = r_{PN})$ is the natural first approximation.

The cosmic time dilation would slow down the time scale of the planetary dynamics and cosmic expansion would lead to adiabatic expansion of the size of the solar system. This would predict the scaling $L(a)/L(a_0) = a/a_0$ for the sizes of the planetary orbits as measured using the r_M coordinate of M^4_+ metric whereas angular velocities of planets would remain constant $\omega(a)/\omega(a_0) = constant$. The solar system would gradually decay.

The condition that solar system does not participate cosmic expansion

If the solar system does not participate in cosmic expansion, one has $L(a)/L(a_0) = constant$ and the scalings

$$\frac{\omega(a)}{\omega(a_0)} = (\frac{a}{a_0})^{3/2} = \frac{t}{t_0} \ , \quad \frac{v(a)}{v(a_0)} = (\frac{a}{a_0})^{1/2} = (\frac{t}{t_0})^{1/2} \tag{7.5.9}$$

for the angular velocity ω and and tangential velocity v along the orbit. The equation for the angular acceleration is $d\omega/dt = \omega/t$. This result differs by a factor of 3 from the equation $d\omega/dt = 3\omega/t$ of Masreliez [41]. On basis of work of Masreliez one can conclude this kind of scaling indeed explains the observed drift quite satisfactorily for $t \simeq 5$ billion years (instead of $t = 15$ billion years of [41]). Thus the effect would allow to see the effects of the cosmic expansion in human time scale and would make possible to determine the value of cosmic time t from the planetary dynamics.

Compensation of cosmic expansion from Bohr quantization of planetary orbits?

The Bohr quantization for planetary orbits predicts that the orbital radii measured in terms of M^4 radial coordinate r_M are constant. This means that planetary system does not participate cosmic expansion so that the orbital radii expressed in terms of the coordinate $r = r_M/a$ shrinking. Therefore the stars accelerate with respect to the Robertson-Walker coordinates $(t, r, \Omega))$ defined by the distant stars since in this case the radii correspond naturally to the coordinate $r = r_M/a$ and time variable corresponds to the $dt/da = \sqrt{g_{aa}}$ giving $dr/dt = -Hr_M$ so that cosmic expansion is exactly compensated. This model for the anomaly brings in no additional assumptions besides Bohr quantization and is favored by Occam's razor.

There is an objection against the model based on the effective shift of the space-time sheet of solar system towards geometric future in each quantum jump so that cosmic expansion is compensated and time effectively ceases to flow. The simplest model for the arrow of psychological time found hitherto [E10] assumes however that this kind of effective shifting indeed occurs but in the reverse direction so that the radii would seem to increase rather than decrease. If the M^4 size remains constant, apparent reduction of radii is predicted.

Quite recently (August 2008) there appeared a new experimental claim related to the problem discussed. There is evidence that the value of astronomical unit AU (distance between Sun and Earth) is increasing with a rate about $dAU/dt = 7$ cm/year [43]. Expressed in terms of the Minkowski proper time $a = R(t)$ the rate is about

$$\frac{dlog(AU)}{da} \simeq 4.6 \times 10^{-13} \quad .$$

If the solar system indeed participates cosmic expansion, one has $\frac{dlog(AU)}{da} = 1/a$ and the prediction for the recent Minkowski age of the Universe is $a_{now} = 2.2 \times 10^{12}$ years. If one assumes $a_R \simeq 3.3 \times 10^7$ y for the time when matter began to dominate, one obtains

$$t - t_R = \int_{a_R}^{a} \sqrt{g_{aa}} da \quad , \quad g_{aa} = (\frac{a}{a_R})^{1/2} \quad .$$

This would give $t_{now} \simeq 4 \times 10^{10}$ years which is about 8 times longer than the age $t_{now} = 0.5 \times 10^{10}$ ly explaining the claims of Mazreliez. The latter would give $a_{now} \simeq 4 \times 10^{11}$ y, which is ten times shorter than the value required by the interpretation of the increase of AU as being due to the cosmic expansion.

In any case, if the increase of AU is real, it challenges the hypothesis that the quantum size of the solar system remains exactly constant and increases only in the phase transitions increasing the value of the gravitational Planck constant. One could consider the possibility that some new effect which is by a factor 1/10 smaller than that caused by the cosmic expansion is present. A possible explanation consistent with the constant M^4 size of the solar system is based on the idea that the space-time sheet along which the radar radiation propagates, develops gradually riples. Also the emergence of new space-time sheets condensed to the space-time sheet along which rader photons propagate could be involved. This increasing metric noise would mean that the distance traveled by the radar photons along the space-time sheet in question gradually increases so that the time taken by the radar signal to travel from Earth to Sun and back increases.

7.5.2 Pioneer anomaly

The data gathered during one quarter of century ([29, 28]) seem to suggest that spacecrafts do not obey the laws of Newtonian gravitation. What has been observed is anomalous constant acceleration of order $(8 \pm 3) \times 10^{-11} g$ ($g = 9.81\ m/s^2$ is gravitational acceleration at the surface of Earth) for the Pioneer/10/11, Galileo and Ulysses [28]. The acceleration is directed towards Sun and could have an explanation in terms of $1/r^2$ long range force if the density of charge carriers of the force has $1/r$ dependence on distance from the Sun. From the data in [29, 28], the anomalous acceleration of the spacecraft is of order

$$\delta a \sim .8 \times 10^{-10} g \ ,$$

where $g \simeq 9.81\ m/s^2$ is gravitational acceleration at the surface of Earth. Using the values of Jupiter distance $R_J \simeq .8 \times 10^{12}$ meters, radius of Earth $R_E \simeq 6 \times 10^6$ meters and the value Sun to Earth mass ratio $M_S/M_E \simeq .3 * 10^6$, one can relate the gravitational acceleration

$$a(R) = \frac{GM_S}{R^2} = \frac{M_S}{M_E}\frac{R_E^2}{R^2}$$

of the spacecraft at distance $R = R_J$ from the Sun to g, getting roughly $a \simeq 1.6 \times 10^{-5} g$. One has also

$$\frac{\delta a}{a} \simeq 1.3 \times 10^{-4} \ .$$

The value of the anomalous acceleration has been found to be $a_F = (8.744 \pm 1.33) \times 10^{-8}$ cm/s^2 and given by Hubble constant: $a_F = cH$. $H = 82$ km/s/Mpc gives $a_F = 8 \times 10^{-8}$ cm/s^2. It is very difficult to believe that this could be an accident. There are also diurnal and annual variations in the acceleration anomaly [59]. These variations should be due to the physics of Earth-Sun system. I do not know whether they can be understood in terms of a temporal variation of the Doppler shift due to the spinning and orbital motion of Earth with respect to Sun.

The most plausible model for the acceleration anomaly relies on the presence of dark matter increasing the effective solar mass. Since acceleration anomaly is constant, a dark matter density behaving like $\rho_d = (3/4\pi)(H/Gr)$, where H is Hubble constant giving $M(r) \propto r^2$, is required. For instance, at the radius R_J of Jupiter the dark mass would be about $(\delta a/a)M(Sun) \simeq 1.3\times 10^{-4} M(Sun)$ and would become comparable to M_{Sun} at about $100R_J = 520$ AU. Note that the standard theory for the formation of planetary system assumes a solar nebula of radius of order 100AU having 2-3 solar masses. For Pluto at distance of 38 AU the dark mass would be about one per cent of solar mass. This model would suggest that planetary systems are formed around dark matter system with a universal mass density. For this option dark matter could perhaps be seen as taking care of the contraction compensating for the cosmic expansion by using a suitable dark matter distribution.

In [59] the possibility that the acceleration anomaly for Pioneer 10 (11) emerged only after the encounter with Jupiter (Saturn) is raised. The model explaining Hubble constant as being due to a radial contraction compensating cosmic expansion would predict that the anomalous acceleration should be observed everywhere, not only outside Saturn. The model in which universal dark matter density produces the same effect would allow the required dark matter density $\rho_d = (3/4\pi)(H/Gr)$ be present only as a primordial density able to compensate the cosmic expansion. The formation of dark matter structures could have modified this primordial density and visible matter would have condensed around these structures so that only the region outside Jupiter would contain this density.

7.5.3 Fly-by anomaly

The so called flyby anomaly [59] might relate to the Pioneer anomaly. Fly-by mechanism used to accelerate space-crafts is a genuine three body effect involving Sun, planet, and the space-craft. Planets are rotating around sun in an anticlockwise manner and when the space-craft arrives from the right hand side, it is attracted by a planet and is deflected in an anticlockwise manner and planet gains energy as measured with respect to solar center of mass system. The energy originates from the rotational motion of the planet. If the space-craft arrives from the left, it loses energy. What happens is analyzed in [59] using an approximately conserved quantity known as Jacobi's integral $J = \mathcal{E} - \omega \overline{e}_z \cdot \overline{r} \times \overline{v}$. Here $\mathcal{E}$ is total energy per mass for the space-craft, ω is the angular velocity of the planet, $\overline{e}_z$ is a unit vector normal to the planet's rotational plane, and various quantities are with respect to solar cm system.

This as such is not anomalous and flyby effect is used to accelerate space-crafts. For instance, Pioneer 11 was accelerated in the gravitational field of Jupiter to a more energetic elliptic orbit directed to Saturn ad the encounter with Saturn led to a hyperbolic orbit leading out from solar system.

Consider now the anomaly. The energy of the space-craft in planet-space-craft cm system is predicted to be conserved in the encounter. Intuitively this seems obvious since the time and length scales of the collision are so short as compared to those associated with the interaction with Sun that the gravitational field of Sun does not vary appreciably in the collision region. Surprisingly, it turned out that this conservation law does not hold true in Earth flybys. Furthermore, irrespective of whether the total energy with respect to solar cm system increases or decreases, the energy in planet-spacecraft cm system increases during flyby in the cases considered.

Five Earth flybys have been studied: Galileo-I, NEAR, Rosetta, Cassina, and Messenger and the article of Anderson and collaborators [59] gives a nice quantitative summary of the findings and of the basic theoretical notions. Among other things the tables of the article give the deviation $\delta\mathcal{E}_{g,S}$ of the energy gain per mass in the solar cm system from the predicted gain. The anomalous energy gain in rest Earth cm system is $\Delta\mathcal{E}_E \simeq \overline{v}\cdot\Delta\overline{v}$ and allows to deduce the change in velocity. The general order of magnitude is $\Delta v/v \simeq 10^{-6}$ for Galileo-I, NEAR and Rosetta but consistent with zero for Cassini and Messenger. For instance, for Galileo I one has $v_{\infty,S} = 8.949$ km/s and $\Delta v_{\infty,S} = 3.92 \pm .08$ mm/s in solar cm system.

Many explanations for the effect can be imagined but dark matter is the most obvious candidate in TGD framework. The model for the Bohr quantization of planetary orbits assumes that planets are concentrations of the visible matter around dark matter structures. These structures could be tubular structures around the orbit or a nearly spherical shell containing the orbit. The contribution of the dark matter to the gravitational potential increases the effective solar mass $M_{eff,S}$. This of course cannot explain the acceleration anomaly which has constant value. One can also consider dark matter rings associated with planets and perhaps even Moon's orbit is an obvious candidate now. It turns out that the tube associated with Earth's orbit and deformed by Earth's presence to equatorial plane of Earth explains qualitatively the known facts.

Roughly half year after writing this, a rather convincing and very simple model explaining the effect as a relativistic transverse Doppler effect appeared [61] (see the comment at the end of this section). Therefore the dark matter ring - if present - can give only an additional contribution to the transverse Doppler effect.

Dark matter at a spherical cell containing Earth's orbit?

For instance, if the space-craft traverses shell structure, its kinetic energy per mass in Earth cm system changes by a constant amount not depending on the mass of the space-craft:

$$\frac{\Delta E}{m} \simeq v_{\infty,E}\Delta v \quad = \quad \Delta V_{gr} = \frac{G\Delta M_{eff,S}}{R} \quad . \tag{7.5.10}$$

Here R is the outer radius of the shell and $v_{\infty,E}$ is the magnitude of asymptotic velocity in Earth cm system. This very simple prediction should be testable. If the space-craft arrives from the direction of Sun the energy increases. If the space-craft returns back to the sunny side, the net anomalous energy gain vanishes. This has been observed in the case of Pioneer 11 encounter with Jupiter [59].

The mechanism would make it possible to deduce the total dark mass of, say, spherical shell of dark matter. One has

$$\begin{aligned} \frac{\Delta M}{M_S} &\simeq \frac{\Delta v}{v_{\infty,E}}\frac{2K}{V} \ , \\ K &= \frac{v^2_{\infty,E}}{2} \ , \ V = \frac{GM_S}{R} \ . \end{aligned} \tag{7.5.11}$$

For the case considered $\Delta M/M_S \geq 2\times 10^{-6}$ is obtained. Note that the amount of dark mass within sphere of 1 AU implied by the explanation of Pioneer anomaly would be about $6.2\times 10^{-6}M_S$ from Pioneer anomaly whereas the mass of Earth is $M_E \simeq 5\times 10^{-6}M_S$. Since the orders of magnitude are same one might consider the possibility that the primordial dark matter has concentrated in spherical shells in the case of inner planets as indeed suggested by the model for quantization of radii of planetary orbits. Of course, the total mass associated with $1/r$ density quite too small to explain entire mass of the solar system.

In the solar cm system the energy gain is not constant. Denote by $\overline{v}_{i,E}$ and $\overline{v}_{f,E}$ the initial and final velocities of the space-craft in Earth cm. Let $\Delta\overline{v}$ be the anomalous change of velocity in the encounter and denote by θ the angle between the asymptotic final velocity $\overline{v}_{f,S}$ of planet in solar cm. One obtains for the corrected $\mathcal{E}_{g,S}$ the expression

$$\mathcal{E}_{g,S} \quad = \quad \frac{1}{2}\left[(\overline{v}_{f,E}+\overline{v}_P+\Delta\overline{v})^2-(\overline{v}_{i,E}+\overline{v}_P)^2\right] \quad . \tag{7.5.12}$$

This gives for the change $\delta \mathcal{E}_{g,S}$

$$\begin{aligned} \delta \mathcal{E}_{g,S} &\simeq (\overline{v}_{f,E} + \overline{v}_P) \cdot \Delta \overline{v} \simeq v_{f,S} \Delta v \times cos(\theta_S) \\ &= v_{\infty,S} \Delta v \times cos(\theta_S) \ . \end{aligned} \quad (7.5.13)$$

Here $v_{\infty,S}$ is the asymptotic velocity in solar cm system and in excellent approximation predicted by the theory.

Using spherical shell as a model for dark matter one can write this as

$$\delta \mathcal{E}_{g,S} = \frac{v_{\infty,S}}{v_{\infty,E}} \frac{G\Delta M}{R} cos(\theta_S) \ . \quad (7.5.14)$$

The proportionality of $\delta \mathcal{E}_{g,S}$ to $cos(\theta_S)$ should explain the variation of the anomalous energy gain.

For a spherical shell $\Delta \overline{v}$ is in the first approximation orthogonal to v_P since it is produced by a radial acceleration so that one has in good approximation

$$\begin{aligned} \delta \mathcal{E}_{g,S} &\simeq \overline{v}_{f,S} \cdot \Delta \overline{v} \simeq \overline{v}_{f,E} \cdot \Delta \overline{v} \simeq v_{f,S} \Delta v \times cos(\theta_S) \\ &= v_{\infty,E} \Delta v \times cos(\theta_E) \ . \end{aligned} \quad (7.5.15)$$

For Cassini and Messenger $cos(\theta_S)$ should be rather near to zero so that $v_{\infty,E}$ and $v_{\infty,S}$ should be nearly orthogonal to the radial vector from Sun in these cases. This provides a clear cut qualitative test for the spherical shell model.

Dark matter at the orbit of Earth?

An alternative model is based on dark matter on the orbit of Earth. One can estimate the change of the kinetic energy in the following manner.

1. Assume that the the orbit is not modified at all in the lowest order approximation and estimate the kinetic energy gained as the work done by the force caused by the dark matter on the space-craft.

$$\begin{aligned} \frac{\Delta E}{m} &= -G \frac{d\rho_{dark}}{dl} \int_{\gamma_E} dl_E \int_{\gamma_S} d\overline{r_S} \cdot \frac{\overline{r}_{SE}}{r_{SE}^3}) \ , \\ \overline{r}_{SE} &\equiv \overline{r}_S - \overline{r}_E \ . \end{aligned} \quad (7.5.16)$$

   Here γ_S denotes the portion of the orbit of space-craft during which the effect is noticeable and γ_E denotes the orbit of Earth.

   This expression can be simplified by performing the integration with respect to r_S so that one obtains the difference of gravitational potential created by the dark matter tube at the initial and final points of the portion of γ_S:

$$\begin{aligned} \frac{\Delta E}{m} &= V(\overline{r}_{S,f}) - V(\overline{r}_{S,i}) \ , \\ V(\overline{r}_S) &= -G \frac{d\rho_{dark}}{dl} \times \int_{\gamma_E} dl_E \frac{1}{r_{SE}} \ . \end{aligned} \quad (7.5.17)$$

2. Use the standard approximation (briefly described in [59]) in which the orbit of the spacecraft consists of three parts joined continuously together: the initial Kepler orbit around Sun, the piece of orbit which can be approximate with a hyperbolic orbit around Earth, and the final Kepler orbit around Sun. The piece of the hyperbolic orbit can be chosen to belong inside the so called sphere of influence, whose radius r is given in terms of the distance R of planet from Sun by the Roche limit $r/R = (3m/M_{Sun})^{2/5}$. γ_S could be in the first approximation taken to correspond to this portion of the orbit of spacecraft.

3. The explicit expression for the hyperbolic orbit can be obtained by using the conservation of energy and angular momentum and reads as

$$\begin{aligned} u = \frac{r_s}{r} = \frac{2GM}{r} &= \frac{u_0^2}{2v_0^2}[1 + \sqrt{1 + 4u_0^2\frac{v_\infty^2 v_0^2}{sin^2(\phi)}}] \ , \\ u_0 &\equiv \frac{r_s}{a} \ , \ |v \times r| \equiv vr \times sin(\phi) \ . \end{aligned} \quad (7.5.18)$$

The unit $c = 1$ is used to simplify the formulas. r_s denotes Schwartschild radius and v_∞ the asymptotic velocity. v_0 and a are the velocity and distance at closest approach and the conserved angular momentum is given by $L/m = v_0 a$. In the situation considered value of r_S is around 1 cm, the value of a around 10^7 m and the value of v_∞ of order 10 km/s so that the approximation

$$u \simeq u_0\frac{v_\infty}{v_0}sin(\phi) \quad (7.5.19)$$

is good even at the distance of closest approach. Recall that the parameters characterizing the orbit are the distance a of the closest approach, impact parameter b, and the angle 2θ characterizing the angle between the two straight lines forming the asymptotes of the hyperbolic orbit in the orbital plane P_E.

Consider first some conclusions that one can make from this model.

1. Simple geometric considerations demonstrate that the acceleration in the region between Earth's orbit and the part of orbit of spacecraft for which the distance from Sun is larger than that of Earth is towards Sun. Hence the distance of the spacecraft from Earth tends to decrease and the kinetic energy increases. In fact, one could also choose the portion of γ_S to be this portion of the spacecraft's orbit.

2. ΔE depends on the relative orientation of the normal n_S of the the orbital plane P_E of spacecraft with respect to normal n_O the orbital plane P_O of Earth. The orientation can be characterized by two angles. The first angle could be the direction angle Θ of the position vector of the nearest point of spacecraft's orbit with respect to cm system. Second angle, call it Φ, could characterize the rotation of the orbital plane of space-craft from the standard orientation in which orbital plane and space-craft's plane are orthogonal. Besides this ΔE depends on the dynamical parameters of the hyperbolic orbit of space-craft given by the conserved energy $E_{tot} = E_\infty$ and angular momentum or equivalently by the asymptotic velocity v_∞ and impact parameter b.

3. Since the potential associated with the closed loop defined by Earth's orbit is expected to resemble locally that of straight string one expects that the potential varies slowly as a function of $\overline{r}_S$ and that ΔE depends weakly on the parameters of the orbit.

The most recent report [60] provides additional information about the situation.

1. ΔE is reported to be proportional to the total orbital energy E_∞/m of the space-craft. Naively one would expect $\sqrt{E_\infty/m}$ behavior coming from the proportionality ΔE to $1/r$. Actually a slower logarithmic behavior is expected since a potential of a linear structure is in question.

2. ΔE depends on the initial and final angles θ_i and θ_f between the velocity $\overline{v}$ of the space-craft with respect to the normal $\overline{n}_E$ of the equatorial plane P_E or Earth and the authors are able to give an empirical formula for the energy increment. The angle between P_E and P_O is 23.4 degrees. One might hope that the formula could be written also in terms of the angle between v and the normal n_O of the orbital plane. For $\theta_i \simeq \theta_f$ the effect is known to be very small. A particular example corresponds to a situation in which one has $\theta_i = 32$ degrees and $\theta_f = 31$ degrees. Obviously the $P_O \simeq P_E$ approximation cannot hold true. Needless to say, also the model based on spherical shell of dark matter fails.

Is the tube containing the dark matter deformed locally into the equatorial plane?

The previous model works qualitatively if the interaction of Earth and flux tube around Earth's orbit containing the dark matter modifies the shape of the tube locally so that the portion of the tube contributing to the anomaly lies in a good approximation in P_E rather than P_O. In this case the minimum value of the distance r_{ES} between γ_E and γ_S is maximal for the symmetric situation with $\theta_i = \theta_f$ and the effect is minimal. In an asymmetric situation the minimum value of r_{ES} decreases and the size of the effect increases. Hence the model works at least qualitatively of the motion of Earth induces a moving deformation of the dark matter tube to P_E. One can actually write ΔE in a physically rather transparent form showing that it is consistent with the basic empirical findings.

1. By using linear superposition one can write the potential as sum of a potential associated with a tube associated with Earths orbit plus the potential associated with the deformed part minus the potential associated with corresponding non-deformed portion of Earth's orbit:

$$\begin{aligned}
\frac{\Delta E}{m} &= V(\overline{r}_{S,f}) - V(\overline{r}_{S,i}) \ , \\
V(\overline{r}_S) &= -G\frac{d\rho_{dark}}{dl}Z(\overline{r}_S) \ , \\
Z(\overline{r}_S) &= X(\gamma_{orb};\overline{r}_S) + X(\gamma_d;\overline{r}_S) - X(\gamma_{nd};\overline{r}_S) \ , \\
X(\gamma_i;\overline{r}_S) &= \int_{\gamma_i} dl\frac{1}{r_{Si}} \ .
\end{aligned} \tag{7.5.20}$$

   Here the subscripts "orb", "d" and "nd" refer to the entire orbit of Earth, to its deformed part, and corresponding non-deformed part. The entire orbit is analogous to a potential of straight string and is expected to give a slowly varying term which is however non-vanishing in the asymmetric situation. The difference of deformed and non-deformed parts gives at large distances dipole type potential behaving like $1/r^2$ and thus being proportional to v_∞^2 by the above expression for the $u = r_s/r$. The fact that ΔE is proportional to v_∞^2 suggests that dipole approximation is good.

2. One can therefore parameterize ΔE as

$$\begin{aligned}
\frac{\Delta E}{m} &= V(\overline{r}_{S,f}) - V(\overline{r}_{S,i}) \ , \\
V(\overline{r}_S) &= -G\frac{d\rho_{dark}}{dl}Z \ , \\
Z(\overline{r}_S) &= X(\gamma_{orb};\overline{r}_S) + \frac{dcos(\Theta)}{r_S^2} \ .
\end{aligned} \tag{7.5.21}$$

   where Θ is the angle between $\overline{r}$ and the dipole $\overline{d}$, which now has dimension of length. The direction of the dipole is in the first approximation in the equatorial plane and and directed orthogonal to the Earth's orbit.

Consider now the properties of ΔE.

1. In a situation symmetric with respect to the equator E_d vanishes but E_{nd} is non-vanishing which gives as a result potential difference associated with entire Earth's orbit minus the part of orbit contributing to the effect so that the result is by the definition of the approximation very small.

2. As already noticed, dipole field like behavior that the large contribution to the potential is proportional to the conserved total energy $v_\infty^2/2$ at the limit of large kinetic energy.

3. From the fact that potential difference is in question it follows that the expression for the energy gain is the difference of parameters characterizing the initial and final situations. This conforms qualitatively with the observation that this kind of difference indeed appears in the empirical fit. $1/r^2$-factor is also proportional to $sin^2(\phi)$ which by the symmetry of the situation is expected to be same for initial and final situation. Furthermore, ΔE is proportional to the difference of the parameter $cos(\Theta_f) - cos(\Theta_i)$ and this should correspond to the reported behavior: it indeed does as I learned after having received the article in email (the prices of PRL on line articles are too dirty for me!). Note that the result vanishes for the symmetric situation in accordance with the empirical findings.

To sum up, it seems that the qualitative properties of ΔE are indeed consistent with the empirical findings. The detailed fit of the formula of [60] should allow to fix the shape of the deformed part of the orbit.

What induces the deformation?

Authors suggest that the Earth's rotation is somehow involved with the effect. The first thing to notice is that the gravimagnetic field of Earth, call it B_E, predicted by General Relativity is quite too weak to explain the effect as a gravimagnetic force on spacecraft and fails also to explain the fact that energy increases always. Gravito-Lorentz force does not do any work so that the total energy is conserved and $\Delta E = -\Delta V = -\nabla V \cdot \Delta \overline{r}$ holds true, where $\Delta \overline{r}$ is the deflection caused by the gravimagnetic field on the orbit during flyby. Since $\Delta \overline{r}$ is linear in v, ΔE changes sign as the velocity of space-craft changes sign so that this option fails in several manners.

Gravimagnetic force of Earth could be however involved but in a different manner. The gravimagnetic force between Earth and flux tube containing the dark matter could explain this deformation as a kind of frame drag effect: dark matter would tend to follow the spinning of Earth.

1. If the dark matter inside the tube is at rest in the rest frame of Sun (this is not a necessary assumption), it moves with respect to Earth with a velocity $v = -v_E$, where v_E is the orbital velocity of Earth. If the tube is thin, the gravito-Lorentz force experienced by dark matter equals in the first approximation to $F = -v_E \times B_E$ with B_E evaluated at the axis of the tube. TGD based model for B_E [D3] does not allow B_E to be a dipole field. B_E has only the component B^θ and the magnitude of this component relates by a factor $1/sin(\theta)$ to the corresponding component of the dipole field and becomes therefore very strong as one approaches poles. The consistency with the existing experimental data requires that B_E at equator is very nearly equal to the strength of the dipole field. The magnitude of B_E and thus of F is minimal when the deformation of the tube is in P_E, and the deformation occurs very naturally into P_E since the non-gravitational forces associated with the dark matter tube must compensate a minimal gravitational force in dynamical equilibrium.

2. B_E^θ at equator is in the direction of the spin velocity ω of the Earth. The direction of v_E varies. It is convenient to consider the situation in the rest system of Sun using Cartesian coordinates for which the orbital plane of Earth corresponds to (x,y) plane with x- and y-axis in the direction of semi-minor and semi-major axes of the Earth's orbit. The corresponding spherical coordinates are defined in an obvious manner. v_E is parallel to the tangent vector $e_\phi(t) = -sin(\Omega t)e_x + cos(\Omega t)e_y$ of the Earth's orbit. The direction of B_E at equator is parallel to ω and can be parameterized as $e_\omega = cos(\theta)e^z + sin(\theta)(cos(\alpha)e_x + sin(\alpha)e_y)$. F is parallel to the vector $-cos(\theta)e_\rho(t) + sin(\theta)cos(\Omega t - \alpha)e_z$, where $e_\rho(t)$ is the unit vector directed from Sun to Earth. The dominant component is directed to Sun.

Fly-by anomaly as transverse relativistic Doppler effect?

A new twist in the story of fly-by anomaly emerged at September twelfth 2007. The proposal of Jean-Paul Mbelek [61] explains fly-by effect as a relativistic transverse Doppler effect and thus purely kinematic effect. Also the functional dependence of the parameter K characterizing the size of the effect on the kinematic parameters is predicted and the prediction is consistent with the empirical findings in the example considered. Therefore the story of fly-by anomaly might be finished and dark matter at the orbit of Earth could bring in only an additional effect. It is probably too much to hope for this kind of effect to be large enough if present.

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Chapter 8

Quantum Astrophysics

8.1 Introduction

The mechanisms behind the formation of planetary systems, galaxies and larger systems are poorly understood but planar structures seem to define a common denominator and the recent discovery of dark matter ring in a galactic cluster in Mly scale [23] suggest that dark matter rings might define a universal step in the formation of astrophysical structures.

Also the dynamics in planet scale is poorly understood. In particular, the rings of Saturn and Jupiter are very intricate structures and far from well-understood. Assuming spherical symmetry it is far from obvious why the matter ends up to form thin rings in a preferred plane. The latest surprise [18] is that Saturn's largest, most compact ring consist of clumps of matter separated by almost empty gaps. The clumps are continually colliding with each other, highly organized, and heavier than thought previously.

The situation suggests that some very important piece might be missing from the existing models, and the vision about dark matter as a quantum phase with a gigantic Planck constant [A9] is an excellent candidate for this piece. The vision that the quantum dynamics for dark matter is behind the formation of the visible structures suggests that the formation of the astrophysical structures could be understood as a consequence of Bohr rules [D6].

8.1.1 Generalization of the notion of imbedding space

Quite generally, the hierarchy of Planck constants is realized by generalizing the notion of imbedding space such that one has a book like structure with various almost-copies of imbedding space glued together like pages of book. Each page of book correspond to a particular level of dark matter hierarchy and darkness means that there are no Feynman diagrams in which particles with different value of Planck constant would appear. The interactions between different levels of hierarchy involve the transfer of the particles mediating the interaction between different pages of the book. Physically this means a phase transition changing the value of Planck constant assignable to the particle so that particle's quantum size is scaled. At classical level the interactions correspond to the leakage of magnetic and electric fluxes and radiation fields between different pages of the book.

The development of the view about generalized imbedding space

The development of precise formulation of the realization of Planck constants in terms of the book like structure of imbedding space has been a sequence of improved trials.+

1. Since space-time surfaces are 4-surfaces in the generalized imbedding space, Bohr rules can be formulated in a manner which is general coordinate invariant and Lorentz invariant. The rules are actually for dark matter structures obeying Z_n symmetry for very large n characterizing a symmetry of field bodies associated with the structure in question. Z_n was identified as a maximal cyclic subgroup for any subgroup $G \subset SO(3)$ appearing in the series of Jones inclusions with index $\mathcal{M}/\mathcal{N} < 4$ but also $\mathcal{M}/\mathcal{N} \geq 4$ can be considered. Two questions arise. What distinguishes between these two cases and what is the precise action of G.

2. The first generalization of the imbedding space assigned Z_n to rotations in M^4 degrees of freedom acting as symmetries of factor space obtained dividing with subgroup of $G \subset SO(3)$ having Z_n as maximal cyclic subgroup. The outcome was a book like structure associated with $M^4\backslash M^2$ with M^2 defining the back of the book and characterizing the direction of quantization axes for spin. The choice of M^2 has interpretation as fixing choice of the direction of quantization axes. The world of classical worlds (WCW) would be union over different choices of M^2.

3. This generalization was not enough to really understand the physics behind gravitational Planck constant, and the next generalization assigned the groups associated with Jones inclusions also with CP_2 degrees of freedom and acting also now as invariance group of orbifold structure associated with CP_2. In CP_2 degrees of freedom the back of the book is defined by homologically trivial geodesic sphere S^2 of CP_2. Therefore one has book like structure in both M^4 and CP_2 degrees of freedom.

4. The attempts to understand Quantum Hall effect suggested a generalization, which allowed both factor spaces and coverings of both M^4 and CP_2. In the case of coverings the action of Z_n contained by the group assignable to Jones inclusion permutes the sheets of the singular covering space of $M^4\backslash M^2$ $(CP_2\backslash S^2)$. In the similar manner the group acts in the singular factor space associated with $M^4\backslash M^2$ $(CP_2\backslash S^2)$. The coverings were assigned with Jones inclusions having index $\mathcal{M}/\mathcal{N} \geq 4$.

5. The emergence of zero energy ontology induced further detail to this picture. In zero energy ontology causal diamond (CD) of M^4 defined as the intersection of future and past directed light-cones is basic structure. $CD \times CP_2$ contains positive (negative) energy parts of the zero energy state at the lower (upper) light-like boundary δM^4_+ δM^4_-. Each CD defines sector in the world of classical worlds (WCW) consisting of light-like 3-surfaces and corresponding 4-surfaces inside $CD \times CP_2$. Each sector of this kind in turn corresponds a union over copies of CDs corresponding to different choices of quantization axes for Poincare and color quantum numbers so that the selection of quantization axis means a localization to one particular variant of given CD. Temporal and spatial localization in turn fixes the lower tip of CD: the location of upper tip is fixed by the condition that the temporal distance between upper and lower tip is quantized in powers of two: this assumption implies p-adic length scale hypothesis. The singular covering and factor spaces of CD:s become the pages of the book like structures. One can say that these books are like rigid bodies located in $M^4 \times CP_2$ and that they have also rotational and color rotational degrees of freedom so that WCW is kind of gigantic quantum library.

6. The most tortuous piece of the tortuous development of the ideas were the guesses for the formula for Planck constant in terms of integers n_a and n_b characterizing the orders of maximal cyclic subgroups of G_a and G_b. The realization that the formula could be interpreted as homomorphism from the set of pages of the book left still two options for which expressions for the Planck constant were inverses of each other. I of course chose the wrong one first. The model for quantum Hall effect however dictated uniquely the correct option [F12], and this option is favored by the gravitational Bohr orbitology and the model for dark graviton emission.

7. For this proposal one obtains in the case of gravitation dark matter symmetries with large Z_n acting in the covering of CD so that no discrete rotational invariance in CD is predicted. In CP_2 degrees of freedom one can have both coverings ($r = \hbar/\hbar_0 = n_a/n_b$) and factor spaces $r = \hbar/\hbar_0 = n_a n_b$, where n_i is the order of the maximal cyclic subgroup of G_i, $i = a, b$ corresponding to M^4 and CP_2 degrees of freedom. The options for which both G_a and G_b act as orbifold symmetries are not favored by dark gravitation but could be realized in living matter where G_a could correspond to a small subgroup of rotation group acting as symmetries of bio-molecules.

Extension of imbedding space by allowing coverings

The allowance of coverings means an extension of the imbedding space by allowing also G_a *resp.* G_b-fold coverings of $\hat{CD} = CD\backslash M^2$ *resp.* $\hat{CP}_2 = CP_2\backslash S^2$. Here M^2 corresponds to 2-D Minkowski space defined by the fixing of rest frame and direction of quantization axis of angular momentum and S^2 to a homologically trivial geodesic sphere of CP_2 which corresponds to a particular choice of group $SO(3) \subset SU(3)$ and thus fixing of quantization axes of color isospin. The surfaces $X^4 \subset M^4 \times S^2$ are vacuum extremals as required by internal consistency of the theory. The leakage between different pages of book occurs via manifolds $CD \times S^2$ and $(M^2 \cap CD) \times CP_2$ which correspond to quantum criticality. The extreme form of quantum criticality corresponds to leakage through $M^2 \times S^2$.

The book structure has four kinds of pages. As the discussion of Appendix shows one can consider two different formulas for the Planck constant and there is a good argument for selecting the second one. Unfortunately, the choice for the formula was wrong in the earlier version of this chapter. The formula, which seems to be the correct one gives the following results.

1. $[\hat{CD}" \times "G_a] \times [\hat{CP}_2" \times "G_b]$ with $\hbar/\hbar_0 = n_a/n_b$;

2. $[\hat{CD}" \times "G_a] \times [\hat{CP}_2/G_b]$ with $\hbar/\hbar_0 = n_a n_b$: " $\times$ "G_i refers to G_i covering. Note that Planck constant is always larger than its standard value $\hbar_0$ ($n_a = n_b = 1$) in this case implying for instance that the binding energy scale of hydrogen atom is scaled up;

3. $[\hat{CD}/G_a] \times [\hat{CP}_2/G_b]$ with Planck constant $\hbar/\hbar_0 = n_b/n_a$: n_i is the order of maximal cyclic subgroup of G_i. Only these pages were included in the original "book": the problem concerning biological applications is that large values of Planck constant require high rotational symmetries;

4. $[\hat{CD}/G_a] \times [\hat{CP}_2" \times "G_b]$ with $\hbar/\hbar_0 = 1/(n_a n_b)$; note that in this case the Planck constant is minimal.

One can distinguish between pages corresponding to coverings and factors spaces of CD.

1. Pages of type 1) and 2) for which G_a acts in covering space of CD are the most promising candidates for the modeling dark gravitons and gravitational Bohr orbitology. They could be involved also with living matter.

2. G_a could act as factor space symmetries in living matter. Molecular rotational symmetries correspond typically to small groups G_a $G_a = Z_n$, $n = 5, 6$ are favored for molecules containing aromatic cycles and could correspond to factor spaces in M^4 degrees of freedom and coverings in CP_2 degrees of freedom ($r = n_b/n_a$). Also genuinely 3-dimensional tedrahedral, octahedral, and icosahedral symmetries appear in living matter. Even the symmetries of snow flakes could be understood if n_b is large enough so that quantum scale proportional to n_b/n_a is macroscopic.

3. Also astrophysical systems might possess small G_a as orbifold symmetries and the hexagonal structure at the North Pole of Saturn could be an example of $n_a = 6$ fold symmetry but the assignment of these symmetries to gravitational interactions does not seem plausible so that these symmetries could be analogous to symmetries of living matter or of snow flakes.

It must be emphasized that this interpretation differs quite a lot from the earlier one which assumed the formula of Planck constant is the inverse of the recent formula.

8.1.2 Gravitational Bohr orbitology

The basic question concerns justification for gravitational Bohr orbitology. The basic vision is that visible matter identified as matter with $\hbar = \hbar_0$ ($n_a = n_b = 1$) concentrates around dark matter at Bohr orbits for dark matter particles. The question is what these Bohr orbits really mean. Should one in improved approximation relate Bohr orbits to 3-D wave functions for dark matter as ordinary Bohr rules would suggest or do the Bohr orbits have some deeper meaning different from that in wave mechanics.

The first vision

The first vision about gravitational Bohr orbitology was inspired by the finding that surprisingly complex geometric structures possessing relatively small subgroups of rotational group as approximate symmetry groups appear in astrophysical scales. This would suggest circles and spokes representing dark matter structures, gravi-electric flux quanta, and also circles representing gravi-magnetic flux tubes orthogonal to the quantization plane become are building blocks of dark matter structures and that the group G_a acting as orbifold symmetries is behind these symmetries.

Simplest of them are rings and cart-wheel like structures with rather small symmetry groups which are however badly broken. One could however argue that this breaking occurs only at the level of visible manner and that the origin of the symmetry is relatively small G_a or its subgroup acting as a subgroup of CD orbifold. This would require very large G_b acting as orbifold symmetry in CP_2 degrees of freedom.

Also large values of n_a the subgroups of Z_{n_a} could be considered. In this case Z_{b_a} would act as rotational symmetries of magnetic body could act as approximate symmetries of the visible matter and if one accepts ruler-and-compass hypothesis powerful predictions follow. On the other hand, n_a can be also small and correspond to symmetries of visible matter in astrophysical scales (say the hexagonal structure associated with Saturnus).

This vision worked nicely for the earlier identification of the formula for Planck constant but not for the identification supported by the explanation of quantum Hall effect. If one assumes that the dark space-time sheets associated with gravitons and matter correspond to same page of the Big Book, this picture leads to difficulties since large n_b for orbifold and small n_a for covering does not lead to plausible picture about what dark gravitons should be.

Quantum Hall effect and dark anyonic systems

Bohr orbitology could be understood if dark matter concentrates on 2-dimensional partonic surfaces usually assigned with elementary particles and having size of order CP_2 radius. The interpretation is in terms of wormhole throats assignable to topologically condensed CP_2 type extremals (fermions) and pairs of them assignable to wormhole contacts (gauge bosons). Wormhole throat defines the light-like 3-surface at which the signature of metric of space-time surface changes from Minkowskian to Euclidian.

Large value of Planck constant could allow gigantic partons. Since anyonic systems are 2-dimensional, the natural idea is that dark matter corresponds to systems carrying large fermion number residing at partonic 2-surfaces of astrophysical size and that visible matter condenses around these. Not only black holes but also ordinary stars, planetary systems, and planets could correspond at the level of dark matter to atom like structures consisting of anyonic 2-surfaces which can have complex topology (flux tubes associated with planetary orbits connected by radial flux tubes to the central spherical anyonic surface) . Charge and spin fractionization are key features of anyonic systems and Jones inclusions inspiring the generalization of imbedding space indeed involve quantum groups central in the modeling of anyonic systems. Hence one has could hopes that a coherent theoretical picture could emerge along these lines.

This seems to be the case. Anyons and charge and spin fractionization are discussed in detail in the chapter [F12] and leads to a precise identification of the delicacies involved with the Kähler gauge potential of CP_2 Kähler form in the sectors of the generalized imbedding space corresponding to various pages of boook like structures assignable to CD and CP_2. The basic outcome is that anyons correspond geometrically to partonic 2-surfaces at the light-like boundaries of CD containing the tip of CD inside them. This is what gives rise to charge fractionization and also to confinement like effects since elementary particles in anyonic states cannot as such leak to the other pages of the generalized imbedding space. G_a and G_b invariance of the states imply that fractionization occurs only at single particle level and total charge is integer valued.

This picture is much more flexible that that based on G_a symmetries of CD orbifold since partonic 2-surfaces do not possess any orbifold symmetries in CD sector anymore. In this framework various astrophysical structures such as spokes and circles would be parts of anyonic 2-surfaces with complex topology representing quantum geometrically quantum coherence in the scale of say solar system. Planets would have formed by the condensation of ordinary matter in the vicinity of the anyonic matter. This would predict stars, planetary system, and even planets to have onion-like structure consisting of shells at the level of dark matter. Similar conclusion is suggested also by purely classical model for the final state of star predicting that matter is strongly concentrated at the surface of the star [D3].

Quantum criticality and quantum chaos

TGD Universe is quantum critical and quantum criticality corresponds very naturally to what has been identified as the transition region to quantum chaos. The basic formulation of quantum TGD is indeed consistent with what has been learned from the properties of quantum chaotic systems and quantum chaotic scattering [16]. Wave functions are concentrated around Bohr orbits in the limit of quantum chaos, which is just what dark matter picture assumes. In this framework the chaotic motion of astrophysical object becomes the counterpart of quantum chaotic scattering and classical description is predicted to fail. By Equivalence Principle the value of the mass of the object does not matter at all so that the motion of sufficiently light objects in solar system might be understandable only as quantum chaotic scattering. The motion of gravitationally unbound comets and rings of Saturn and Jupiter and the collisions of galactic structures known to exhibit the presence of cart-wheel like structures define possible applications.

The description of gravitational radiation provides a stringent test for the idea about dark matter hierarchy with arbitrary large values of Planck constants. In accordance with quantum classical correspondence, one can take the consistency with classical formulas as a constraint allowing to deduce information about how dark gravitons interact with ordinary matter. The standard facts about gravitational radiation are discussed first and then TGD based view about the situation is sketched in two cases corresponding to large value of n_a characterizing singular CD covering and n_b characterizing either singular CP_2 covering or orbifold.

This discussion forces an important conclusion. The sequential de-coherence leading from dark gravitons with $(n_a > 1, n_b > 1)$ in stepwise manner to visible gravitons having $(n_a = 1, n_b = 1)$ necessary involves steps in which the frequency of resulting lower level gravitons is subharmonic of the original frequency. Period doubling is favored since powers of two are favored for n_a and n_b. The generation of sub-harmonics is one of the basic routes to chaos which suggests that chaos in astrophysical systems corresponds to large values of n_b with powers of 2 favored. Quite generally, the approach to quantum chaos would transform $\hbar/\hbar_0$ from integer to a rational with increasing denominator.

The planetary Bohr orbitology has been already discussed in the chapter "TGD and Astrophysics" [D6] with applications solar system and exo-planets. This discussion is not based on the full generalization of the imbedding space but the general results are not changed since they depend on the value of Planck constant only. Instead of repeating this discussion, a formulation of these rules which is general coordinate invariant and Lorentz invariant is proposed.

About the spectrum of v_0

The proposed generalization of the imbedding space allows in principle any rational multiple of $\hbar_0$ as the value of Planck constant and given value of Planck constant is realized by very many pages of the book like structure. For instance, when both M^4 and CP_2 correspond to coverings all integer multiples of (n_a, n_b) produce same Planck constant.

The dependence of the gravitational Planck constant on masses is fixed by Equivalence Principle. Its strongest form would require a universal value of v_0. This form is not realized.

1. Different value of v_0 is required for inner and outer planets. I have discussed a simple model explaining why inner and outer planets must have different values of v_0 by taking into account cosmic string contribution to the gravitational potential which is negligible nowadays but was not so in primordial times. Among other things this implies that planetary system has a finite size, at least about 1 ly in case of Sun (nearest star is at distance of 4 light years). The proposed anyonic picture would suggest that the anyonic 2-surface assignable to outer and inner planets is different.

2. Quantization rules have been applied to exoplanets in the case that the central mass and orbital radius are known (the discussion is moved from the chapter "Astrophysics" to the the Appendix of this chapter). Errors are around 10 per cent for the most favored value of $v_0 = 2^{-11}$. The "anomalous" planets with very small orbital radius correspond to $n = 1$ Bohr orbit ($n = 3$ is the lowest orbit in solar system). The universal velocity spectrum $v = v_0/n$ in simple systems perhaps the most remarkable prediction and certainly testable: this alone implies that the Bohr radius GM/v_0^2 defines the universal size scale for systems involving central mass. Obviously this is something new and highly non-trivial.

3. The recently observed dark ring in MLy scale is a further success and also the rings and Moons of Saturn and Jupiter obey the same universal length scale ($n \geq 5$ and $v_0 \rightarrow (16/15) \times v_0$ and $v_0 \rightarrow 2 \times v_0$).

4. For our own Moon orbital radius is much larger than Bohr radius for $v_0 = 2^{-11}$: one would have $n \simeq 138$. $n \simeq 7$ results for $v_0 \to v_0/20$ giving $r_0 \simeq 1.2R_E$. The small value of v_0 could be understood to result from a sequence of phase transitions reducing the value of v_0 to guarantee that solar system participates in the average sense to the cosmic expansion and from the fact inner planets are older than outer ones in the proposed scenario. The findings of Masreliez [22] discussed in the last section of [D6] support the prediction that planetary system does not participate cosmic expansion in a smooth manner.

The question becomes how to explain what is the correct manner to weaken Equivalence Principle and why the values of v_0 are what they are. The simplest hypothesis is that v_0 has a fixed value for orbits connected by radial flux tubes to a given anyonic 2-surface. If the value of v_0 characterizes different anyonic 2-surfaces to which flux tubes around planetary orbits are connected by radial flux tubes then inner and outer planets would correspond to different anyonic two-surfaces. This would also give a precise characterization for the weakened form of Equivalence Principle. One could see outer planets as planets of the central object formed by Sun and inner planets. This picture would raise spherical surface at the distance of Earth to a very special role as the boundary of this central object and one can wonder whether the very special properties of Earth relate to this special role.

Planetary Bohr orbitology was born as a generalization of atomic Bohr orbitology. One can however turn the situation upside down and ask whether also atom could be seen as an anyonic system in which flux tubes surrounding classical electronic orbits are connected to an anyonic 2-surface assignable to nucleus by radial flux tubes mediating Coulomb interaction. Charge and spin fractionization do not support this idea and anyonic systems are also many-particle systems. It is indeed quite conceivable that atoms in electrons corresponds to CP_2 sized partonic 2-surfaces with atomic wave function assignable to the position of this 2-surface in the interior of larger 3-surface.

There is still one question to be considered. Could one understand why the values of v_0 are what they are?

1. The condition that $\hbar = GM^2/v_0$ gives for the dark Planck length $L_P = \sqrt{\hbar G}$ a value of order Schwartschild radius $r_S = 2GM$ forces $v_0 = 1/4$. The Planck length for $\hbar = GM(sun)M(Planet)/v_0$ corresponds to

$$L_P(\hbar) = \sqrt{\frac{r_S(Sun)r_S(Planet)}{4v_0}} = r_S(Sun)\sqrt{\frac{M(Planet)}{M(Sun)}}\sqrt{\frac{1}{4v_0}} \ .$$

   The smaller mass of planet is compensated by the smallness of v_0 so that $G(\hbar)$ is not too far from $r_S(Sun)$: maybe this condition might fix at least the order of magnitude of v_0 somehow. In the case of Earth and Jupiter having $v_0 = 2^{-11}/5$ one has $G(\hbar) \simeq .27r_S(Sun)$ and $G(\hbar) \simeq 1.6r_S(Sun)$.

2. One can also find justification for why just $v_0 = 2^{-11}$ is preferred. This number corresponds to the rotation velocity v/c of matter around cosmic string like objects assignable to galaxies and is expressible in terms of basic constants of quantum TGD (CP_2 length and Kähler coupling strength) appearing in the expression of string tension of cosmic strings.

8.1.3 How General Coordinate Invariance and Lorentz invariance are achieved?

The basic objection of General Relativist against the planetary Bohr orbitology model is the lack of the manifest General Goordinate and Lorentz invariances. In GRT context this objection would be fatal. In TGD framework the lack of these invariances is only apparent.

One can use Minkowski coordinates of the M^4 factor of the imbedding space $H = M^4 \times CP_2$ as preferred space-time coordinates. The basic aspect of dark matter hierarchy is that it realizes quantum classical correspondence at space-time level by fixing preferred M^4 coordinates as a rest system. This guarantees preferred time coordinate and quantization axis of angular momentum. The physical process of fixing quantization axes thus selects preferred coordinates and affects the system itself at the level of space-time, imbedding space, and configuration space (world of classical worlds). This is definitely something totally new aspect of observer-system interaction.

One can identify in this system gravitational potential Φ_{gr} as the g_{tt} component of metric and define gravi-electric field E_{gr} uniquely as its gradient. Also gravi-magnetic vector potential A_{gr} and and gravi-magnetic field B_{gr} can be identified uniquely.

Quantization condition for simple systems

Consider now the quantization condition for angular momentum with Planck constant replaced by gravitational Planck constant $\hbar_{gr} = GMm/v_0$ in the simple case of point like central mass. The condition is

$$m \oint v \bullet dl \quad = \quad n \times \hbar_{gr} \quad . \tag{8.1.1}$$

The condition reduces to the condition on velocity circulation

$$\oint v \bullet dl \quad = \quad n \times \frac{GM}{v_0} \quad . \tag{8.1.2}$$

In simple systems with circular orbits the condition reduces to a universal velocity spectrum $v = v_0/n$ so that only the radii of orbits depend on mass distribution. For systems for which cosmic string dominates only $n = 1$ is possible. This is the case in the case of stars in galactic halo if primordial cosmic string going through the center of galaxy in direction of jet dominates the gravitational potential. The velocity of distant stars is correctly predicted.

For circular orbits there is no need to apply the condition for other canonical momenta (radial canonical momentum in Kepler problem). The nearly circular orbits of visible matter objects would be naturally associated with dark matter rings or more complex structures dark matter rings could suffer partial or complete phase transition to visible matter.

Generalization of the quantization condition

By Equivalence Principle dark ring mass disappears from the quantization conditions and the left hand side of the quantization condition equals to a generalized velocity circulation applying when central system rotates

$$\oint (v - A_{gr}) \bullet dl. \tag{8.1.3}$$

Note that the geodesic motion of visible matter does not mean closed orbit (perihelion shift of Mercury) and cannot therefore correspond exactly to a motion concentrated at partonic 2-surface containing anyonic dark matter unless dark matter itself is rotating slowly. This is not a problem if the dark matter is concentrated at flux tube surrounding the orbit in turn connected by flux tubes to an anyonic 2-surface assignable to Sun.

The right hand side of the quantization condition would be the generalization of GM by the replacement

$$GM \rightarrow \oint e \bullet r^2 E_{gr} \times dl. \tag{8.1.4}$$

e is a unit vector in direction of quantization axis of angular momentum, $\times$ denotes cross product, and r is the radial M^4 coordinate in the preferred system. Everything is Lorentz and General Coordinate Invariant and for Schwartschild metric this reduces to the expected form and reproduces also the contribution of cosmic string to the quantization condition correctly.

8.2 General quantum vision about formation of structures

The basic observation is that in the case of a straight cosmic string creating a gravitational potential of form v_1^2/ρ Bohr quantization does not pose any conditions on the radii of the circular orbits so that a continuous mass distribution is possible.

This situation is obviously exceptional. If one however accepts the TGD based vision [D5] that the very early cosmology was cosmic string dominated and that elementary particles were generated in the decay of cosmic strings, this situation might have prevailed at very early times. If so, the differentiation of a continuous density of ordinary matter to form the observed astrophysical structures would correspond to an approach to a stationary situation governed by Bohr rules and in the first approximation one could neglect the intermediate stages.

Cosmic string need not be infinitely long: it could branch into flux tubes or flux sheets carrying the return flux. For large distances the whole structure would behave as a single mass point creating ordinary Newtonian gravitational potential. Also phase transitions in which the system emits magnetic flux tubes so that the contribution of the cosmic string to the gravitational force is reduced, are possible.

What is of utmost importance is that the cosmic string induces a breaking of the rotational symmetry selecting a unique preferred orbital plane in which gravitational acceleration is parallel to the plane. This is just what is observed in astrophysical systems and not easily explained in the Newtonian picture. In TGD framework this relates directly to the choice of quantization axis of angular momentum at the level of dark matter. This mechanism could be behind the formation of planar systems in all length scales including planets and their moons, planetary systems, galaxies, galaxy clusters in the scale of Mly, and even the concentration of matter at the walls of large voids in the scale of 100 Mly.

8.2.1 Simple quantitative model

The following elementary model allows to see how the addition of central mass forces the matter to quantized Bohr orbits via the formation of dark matter rings.

The equation for gravitational acceleration

The elementary model for circular orbits involves two equations: the identification radial kinetic acceleration with the acceleration due to the gravitational force and the condition stating quantization of the angular momentum, which requires some additional thought when cosmic string has infinite length.

In cylindrical coordinates the gravitational acceleration due to cosmic string is given by

$$\begin{aligned} a &= \frac{v_1^2}{\rho} \ , \\ v_1^2 &= G\frac{dM}{dL} \ . \end{aligned} \tag{8.2.1}$$

Here v_1 is the rotational velocity of the matter around cosmic string neglecting its own gravitational effects.

The condition for the radial acceleration gives

$$u = \frac{1}{\rho} = \frac{v^2 - v_1^2}{GM} \ . \tag{8.2.2}$$

Quantization of angular momentum

The condition for the quantization of angular momentum is not quite obvious since taking into account the mass of entire cosmic string would give an infinite Planck constant. The resolution of the problem relies on the effective 2-dimensionality and Z_n symmetry of the dark matter meaning that it forms rings.

Consider first the situation when only cosmic is present. For dark matter rings it is angular momentum per unit length which is quantized so that Planck constant is replaced with Planck constant per unit length. Hence one has

$$\frac{d\hbar}{dl} = G \times \frac{m}{2\pi} \times \frac{dM}{dL} \times \frac{1}{v_0} = \frac{m}{2\pi} \times \frac{v_1^2}{v_0} \ . \tag{8.2.3}$$

where m is the mass of dark matter ring. The inclusion of 2π is necessary in order to obtain internal consistency.

The quantization condition for the circular orbits in the presence of only cosmic string would read as

$$\frac{dm}{dl} \times v\rho = n \times \frac{d\hbar}{dl} = n \times \frac{m}{2\pi} \times \frac{v_1^2}{v_0} \ . \tag{8.2.4}$$

By using $dm/dl = m/2\pi\rho$, one obtains

$$v = n\frac{v_1^2}{v_0} \ . \tag{8.2.5}$$

Only $n = 1$ is consistent with $v = v_1^2/v_0$ resulting from the condition for the radial acceleration and there is no condition on ρ.

The contribution of the cosmic string to the Planck constant can be identified as

$$\hbar(string) = m \times \frac{v_1^2}{v_0}\rho \ . \tag{8.2.6}$$

One can say that a length ρ of cosmic string contributes to the Planck constant, and that the active part of that cosmic string and point on ring define an equilateral triangle with sides 1 and $\sqrt{5}$ so that Golden Mean emerges.

The generalization of this equation to the case when also central mass is present reads as

$$v\rho = n\frac{GM + \frac{v_1^2}{v_0}\rho}{v_0} \ . \tag{8.2.7}$$

This gives the quantization condition

$$u = \frac{vv_0 - nv_1^2}{nGM} \ . \tag{8.2.8}$$

Combination of the conditions

The two equations for $u = 1/\rho$ fix the spectrum of velocities and orbital radii. By introducing the parameter $v_1/v_0 = \epsilon$ and the variable $x = v/v_0$ one can write the basic equation as

$$x^2 - \frac{x}{n} = 0 \ . \tag{8.2.9}$$

The solutions are $x = 0$ and $x = 1/n$. Only the latter solution corresponds to $u > 0$. The same spectrum $v = v_0/n$ of velocities is obtained as in the case of hydrogen atom model so that only the radii are modified. The universality of the velocity spectrum corresponds to the reduction of the quantization of angular momentum to that of circulation implied by the Equivalence Principle.

The radii of the orbits are given by

$$\begin{aligned} \rho(n) &= \frac{n^2}{1-n^2\epsilon^2}\times r_0 \ , \\ r_0 &= \frac{GM}{v_0^2} \ . \end{aligned} \quad (8.2.10)$$

For small values of n one obtains Bohr orbits for hydrogen atom like model. For $n = 1$ there is an upwards scaling of Bohr radius by $1/(1-\epsilon^2)$. For large values of n the distances between sub-sequent radii begin to rapidly increase and at the limit $n \rightarrow 1/\epsilon$ the radius becomes infinite. Hence only $n < 1/\epsilon$ orbits are possible meaning that the system has necessarily a finite size for a given value of v_0. Several values of v_0 are however suggested by the Bohr orbit model for the solar system.

8.2.2 Formation of ring like structures

One can consider an initial situation in which one has a continuous mass density rotating with a constant velocity around cosmic string defining the rotation axis of the planet. The situation is inherently unstable and a small perturbation forces the accumulation of both dark and visible matter to Bohr orbits and the upper bound for the value of n implies finite size of the system proportional to the central mass.

Rings of Saturn and Jupiter

The rings of Saturn and Jupiter [19, 20] could be seen a intermediate states in the process leading to the formation of satellites. Both planets indeed possess a large number of satellites [19, 20]. This would suggest that Saturn and Jupiter and outer planets in general are younger than the inner planets in accordance with the different values of v_0. The orbital radii for lowest satellites correspond to $v_0 \rightarrow 16/15v_0$, and $n = 5$ for Saturn and $v_0 \rightarrow 2v_0$ and $n = 5$ for Jupiter from the requirement that the two lowest satellites correspond in a reasonable approximation to the two lowest Bohr orbits. The radii of satellites do not directly correspond to the radii for Bohr orbits. Also the formation of inner and outer satellite systems differing by a fractal scaling from each other can be considered. Same mechanism would be at work in all length scales and the recently observed dark matter ring associated with a galactic cluster could result by a similar mechanism [23].

The hierarchy of dark matters continues to elementary particle level and the differentiation by Bohr rules continues down to these levels. In particular, the formation of clumps of matter in Saturn rings [18] could be seen as a particular instance of this process.

NASA Hubble Space Telescope Detects Ring of Dark Matter

The following announcement caught my attention during my morning webwalk.

NASA will hold a media teleconference at 1 p.m. EDT on May 15 to discuss the strongest evidence to date that dark matter exists. This evidence was found in a ghostly ring of dark matter in the cluster CL0024+17, discovered using NASA's Hubble Space Telescope. The ring is the first cluster to show a dark matter distribution that differs from the distribution of both the galaxies and the hot gas. The discovery will be featured in the May 15 issue of the Astrophysical Journal.

"Rings" puts bells ringing! Recall that in TGD Universe dark matter characterized by a gigantic value of constant [A9] making dark matter a macroscopic quantum phase in astrophysical length and time scales. In the model of planetary orbits the rings of dark matter around Bohr orbits force the visible matter at Bohr orbits. Rings- and also shell like structures - connected by radial flux tubes to central anyonic surface are expected in all length scales, even that for galaxy clusters and large voids.

Recall that the number theoretic hypothesis for the preferred values of Planck constants states that the gravitational Planck constant

$$\hbar = \frac{GMm}{v_0}$$

equals to a ruler-and-compass rational which is ratio $q = n_1/n_2$ of ruler-and-compass integers n_i expressible as a product of form $n = 2^k \prod F_s$, where all Fermat primes F_s are different. Only four of them are known and they are given by 3, 5, 17, 257, $2^{16}+1$. $v_0 = 2^{-11}$ applies to inner planets and $v_0 = 2^{-11}/5$ to outer planets and the conditions from the quantization of hbar are satisfied.

The obvious TGD inspired hypothesis is that the dark matter ring corresponds to Bohr orbit. If so, the radius of the ring is given by

$$r_n = n^2 r_0 \ ,$$

where r_0 is Bohr radius and n is integer. The Bohr radius is given

$$r_0 = \frac{GM}{v_0^2} \ ,$$

where one has $1/v_0 = k \times 2^{11}$, k a small integer with preferred value $k = 1$. M is the total mass in the dense core region inside the ring. This would give a radius of about 2000 times Schwartschild radius for the lowest orbit.

This prediction can be confronted with the data [23].

1. From the "*Summary and Conclusions*" of the article the radius of the ring is about .4 Mpc, which makes in a good approximation r=1.2 Mly. The ring corresponds actually to a bump in the interval 60"-85" centered at 75" (figure 10 of [23] gives idea about the bump). The mass in the dense core within radius which is almost half of the ring radius is about $M = 1.5 \times 10^{14} \times M_{Sun}$. The mass estimate based on gravitational lensing gives $M = 1.8 \times 10^{14} \times M_{Sun}$. If the gravitational lensing involves dark mass not in the central core, the first value can be used as the estimate. The Bohr radius this system is therefore

$$r_0 = 1.5 \times 10^{14} \times r_0(Sun) \ ,$$

where I have assumed $v_0 = 2^{-11}$ as for the inner planets in the model for the solar system.

2. The Bohr orbit for our planetary system predicts correctly Mercury's orbital radius as n=3 Bohr orbit for $v_0 = 2^{-11}$ so that one has

$$r_0(Sun) = \frac{r_M}{9} \ ,$$

where r_M is Mercury's orbital radius. This gives

$$r_0 = 1.5 \times 10^{14} \times \frac{r_M}{9} \ .$$

Mercury's orbital radius is in a good approximation $r_M = .4$ AU =.016 ly. This gives $r_0 = 11$ Mly to be compared with $r_0 = 1\ 1.2$ Mly deduced from the observations. The result is 9 times too large.

3. If one replaces v_0 with $3v_0$ one obtains downwards scaling by a factor of 1/9, which gives $r_0 = 1.2$ Mly which can be found from the Summary and Conclusions of [23]. The general hypothesis indeed allows to scale v_0 by a factor 3.

4. If one considers instead of Bohr orbits genuine solutions of Schrödinger equation then only $n > 1$ structures can correspond to rings like structures. Minimal option would be $n = 2$ with v_0 replaced with $6v_0$.

The conclusion would be that the ring could correspond to the lowest possible Bohr orbit for $v_0 = 3 \times 2^{-11}$. I would have been really happy if the favored value of v_0 had appeared in the formula but the consistency with the ruler-and-compass hypothesis serves as a consolation. Skeptic can of course always argue that this is a pure accident. If so, it would be an addition to long series of accidents (planetary radii in solar system and radii of exoplanets). One can of course search rings at radii corresponding to $n = 2, 3, ...$

8.2.3 A quantum model for the dark part of the central mass and rings

It is interesting to look for a simple quantum model for the dark part of the central mass and possibly also of rings. As a first approximation one can consider a cylindrically symmetric pan-cake of height L and radius R. Approximate spherical symmetry suggest $L = 2R$.

The governing conditions are

$$\begin{aligned} v^2(\rho) &= G(dM/dl)(\rho) + v_1^2 \ , \\ v(\rho) &= \frac{v_0}{n} \ . \end{aligned} \quad (8.2.11)$$

Previous considerations suggest that the v_1^2 term from the cosmic string can be neglected. The general prediction is that the system has finite size and mass irrespective of the form of the distribution.

Four options

One can consider four kinds of mass distributions.

1) The scaling law $(dM/dl)(\rho) \propto K(\rho/\rho_0)^k$, $k \geq 0$, implies

$$\begin{aligned} v(\rho) &= \sqrt{GK}(\rho/\rho_0)^{k/2} \ , \\ \omega(\rho) &= \sqrt{GK}(\rho/\rho_0)^{k/2-1} \ , \\ \rho(n) &= \rho_0(v_0/\sqrt{GK})^{2/k} \times n^{-2/k} \ . \end{aligned} \quad (8.2.12)$$

The radii decrease as $n^{-2/k}$ and largest radius is $\rho_0(v_0^2/GK)$. For constant mass density one obtains $k = 2$, rigid body rotation, and $\rho = \rho_0/n$ so that kind of reverted harmony of spheres would result. Quite generally, $v(\rho)$ is a non-decreasing function of ρ from the first condition. This reflects the 2-dimensionality of the situation.

2) If the mass distribution is logarithmic $M(\rho) = Klog^2(\rho/\rho_0)$ one has $v = \sqrt{GK}log(\rho/\rho_0)$ and $\rho(n) = \rho_0 exp(k/n)$, $k = v_0/\sqrt{GK}$. One obtains what might be regarded as a cylindrical shell $\rho/\rho_0 \in [1, e^k]$ and with density $dM/dl \propto 2log(\rho)/\rho$. This kind of distribution could work in the case of planetary rings if the tidal effects of the central mass can be neglected.

3) p-Adic length scale hypothesis suggest the distribution $\rho(n) = 2^{-k}\rho_0$ for the radii of the "mass shells". This would give $v(\rho) = v_0/|log_2(\rho/\rho_0)|$ and

$$(dM/dl)(\rho) = \frac{v_0^2}{G|log_2(\rho/\rho_0)|^2} = \frac{M}{r_0|log_2(\rho/\rho_0)|^2} \ .$$

Note that the most general form of p-adic length scale hypothesis allows $\rho(n) = 2^{-k/2}\rho_0$ This option defines the only working alternative for the dark central mass. Note that this would explain Titius-Bode law [24] if planets have formed around dark matter shells or rings which have formed part of Sun during primordial stage.

4) The distribution of radii of form $\rho(n)/\rho_0 = x - n$ might serve as a model for planetary rings if the tidal effects of the central mass can be neglected. In this case one as

$$(dM/dl)(\rho) = \frac{M}{r_0(x - \frac{\rho}{\rho_0})^2} \ .$$

The radius R must satisfy $R < x\rho_0$. The masses of the annuli must increase with ρ.

Only the p-adic variant works as a model for central mass

It is interesting to look what the three variants of the model would predict for the radius of Earth. If the pancake has height $2R$, the relationship between radius and total mass can be expressed as $M = 2\pi(dM/dl)R^3$. Using $M_E = 3 \times 10^{-6} M_{Sun}$, and $r_0(Sun) \simeq R_M/9$, where $r_M = 5.8 \times 10^4$ Mm is the orbital radius of Mercury, one obtains by scaling $r_0 = GM_E/v_0^2 \simeq 20$ km for $v_0 = 2^{-11}$.

1. The options 1) and 2) fail. Constant density would give $R = 140$ km, which is about 2 per cent of the actual radius $R_E = 6.372797$ Mm and 10 percent about the radius 1.2 Mm of the inner core. The "inner inner core" of Earth happens to have radius of 300 km. For the logarithmic mass distribution one would obtain $R = r_0/2 \simeq 10$ km.

2. The option 3) inspired by the p-adic length scale hypothesis works and predicts $k^2|log_2(R/\rho_0)|^2 = 2R/r_0$. $\rho_0 = 2R$ gives $k \simeq 25$. This alternative works also in the more general case since one can make the radius arbitrarily large by a proper choice of the integer k. The universal prediction would be that dark matter appears as shells corresponding to decreasing p-adic length scales coming as powers $p \simeq 2^k$. The situation would be very much analogous to that in atomic physics. The prediction conforms with the many-sheeted generalization of the model for the asymptotic state of the star for which the matter is concentrated on a thin cell [D3]. The model brings in mind also the large voids of size about 100 Mly.

3. The suspiciously small value of r_0 forces to ask whether the value of v_0 for Earth should be much smaller than $v_0 = 2^{-11}$. Also the radius of Moon's orbit would require $n \sim 138$ for this value to be compared with $n \geq 5$ for the moons of Saturn and Jupiter. If the age of Earth is much longer than that of outer planets, one would expect that more phase transitions reducing v_0 forced by the cosmic expansion in average sense have taken place. $v_0 \rightarrow v_0/20$ would give $r_0 \simeq 8$ Mm to be compared with $R_E = 6.4$ Mm. Moon's orbit would correspond to $n = 7$ in a reasonable approximation. This choice of v_0 would allow $k = 1$.

The small value of v_0 might be understood from the fact that inner planets are older than outer ones so that the cosmic expansion in the average sense has forced larger number of phase transitions reducing the value of v_0 inducing a fractal scaling of the system. Ruler-and-compass hypothesis [D6] suggests preferred values of cosmic times for the occurrence of these transitions. Without this hypothesis the phase transitions could form almost continuum. For this option the failure of options 1) and 2) is even worse.

8.2.4 Two stellar components in the halo of Milky Way

Bohr orbit model for astrophysical objects suggests that also galactic halo should have a modular structure analogous to that of planetary system or the rings of Saturn rather than that predicted by continuous mass distribution. Quite recently it was reported that the halo of Milky Way - earlier thought to consist of single component - seems to consist of two components [34, 35]. Even more intriguingly, the stars in these halos rotate in opposite directions. The average velocities of rotation are about 25 km/s and 50 km/s for inner and outer halos respectively. The inner halo corresponds to a range 10-15 kpc of orbital radii and outer halo to 15-20 kpc. Already the constancy of rotational velocity is strange and its increase even stranger. The orbits in inner halo are more eccentric with axial ratio $r_{min}/r_{max} \simeq .6$. For outer halo the ratio varies in the range $.9 - 1.0$. The abundances of elements heavier than Lithium are about 3 times higher in the inner halo which suggests that it has been formed earlier.

Bohr orbit model would explain halos as being due to the concentration of visible matter around ring like structures of dark matter in macroscopic quantum state with gigantic gravitational Planck constant. This would explain also the opposite directions of rotation.

One can consider two alternative models predicting constant rotation velocity for circular orbits. The first model allows circular orbits with arbitrary plane of rotation, second model and the hybrid of these models only for the orbits in galactic plane.

1. The original model assumes that galactic matter has resulted in the decay of cosmic string like object so that the mass inside sphere of radius R is $M(R) \sim kR$.

2. In the second model the gravitational acceleration is due to gravitational field of a cosmic string like object transversal to the galactic plane. String creates no force parallel to string but $1/\rho$ radial acceleration orthogonal to the string. Of course, there is the gravitational force created by galactic matter itself. One can also associate cosmic string like objects with the circular halos themselves and it seems that this is needed in order to explain the latest findings.

The big difference in the average rotation velocities $\langle v_\phi \rangle$. or inner and outer halos cannot be understood solely in terms of the high eccentricity of the orbits in the inner halo tending to reduce $\langle v_\phi \rangle$. Using the conservation laws of angular momentum ($L = mv_{min}\rho_{max}$) and of energy in Newtonian approximation one has $\langle v_\phi \rangle = \rho_{max} v_{min} \langle\langle 1/\rho \rangle$. This gives the bounds

$$v_{min} < \langle v_\phi \rangle < v_{max} = v_{min}\frac{\rho_{max}}{\rho_{min}} \simeq 1.7 v_{min} \quad .$$

For both models $v = v_0 = \sqrt{k}$, $k = TG$, (T is the effective string tension) for circular orbits. Internal consistency would require $v_{min} < \langle v_\phi \rangle \simeq .5v_0 < v_{max} \simeq 1.7v_{min}$. On the other hand, $v_{max} > v_0$ and thus $v_{min} > .6v_0$ must hold true since the sign of radial acceleration for ρ_{min} is positive. $.5v_0 > v_{min} > .6v_0$ means a contradiction.

The big increase of the average rotation velocity suggests that inner and outer halos correspond to closed cosmic string like objects around which the visible matter has condensed. The inner string like object would create an additional gravitational field experienced by the stars of the outer halo. The increase of the effective string tension by factor x corresponds to the increase of $\langle v_\phi \rangle$ by a factor $\sqrt{x}$. The increase by a factor 2 plus higher eccentricity could explain the ratio of average velocities.

8.3 Quantum chaos in astrophysical length scales

The stimulus for writing this section came from the article "Quantum Chaos" by Martin Gurtzwiller [16]. Occasionally it can happen that even this kind of a masterpiece of scientific writing manages to stimulate only an intention to read it more carefully later. When you indeed read it again years later it can shatter you into a wild resonance. Just this occurred at this time.

8.3.1 Brief summary about quantum chaos

The article discusses of Gurtzwiller the complex regime between quantal and classical behavior as it was understood at the time of writing (1992). As a non-specialist I have no idea about possible new discoveries since then.

The article introduces the division of classical systems into regular (R) and chaotic (P in honor of Poincare) ones. Besides this one has quantal systems (Q). There are three transition regions between these three realms.

1. R-P corresponds to transition to classical chaos and KAM theorem is a powerful tool allowing to organize the view about P in terms of surviving periodic orbits.

2. Quantum-classical transition region R-Q corresponds to high quantum number limit and is governed by Bohr's correspondence principle. Highly excited hydrogen atom - Rydberg atom - defines a canonical example of the situation.

3. Somewhat surprisingly, it has turned out that also P-Q region can be understood in terms of periodic classical orbits (nothing else is available!). P-Q region can be achieved experimentally if one puts Rydberg atom in a strong magnetic field. At the weak field limit quantum states are delocalized but in chaotic regime the wave functions become strongly concentrated along a periodic classical orbits.

   At the level of dynamics the basic example about P-Q transition region discussed is the chaotic quantum scattering of electron in atomic lattice. Classical description does not work: a superposition of amplitudes for orbits, which consist of pieces which are fragments of a periodic orbit plus localization around atom is necessary.

   The fractal wave function patterns associated with say hydrogen atom in strong magnetic field are extremely beautiful and far from chaotic. Even in the case of chaotic quantum scattering one has interference of quantum amplitudes for classical Bohr orbits and also now Fourier transform exhibits nice peaks corresponding to the periods of classical orbits. The term chaos seems to be an unfortunate choice referring to our limited cognitive capacities rather than the actual physical situation and the term quantum complexity would be more appropriate.

4. For a consciousness theorist the challenge is to try to formulate in a more precise manner this fact. Quantum measurement theory with a finite measurement resolution indeed provide the mathematics necessary for this purpose.

8.3.2 What does the transition to quantum chaos mean?

The transition to quantum chaos in the sense the article discusses it means that a system with a large number of virtually independent degrees of freedom (in very general sense) makes a transition to a phase in there is a strong interaction between these degrees of freedom. Perturbative phase becomes non-perturbative. This means emergence of correlations and reduction of the effective dimension of the system to a finite fractal dimension. When correlations become complete and the system becomes a genuine quantum system, the dimension of the system is genuinely reduced and again non-fractal. In this sense one has transition via complexity to new kind of order.

The level of stationary states

At the level of energy spectrum this means that the energy of system which correspond to sums of virtually independent energies and thus is essentially random number becomes non-random. As a consequence, energy levels tend to avoid each other, order and simplicity emerge but at the collective level. Spectrum of zeros of Zeta has been found to simulate the spectrum for a chaotic system with strong correlations between energy levels. Zeta functions indeed play a key role in the proposed description of quantum criticality associated with the phase transition changing the value of Planck constant.

The importance of classical periodic orbits in chaotic scattering

Poincare with his immense physical and mathematical intuition foresaw that periodic classical orbits should have a key role also in the description of chaos. The study of complex systems indeed demonstrates that this is the case although the mathematics and physics behind this was not fully understood around 1992 and is probably not so even now. The basic discovery coming from numerical simulations is that the Fourier transform of a chaotic orbits exhibits peaks at frequencies which correspond to the periods of closed orbits. From my earlier encounters with quantum chaos I remember that there is quantization of periodic orbits so that their periods are proportional to $log(p)$, p prime in suitable units. This suggests a connection of arithmetic quantum field theory and with p-adic length scale hypothesis.

The chaotic scattering of electron in atomic lattice is discussed as a concrete example. In the chaotic situation the notion of electron consists of periods spend around some atom continued by a motion along along some classical periodic orbit. This does not however mean loss of quantum coherence in the transitions between these periods: a purely classical model gives non-sensible results in this kind of situation. Only if one sums scattering amplitudes over all piecewise classical orbits (not all paths as one would do in path integral quantization) one obtains a working model.

In what sense complex systems can be called chaotic?

Speaking about quantum chaos instead of quantum complexity does not seem appropriate to me unless one makes clear that it refers to the limitations of human cognition rather than to physics. If one believes in quantum approach to consciousness, these limitations should reduce to finite resolution of quantum measurement not taken into account in standard quantum measurement theory.

In the framework of hyper-finite factors of type II_1 finite quantum measurement resolution is described in terms of inclusions $\mathcal{N} \subset \mathcal{M}$ of the factors and sub-factor $\mathcal{N}$ defines what might be called $\mathcal{N}$-rays replacing complex rays of state space. The space $\mathcal{M}/\mathcal{N}$ has a fractal dimension characterized by quantum phase and increases as quantum phase $q = exp(i\pi/n)$, $n = 3, 4, ...$, approaches unity which means improving measurement resolution since the size of the factor $\mathcal{N}$is reduced.

Fuzzy logic based on quantum qbits applies in the situation since the components of quantum spinor do not commute. At the limit $n \to \infty$ one obtains commutativity, ordinary logic, and maximal dimension. The smaller the n the stronger the correlations and the smaller the fractal dimension. In this case the measurement resolution makes the system effectively strongly correlated as n approaches its minimal value $n = 3$ for which fractal dimension equals to 1 and Boolean logic degenerates to single valued totalitarian logic.

Non-commutativity is the most elegant description for the reduction of dimensions and brings in reduced fractal dimensions smaller than the actual dimension. Again the reduction has interpretation as something totally different from chaos: system becomes a single coherent whole with strong but not complete correlation between different degrees of freedom. The interpretation would be that in the transition to non-chaotic quantal behavior correlation becomes complete and the dimension of system again integer valued but smaller. This would correspond to the cases $n = 6$, $n = 4$, and $n = 3$ ($D = 3, 2, 1$).

8.3.3 Quantum chaos in astrophysical scales?

The following considerations represent an updated form of the first sketch about how quantum chaos could emerge in astrophysical length scales.

Transition to quantum chaos as the emergence of rational values of $\hbar/\hbar_0$

Anyonic 2-surfaces formed by flux tubes around orbits of massive objects connected to the central nearly spherical anyonic 2-surfaces by radial flux tubes and characterized by a fixed value of v_0 is the first key element of the picture. Second key element is the general formula for Planck constant forcing to conclude that the sequential de-coherence reducing (n_a, n_b) gradually to $(n_a, n_b) = (1, 1)$ requires generation of sub-harmonics of the original graviton frequency in the situation when $r = \hbar/\hbar_0$ is genuine rational $r = m/n$. Quantum chaos would result in the transition leading from integer valued r to rational values of r. At the level of classical orbits this would correspond to the emergence of small perturbations with n-fold period spoiling exact periodicity.

In CP_2 degrees of freedom transition to chaos would correspond to the generation of CP_2 coverings with larger covering group if one accepts the proposed formula for Planck constant. In M^4 degrees of freedom transition to chaos means generation of orbifold symmetries. In both cases the value of Planck constant is reduced. Contrary to naive expectations transition to chaos generates symmetry in both cases. Ruler-and-compass hypothesis implies very powerful predictions for the remnants of this symmetry at the level of visible matter.

Quantum criticality and chaos

1. TGD Universe is quantum critical. The most important implication of quantum criticality of TGD Universe is that it fixes the value of Kähler coupling strength, the only free parameter appearing in definition of the theory as the analog of critical temperature. The dark matter hierarchy characterized partially by the increasing values of Planck constant allows to characterize more precisely what quantum criticality might means. By quantum criticality space-time sheets are analogs of Bohr orbits. Since quantum criticality corresponds to P-Q region, the localization of wave functions around generalized Bohr orbits should occur quite generally in some scale.

2. Elementary particles are maximally quantum critical systems analogous to H_2O at tri-critical point and can be said to be in the intersection of imbedding spaces labeled by various values of Planck constants. Planck constant does not characterize the elementary particle proper. Rather, each field body of particle (em, weak, color, gravitational) is characterized by its own Planck constant and this Planck constant characterizes interactions. The generalization of the notion of the imbedding space allows to formulate this idea in precise manner and each sector of imbedding space is characterized by discrete symmetry groups G_a and G_b acting in M^4 and CP_2 degrees of freedom either on covering or orbifold assignable to CD and CP_2.

3. Dark matter hierarchy makes TGD Universe an ideal laboratory for studying P-Q transitions with chaos identified as quantum critical phase between two values of Planck constant with larger value of Planck constant defining the "quantum" phase and smaller value the "classical" phase. Dark matter is localized near Bohr orbits and is analogous to quantum states localized near the periodic classical orbits. Planetary Bohr orbitology provides a particularly interesting astrophysical application of quantum chaos.

4. The above described picture applies about chaotic quantum scattering applies quite generally in quantum TGD. Path integral is replaced with a functional integral over classical space-time evolutions and the failure of the complete classical non-determinism is analogous to the transition between classical orbits. Functional integral also reduces to perturbative functional integral around maxima of Kähler function.

Dark matter structures as generalization of periodic orbits

The matter with ordinary or smaller value of Planck constant can form bound states with these dark matter structures. The dark matter circles would be the counterparts for the periodic Bohr orbits dictating the behavior of the quantum chaotic system. Visible matter (and more generally, dark matter at the lower levels of hierarchy behaving quantally in shorter length and time scales) tends to stay around these periodic orbits and in the ideal case provides a perfect classical mimicry of quantum behavior. Dark matter structures would effectively serve as selectors of the closed orbits in the gravitational dynamics of visible matter.

As one approaches classicality the binding of the visible matter to dark matter gradually weakens. Mercury's orbit is not quite closed, planetary orbits become ellipses, comets have highly eccentric orbits or even non-closed orbits. For non-closed quantum description in terms of binding to dark matter does not makes sense at all.

The classical regular limit (R) would correspond to a decoupling between dark matter and visible matter. A motion along geodesic line is obtained but without Bohr quantization in gravitational sense since Bohr quantization using ordinary value of Planck constant implies negative energies for $GMm \geq 1$. The preferred extremal property of the space-time sheet could however still imply some quantization rules but these might apply in "vibrational" degrees of freedom.

Quantal chaos in gravitational scattering?

The chaotic motion of astrophysical object becomes the counterpart of quantum chaotic scattering. By Equivalence Principle the value of the mass of the object does not matter at all so that the motion of sufficiently light objects in solar system might be understandable only by assuming quantum chaos.

The orbit of a gravitationally unbound object such as comet could define the basic example. The rings of Saturn and Jupiter could represent interesting shorter length scale phenomena possible involving quantum scattering. One can imagine that the visible matter object spends some time around a given dark matter circle (binding to atom), makes a transition along a radial spoke to the next circle, and so on.

The prediction is that dark matter forms rings and cart-wheel like structures of astrophysical size. These could become visible in collisions of say galaxies when stars get so large energy as to become gravitationally unbound and in this quantum chaotic regime can flow along spokes to new Bohr orbits or to gravi-magnetic flux tubes orthogonal to the galactic plane. Hoag's object represents a beautiful example of a ring galaxy [26]. Remarkably, there is direct evidence for galactic cart-wheels (for pictures of them see [25]). There are also polar ring galaxies consisting of an ordinary galaxy plus ring approximately orthogonal to it and believed to form in galactic collisions [27]. The ring rotating with the ordinary galaxy can be identified in terms of gravi-magnetic flux tube orthogonal to the galactic plane.

8.4 Gravitational radiation and large value of gravitational Planck constant

The description of gravitational radiation provides a stringent test for the idea about dark matter hierarchy with arbitrary large values of Planck constants. In accordance with quantum classical correspondence, one can take the consistency with classical formulas as a constraint allowing to deduce information about how dark gravitons interact with ordinary matter. In the following standard facts about gravitational radiation are discussed first and then TGD based view about the situation is sketched.

8.4.1 Standard view about gravitational radiation

Gravitational radiation and the sources of gravitational waves

Classically gravitational radiation corresponds to small deviations of the space-time metric from the empty Minkowski space metric [29]. Gravitational radiation is characterized by polarization, frequency, and the amplitude of the radiation. At quantum mechanical level one speaks about gravitons characterized by spin and light-like four-momentum.

The amplitude of the gravitational radiation is proportional to the quadrupole moment of the emitting system, which excludes systems possessing rotational axis of symmetry as classical radiators. Planetary systems produce gravitational radiation at the harmonics of the rotational frequency. The formula for the power of gravitational radiation from a planetary system given by

$$P = \frac{dE}{dt} = \frac{32}{\pi}\frac{G^2 M_1 M_2 (M_1+M_2)}{R^5} \ . \qquad (8.4.1)$$

This formula can be taken as a convenient quantitative reference point.

Planetary systems are not very effective radiators. Because of their small radius and rotational asymmetry supernovas are much better candidates in this respect. Also binary stars and pairs of black holes are good candidates. In 1993, Russell Hulse and Joe Taylor were able to prove indirectly the existence of gravitational radiation. Hulse-Taylor binary consists of ordinary star and pulsar with the masses of stars around 1.4 solar masses. Their distance is only few solar radii. Note that the pulsars have small radius, typically of order 10 km. The distance between the stars can be deduced from the Doppler shift of the signals sent by the pulsar. The radiated power is about 10^{22} times that from Earth-Sun system basically due to the small value of R. Gravitational radiation induces the loss of total energy and a reduction of the distance between the stars and this can be measured.

How to detect gravitational radiation?

Concerning the detection of gravitational radiation the problems are posed by the extremely weak intensity and large distance reducing further this intensity. The amplitude of gravitational radiation is measured by the deviation of the metric from Minkowski metric, denote by h.

Weber bar [29] provides one possible manner to detect gravitational radiation. It relies on a resonant amplification of gravitational waves at the resonance frequency of the bar. For a gravitational wave with an amplitude $h \sim 10^{-20}$ the distance between the ends of a bar with length of 1 m should oscillate with the amplitude of 10^{-20} meters so that extremely small effects are in question. For Hulse-Taylor binary the amplitude is about $h = 10^{-26}$ at Earth. By increasing the size of apparatus one can increase the amplitude of stretching.

Laser interferometers provide second possible method for detecting gravitational radiation. The masses are at distance varying from hundreds of meters to kilometers[29]. LIGO (the Laser Interferometer Gravitational Wave Observatory) consists of three devices: the first one is located with Livingston, Lousiana, and the other two at Hanford, Washington. The system consist of light storage arms with length of 2-4 km and in angle of 90 degrees. The vacuum tubes in storage arms carrying laser radiation have length of 4 km. One arm is stretched and one arm shortened and the interferometer is ideal for detecting this. The gravitational waves should create stretchings not longer that 10^{-17} meters which is of same order of magnitude as intermediate gauge boson Compton length. LIGO can detect a stretching which is even shorter than this. The detected amplitudes can be as small as $h \sim 5 \times 10^{-22}$.

8.4.2 Model for dark gravitons

In this subsection models for dark gravitons are discussed.

Gravitons in TGD

Unlike the naive application of Mach's principle would suggest, gravitational radiation is possible in empty space in general relativity. In TGD framework it is not possible to speak about small oscillations of the metric of the empty Minkowski space imbedded canonically to $M^4 \times CP_2$ since

Kähler action is non-vanishing only in fourth order in the small deformation and the deviation of the induced metric is quadratic in the deviation. Same applies to induced gauge fields. Even the induced Dirac spinors associated with the modified Dirac action fixed uniquely by super-symmetry allow only vacuum solutions in this kind of background. Mathematically this means that both the perturbative path integral approach and canonical quantization fail completely in TGD framework. This led to the vision about physics as Kähler geometry of "world of classical worlds" with quantum states of the universe identified as the modes of classical configuration space spinor fields.

The resolution of various conceptual problems is provided by the parton picture and the identification of elementary particles as light-like 3-surfaces associated with the wormhole throats. Gauge bosons correspond to pairs of wormholes and fermions to topologically condensed CP_2 type extremals having only single wormhole throat.

Gravitons are string like objects in a well defined sense. This follows from the mere spin 2 property and the fact that partonic 2-surfaces allow only free many-fermion states. This forces gauge bosons to be wormhole contacts whereas gravitons must be identified as pairs of wormhole contacts (bosons) or of fermions connected by flux tubes. The strong resemblance with string models encourages to believe that general relativity defines the low energy limit of the theory. Of course, if one accepts dark matter hierarchy and dynamical Planck constant, the notion of low energy limit itself becomes somewhat delicate.

The expression for Planck constant

The question how do the Planck constants associated with factors and coverings relate is far from trivial and I have considered several options.

1. If one assumes that $\hbar^2(X)$, $X = M^4$, CP_2 corresponds to the scaling of the covariant metric tensor g_{ij} and performs an over-all scaling of metric allowed by Weyl invariance of Kähler action by dividing metric with $\hbar^2(CP_2)$, one obtains $r^2 \equiv \hbar^2/\hbar_0^2\hbar^2(M^4)/\hbar^2(CP_2)$. This puts M^4 and CP_2 in a very symmetric role and allows much more flexibility in the identification of symmetries associated with large Planck constant phases.

2. Algebraist would argue that Planck constant must define a homomorphism respecting multiplication and division (when possible) by G_i. This requires $r(X) = \hbar(X)\hbar_0 = n$ for covering and $r(X) = 1/n$ for factor space or vice versa. This gives two options.

3. Option I: $r(X) = n$ for covering and $r(X) = 1/n$ for factor space gives $r \equiv \hbar/\hbar_0 = r(M^4)/r(CP_2)$. This gives $r = n_a/n_b$ for $\hat{H}/G_a \times G_b$ option and $r = n_b/n_a$ for $\hat{H}\hat{times}(G_a \times G_b)$ option with obvious formulas for hybrid cases.

4. Option II: $r(X) = 1/n$ for covering and $r(X) = n$ for factor space gives $r = r(CP_2)/r(M^4)$. This gives $r = n_b/n_a$ for $\hat{H}/G_a \times G_b$ option and $r = n_a/n_b$ for $\hat{H}\hat{times}(G_a \times G_b)$ option with obvious formulas for the hybrid cases.

5. At quantum level the fractionization would come from the modification of fermionic anti-commutation (bosonic commutation) relations involving $\hbar$ at the right hand side so that particle number becomes a multiple of $1/n$ or n. If one postulates that the total number states is invariant in the transition, the increase in the number of sheets is compensated by the increase of the fundamental phase space volume proportional to $\hbar$. This would give $r(X) \rightarrow r(X)/n$ for factor space and $r(X) \rightarrow nr(X)$ for the covering space to compensate the n-fold reduction/increase of states. This would favor Option II.

6. The second manner to distinguish between these two options is to apply the theory to concrete physical situations. Since G_a and G_b act as symmetries in CD and CP_2 degrees of freedom, one might of being able to distinguish between the two options if it is possible to distinguish between the action of G as symmetry of quantum states associated with covering and factor space. Also the quantization of the orbital spin quantum number at single particle level as multiples of n can be distinguished from that in multiples of $1/n$.

7. Somewhat surprisingly, for option II (unlike for option I) the value of the unit of angular momentum is $\hbar_0$ in both cases. In the case of covering space of M^4 the replacement of partial waves

with fractional partial waves implies $m \to m/n_a$ but the upwards scaling of Planck constant by n_a reduces the unit of angular momentum back to $\hbar_0$. Only if one assumes G_a singletness for covering, the unit of angular momentum is scaled up by n_a and the interpretation is in terms of n_a copies of ordinary particle at sheets of the covering. In fractional Quantum Hall effect this takes place which supports G_a singletness. For factor space singletness is necessary and guaranteed for $m = nn_a$ but downwards scaling $\hbar \to \hbar/n_a$ reduces the unit to $\hbar_0$. It is important to notice that G_a singletness holds only for the entire many particle state. The unit of angular momentum for single particle states can be $\hbar_0$ for coverings and $\hbar_0/n_a$ for factor spaces. In anyonic many particle states this kind of spin and charge fractionization can take place [F12].

8. The covering (factor) space property in CP_2 degrees of freedom reduces (increases) the unit of angular momentum for Option II. This looks somewhat strange and reader can decide whether or not to take the following argument seriously. $\hbar(M^4)$ *resp.* $\hbar(CP_2)$ serves as a unit for M^4 *resp.* CP_2 quantum numbers. By the scaling invariance of Kähler action the covariant metric of M^4 can be taken to be proportional to the square of their ratio $r = \hbar(M^4)/\hbar(CP_2)$ so that CP_2 metric is always the same. Since Kähler function depends only on r, it is possible to use $\hbar_0$ as a unit for CP_2 quantum numbers and $r\hbar_0$ for M^4 quantum numbers. More concretely, there is no manner to measure the size of CP_2 since this size itself is the fundamental unit so that the change of CP_2 size can be seen only through the change of the scale of M^4 metric and therefore M^4 Planck constant.

9. The resulting spectrum of Planck constants consists of rationals in the most general case. Gravitational Planck constant for planetary systems correlates with the mass parameters of the system to guarantee Equivalence Principle and is determined by the formula $\hbar_{gr} = GM_1M_2/v_0$, where v_0 can have several values. $v_0 = 2^{-11}$ holds for inner planets. Scaling hierarchies in powers of 2 and also in powers of 2^{-11} are suggested by various fractality based arguments and rations of Fermat primes are suggested by number theoretic vision. For black hole like objects $\hbar_{gr} = GM^2/v_0$ implies that Planck length $L_P = \sqrt{\hbar G}$ scales as $\sqrt{\hbar}$ and is of the same order of magnitude as Schwarzschild radius, which thus becomes kind of minimal quantum length. The identification of the black-hole horizon as a macroscopic partonic 2-surface containing matter in anyonic state is indeed highly suggestive [F12]. Note that black hole entropy is proportional to $1/\hbar$ and of order unity if black hole horizon corresponds to a dark anyonic system. In this picture the collapse of the star to black hole would mean a formation of this kind of anyonic system with a large value of $\hbar$ (also several systems of this kind with different value of $\hbar$ can be considered).

In the sequel only option II guaranteing the conservation of number of states in phase transitions changing Planck constant will be discussed. The earlier treatment was based on option I but because of the algebraic symmetry between the two cases only the treatment remains as such as far as basic formulas are considered and only the identification of what large $\hbar$ gravitons and and what occurs in the transformations of large $\hbar$ gravitons to ordinary ones changes.

What kind of dark gravitons can one consider?

First of all one must decide what sector of the generalized imbedding space dark graviton correspond to. There are four options of which three can give rise to large $\hbar$.

1. Option II_a: $[\hat{M}^4\text{''} \times \text{''}G_a] \times [\hat{CP}_2\text{''} \times \text{''}G_b]$ corresponds to Planck constant $\hbar/\hbar_0 = n_a/n_b$ with n_a defining the order of the maximal subgroup of G_a very large. G_a would act in the covering space of causal diamond CD assignable to the gravitational field body. If G_a singletness is assumed, the unit of angular momentum of the giant graviton is very large and the very interpretation is that a bundle of ordinary gravitons is in question. The covering space property in CP_2 degrees of freedom reduces the unit of angular momentum.

2. Option II_b: $[\hat{M}^4\text{''} \times \text{''}G_a] \times [\hat{CP}_2/G_b]$ corresponds to Planck constant $\hbar/\hbar_0 = n_a \times n_b$ with n_b possibly large. This case allows small n_a. G_b could be interpreted as a geometric color rotation symmetry of the dark matter. If one accepts discretization realized in terms of number theoretic braids as a correlate for finite measurement resolution, G_b invariance could be interpretation as discrete version for color singletness.

3. Option II_c: $[\hat{M}^4/G_a] \times [\hat{CP}_2/G_b]$ corresponds to $\hbar/\hbar_0 = n_b/n_a$ and n_b should be very large. In this case graviton has G_a-fold rotational symmetry with respect in M^4 and would correspond to a partial wave with $m = kn_a$ but having orbital angular momentum $n_b k\hbar_0$. This option does not correspond to intuitive view about gravitons.

Only the options II_a and II_b -briefly a) and b) - will be discussed in the sequel.
Consider first the general view about de-coherence process.

1. Once the sector of the generalized imbedding space is selected, one has still two options corresponding to spherical and plane waves. Spherical dark gravitons could be emitted in quantum transitions of say dark gravitational variant of hydrogen atom or of dark part of the astrophysical object. Emission process could also yield a sufficiently large number of MEs with large $\hbar$.

2. Spherical dark graviton can de-cohere into spherical gravitons with smaller covering group G_a. Sooner or later spherical giant graviton must de-cohere into topological light rays ("MEs") defining the TGD counterparts of plane waves of finite width and define second model for dark graviton. They are expected to be detectable by human built detectors.

3. In CP_2 degrees of freedom de-coherence would take place in the same manner as for M^4 for option I. For option II de-coherence would correspond to the decay to MEs with a smaller symmetry group G_b (Z_{n_b} or or Z_{n_b} plus reflection).

4. Assuming singletness with respect to G_a and G_b, de-coherence could be seen as a sequence of symmetry breakdowns for both coverings and factor spaces. At given step the orders of the resulting symmetry groups G_a and G_b are divisors of the orders of the original groups. The final step would lead to trivial covering and factor spaces.

Emission of dark gravitons

One must answer several non-trivial questions if one is to defend dark gravitational radiation.

Frequencies of dark gravitons turn out to correspond to orbital frequencies at large quantum number limit. However, if gravitational radiation is emitted as dark gravitons, they have enormous energies since the energy must correspond to the change of the energy of an astrophysical object jumping to a smaller Bohr orbit.

Hulse-Taylor binary system was used to demonstrate that the energy loss of the binary system equals to the classically predicted power of gravitational radiation. The power of gravitational radiation was deduced from the gradual reduction of the distance between the two stars. The obvious question is whether the consistency of the power emitted by Hulse-Taylor binary with the prediction of the classical theory kills the hypothesis about gigantic gravitational Planck constant.

1. If one assumes that v_0 is of same order of magnitude as for planetary systems as the value of the orbital radius indeed suggests, single spherical dark graviton emitted in the transition would carry away an essentially astrophysical energy. For option II also MEs are possible if one assumes that sufficiently high number of them is emitted so that the total recoil momentum is small.

2. If dark graviton is spherical or -more generally - corresponds to a partial wave with a definite value of angular momentum (in a sense to be specified), it must decay gradually to spherical or ME type gravitons with smaller values of Planck constant. The measurement process should induce this kind of decay.

3. The prediction that energy is emitted in bunches should have testable experimental implications. The case of hydrogen atom inspires the question whether the lowest orbit is stable and does not emit gravitational radiation meaning that the binary ends up to the stable state rather than collapsing. Of course, the idealization as hydrogen atom like system might fail. The identification of dark gravitons as dark topological light rays (massless extremals, MEs) containing topologically condensed ordinary gravitons will be discussed later.

By quantum classical correspondence this process must have a space-time description.

1. The natural proposal is that below the time scale associated with the emission process the space-time picture about the emission process looks like a continuous process, at least asymptotically when the space-time itself is replaced repeatedly with a new one. Thus the transition between orbitals at the level of space-time correlates must occur continuously below the time scale assigned to it classically. Quantum emission would quite generally mean in sub-quantum time scales continuous classical process at space-time level.

2. TGD based quantum model for living system suggests that the transition occurs in a fractal manner proceeding from long to short dark time scales. First a quantum jump in the longest time scale occurs and induces the replacement of the entire space-time with a new one differing dramatically from the previous one. This quantum jump is followed by quantum jumps in shorter time scales. At each step space-time sheet characterizing the system is replaced by a new one and eventually by a space-time surface which describes the process as more or less continuous one. The final space-time could be regarded as symbolic description of the process as a classical continuous process.

3. The time interval for the occurrence of the transition at space-time level should correspond to a dark p-adic time scale and in the case of Hulse-Taylor binary be of same order as the lifetime of the period during which the system ends up to a stable state. In the Hulse-Taylor case the emission would correspond to small values of n, most naturally $n = 2 \rightarrow n = 1$ transition so that the frequency of the gravitational radiation would not correspond to the orbital frequency. This might some day be used as a test for the theory. The time duration T for the transition can be estimated from $T = \Delta E/P$, where P is the classical formula for the emission power.

Model for the spherical graviton

Detector, giant graviton, source, and topological light ray will be denoted simply by D, G, and S, and ME in the following. Consider first the model for the giant graviton.

1. Orbital plane defines the natural quantization axis of angular momentum for spherical graviton. Spherical graviton corresponds to a graviton with very large unit of angular momentum corresponding to G_a invariance acting in covering space degrees of freedom but can be regarded as a Bose-Einstein condensate like state of ordinary gravitons.

2. The total angular momentum of the giant graviton must correspond to the change of angular momentum in the quantum transition between initial and final orbit. Orbital angular momentum in the direction of quantization axis should be a small multiple of dark Planck constant associated with the system formed by giant graviton and source. These states correspond to Bose-Einstein condensates of ordinary gravitons in eigen state of orbital angular with ordinary Planck constant. Unless S-wave is in question the intensity pattern of the gravitational radiation depends on the direction in a characteristic non-classical manner. The coherence of dark graviton regarded as Bose-Einstein condensate of ordinary gravitons is what distinguishes the situation in TGD framework from that in GRT.

3. It is not quite clear what the number N of ordinary gravitons contained by giant graviton is.

   (a) The formula $E = \hbar\omega$ would suggests that if the frequency of gravitons gravitons resulting in de-coherence is same as that of ordinary gravitons the number of gravitons is $N = \hbar/\hbar_0 = r$. The problem is that the number of gravitons can be fractional. The simplest solution of the problem is that for $N = \hbar/\hbar_0 = r/s$ the de-coherence produces r gravitons with frequency ω/s. When n_b corresponds to a power of 2, the approach to chaos by period doubling might be an appropriate interpretation.

   (b) Common sense view about what the number of gravitons means would suggest that if one has n-fold covering this gives a factor n to N whereas factor space gives factor $1/n$. This would give $(N, r) = (n_a n_b, n_a/n_b)$ for option a) and $(N, r) = (n_a/n_b, n_a n_b)$ for option b). Again fractional graviton number is possible if frequency is assumed to be ω. Also now the simplest interpretation for fractional graviton numbers is in terms of sub-harmonics of ω.

   (c) These arguments suggest that the de-coherence can produce both harmonics (sub-harmonics) for which n is divisor of r (s) of $N = r/s$.

4. The estimate for the number of ordinary gravitons gives estimate for the radiated energy per solid angle. This estimate follows also from the energy conservation for the transition. The requirement that average power equals to the prediction of GRT allows to estimate the geometric duration associated with the transition. The condition $\hbar\omega = E_f - E_i$ is consistent with the identification of $\hbar$ for the pair of systems formed by giant-graviton and emitting system.

Dark graviton as topological light ray

Second kind of dark graviton is analog for plane wave with a finite transversal cross section. TGD indeed predicts what I have called topological light rays, or massless extremals (MEs) as a very general class of solutions to field equations [D1].

MEs are typically cylindrical structures carrying induced gauge fields and gravitational field without dissipation and dispersion and without weakening with the distance. These properties are ideal for targeted long distance communications which inspires the hypothesis that they play a key role in living matter [J4, K4] and make possible a completely new kind of communications over astrophysical distances. Large values of Planck constant allow to resolve the problem posed by the fact that for long distances the energies of these quanta would be below the thermal energy of the receiving system.

Giant gravitons are expected to decay to this kind of dark gravitons having smaller value of Planck constant via de-decoherence and that it is these gravitons which are detected. Quantitative estimates indeed support this expectation.

The same general picture that applies to spherical gravitons applies to MEs. The only difference is that quantization axis of angular momentum left point-wise invariant under G_a is parallel to the direction of propagation. Thus the de-coherence of a spherical graviton into MEs means dispersion to a sector of the world of classical worlds possessing different quantization axes.

8.4.3 Detection of gravitational radiation

One should also understand how the description of the gravitational radiation at the space-time level relates to the picture provided by general relativity to see whether the existing measurement scenarios really measure the gravitational radiation as they appear in TGD. There are more or less obvious questions to be answered (or perhaps obvious after a considerable work).

What is the value of dark gravitational constant which must be assigned to the pair formed by the measuring system and gravitational radiation from a given source? Is the detection of primary giant graviton possible by human means or is it possible to detect only dark gravitons produced in the sequential de-coherence of giant graviton? Do dark gravitons enhance the possibility to detect gravitational radiation as one might expect? What are the limitations on detection due to energy conservation in de-coherence process?

TGD counterpart for the classical description of detection process

The oscillations of the distance between the two masses defines a simplified picture about the receival of gravitational radiation.

Now ME would correspond to n_a-"Riemann-sheeted" covering of M^4 with each sheet oscillating with the same frequency: simply a stack of ordinary MEs defining a bundle of ordinary gravitons. Classical interaction would suggest that the measuring system topologically condenses at the topological light ray so that the distance between the test masses measured along the topological light ray in the direction transverse to the direction of propagation starts to oscillate. This (or these) topological light rays must however result via de-coherence to $n_a = n_b = 1$ sector of the imbedding space unless measurement system itself corresponds to dark matter. If only single topological light ray results it must carry large number of gravitons. Topological light rays can be indeed regarded as space-time correlates for massless collinear bosons of various kinds. One can also consider the possibility that measurement system is quantum critical itself.

Obviously the classical behavior is essentially the same as predicted by general relativity. If all elementary particles are maximally quantum critical systems and therefore also gravitons, then gravitons can be absorbed at each step of the process, and the number of absorbed gravitons and energy is N-fold.

Model for sequential de-coherence

Suppose that the detecting system has some mass m and suppose that the gravitational interaction is mediated by the gravitational field body connecting the two systems.

Planck constant must characterize the system formed by dark graviton and measuring system. In the case that the energy E of graviton is comparable to the mass m of measuring system or larger, the expression for $r\hbar/\hbar_0$ must replaced with the relativistically invariant formula in which m and E are replaced with the energies in center of mass system. This gives

$$r = \frac{GmE}{v_0(1+\beta)\sqrt{1-\beta}} \ , \ \beta = z(-1+\sqrt{1+\frac{2}{x}}) \ , \ x = \frac{E}{2m} \ . \tag{8.4.2}$$

Assuming $m >> E_0$ this gives in a good approximation $r = Gm_1E_0/v_0 = G^2m_1mM/v_0^2$. Note that in the interaction of identical masses ordinary $\hbar$ is possible for $m \leq \sqrt{v_0}M_{Pl}$. For $v_0 = 2^{-11}$ the critical mass corresponds roughly to the mass of water blob of radius 1 mm.

One can interpret the formula by saying that de-coherence splits from the incoming dark graviton dark piece having energy $E_1 = (Gm_1E_0/v_0)\omega$, which makes a fraction $E_1/E_0 = (Gm_1/v_0)\omega$ from the energy of the graviton with frequency ω. At the n:th step of the process the system would split from the dark graviton of previous step the fraction

$$\frac{E_n}{E_0} = (\frac{G\omega}{v_0})^n \prod_i (m_i) \ .$$

from the total emitted energy E_0. De-coherence process would proceed in steps such that the typical masses of the measuring system decrease gradually as the process goes downwards in length and time scale hierarchy. This splitting process should lead at large distances to the situation in which the original spherical dark graviton has split to ordinary gravitons with angular distribution being same as predicted by GRT.

The splitting process should stop when the condition $r \leq 1$ is satisfied and the topological light ray carrying gravitons becomes 1-sheeted covering of M^4. For $E << m$ this gives $GmE \leq v_0$ so that $m >> E$ implies $E << M_{Pl}$. For $E >> m$ this gives $GE^{3/2}m^{1/2} < 2v_0$ or

$$\frac{E}{m} \leq (\frac{2v_0}{Gm^2})^{2/3} \ . \tag{8.4.3}$$

Each de-coherence phase transition means symmetry breaking $(G_a, G_b) \rightarrow (H_a, H_b) \subset (G_a, G_b)$ so that the $n(G_i)$ is divisible by $n(H_i)$ for both (G_a, G_b) corresponding maximal cyclic subgroups. Despite the fact that the value of n_a is very large, the number of de-coherence sequences is rather small and if n_i is prime de-coherence can take place at single step. If n_a is power of 2 the number of steps is maximal but relatively small even in this case. This rule can be satisfied if v_0 varies and masses m_i are quantized. Also ω which classically corresponds to harmonics of the rotation frequency for the radiating two-body system is quantized Bohr rules imply.

If one makes the stronger assumption that the values of r correspond to ruler-and-compass rationals expressible as ratios of the number theoretically preferred values of integers expressible as $n = 2^k \prod_s F_s$, where F_s correspond to different Fermat primes (only four is known), very strong constraints on the masses of the systems participating in the de-coherence sequence result. Analogous conditions appear also in the Bohr orbit model for the planetary masses and the resulting predictions were found to be true with few per cent. One cannot therefore exclude the fascinating possibility that the de-coherence process might in a very clever manner code information about masses of systems involved with its steps.

The value of $r = \hbar/\hbar_0$ depends on the mass of the detecting system and the energy of graviton which in turn depends on the de-coherence history in corresponding manner. As found, the number of de-coherence histories is limited and characterized by the manners to extract sequences of factors $1 \perp n_{i,1} \perp n_{i,2} ... \perp n_i$, where $m \perp n$ tells that m divides n, for the integers n_a and n_b. Therefore the total energy absorbed from the pulse codes via the value of r information about the masses appearing in the de-coherence process. For a process involving only single step the value of the source mass can be deduced from this data. In principle this could some day provide totally new means of deducing information about the masses of distant objects: something totally new from the point of view of classical and string theories of gravitational radiation. This kind of information theoretic bonus gives a further good reason to take the notion of quantized Planck constant seriously.

The time interval during which the interaction with dark graviton takes place?

If the duration of the bunch is $T = E/P$, where P is the classically predicted radiation power in the detector and T the detection period, the average power during bunch is identical to that predicted by GRT. Also T would be proportional to r, and therefore code information about the masses appearing in the sequential de-coherence process.

An alternative, and more attractive possibility, is that T is same always and correspond to $r = 1$. The intuitive justification is that absorption occurs simultaneously for all r "Riemann sheets". This would multiply the power by a factor r and dramatically improve the possibilities to detect gravitational radiation. The measurement philosophy based on standard theory would however reject these kind of events occurring with $1/r$ time smaller frequency as being due to the noise (shot noise, seismic noise, and other noise from environment). This might relate to the failure to detect gravitational radiation.

8.4.4 Quantitative model

In this subsection a rough quantitative model for the de-coherence of giant (spherical) graviton to topological light rays (MEs) is discussed and the situation is discussed quantitatively for hydrogen atom type model of radiating system. The basic assumption is irreversibility in the sense that the integers n_a and n_b approach to unity in the de-coherence process.

Leakage of the giant graviton to the sectors of imbedding space with smaller value of Planck constant

Consider first the model for the leakage of giant graviton to the sectors of H with smaller Planck constant.

1. Giant graviton leaks to sectors of H with a smaller value of Planck constant via quantum critical points common to the original and final sector of H. If ordinary gravitons are quantum critical they can be regarded as leakage points.

2. It is natural to assume that the resulting dark graviton corresponds to a radial topological light ray (ME).

3. Energy should be conserved in the leakage process. The secondary dark graviton receives the fraction $\Delta\Omega/4\pi = S/4\pi r^2$ of the energy of giant graviton, where $S(ME)$ is the transversal area of ME, and r the radial distance from the source, of the energy of the giant graviton. Energy conservation gives

$$\frac{S(ME)}{4\pi r^2}\hbar(G,S)\omega = \hbar(ME,G)\omega \ . \tag{8.4.4}$$

or

$$\frac{S(ME)}{4\pi r^2} = \frac{\hbar(ME,G)}{\hbar(G,S)} \simeq \frac{E(ME)}{M(S)} \ . \tag{8.4.5}$$

The larger the distance is, the larger the area of ME. This means a restriction to the measurement efficiency at large distances for realistic detector sizes since the number of gravitons must be proportional to the ratio $S(D)/S(ME)$ of the areas of detector and ME.

The direct detection of giant graviton is not possible for long distances

Primary detection would correspond to a direct flow of energy from the giant graviton to detector. Assume that the source is modelable using large $\hbar$ variant of the Bohr orbit model for hydrogen atom. Denote by $q = r/s$ the rational defining Planck constant as $\hbar = q\hbar_0$.

For G-S system one has

$$q(G,S) = \frac{r(G,S)}{s(G,S)} = \frac{GME}{v_0} = GMmv_0 \times \frac{k}{n^3} \quad . \tag{8.4.6}$$

where k is a numerical constant of order unity and m refers to the mass of planet. For Hulse-Taylor binary $m \sim M$ holds true.

For D-G system one has

$$q(D,G) = \frac{r(D,G)}{s(D,G)} = \frac{GM(D)E}{v_0} = GM(D)mv_0 \times \frac{k}{n^3} \quad . \tag{8.4.7}$$

The ratio of these rationals (in general) is of order $M(D)/M$.

Suppose first that the detector has a disk like shape. This gives for the total number $n(D)$ of ordinary gravitons of frequency $\omega/s(G,S)$ going to the detector the estimate

$$n(D) = (\frac{d}{r})^2 \times r(G,S) \quad . \tag{8.4.8}$$

This gives

$$\begin{aligned} n(D) &= (\frac{d}{r})^2 \times GMmv_0 \times n_b(G,S) \times \frac{k}{n^3} \quad \text{for } \textbf{Option a)} \quad , \\ n(D) &= (\frac{d}{r})^2 \times GMmv_0 \times \times \frac{k}{n^3} \quad \text{for } \textbf{Option b)} \quad . \end{aligned} \tag{8.4.9}$$

If the actual area of detector is smaller than d^2 by a factor x one has

$$n(D) \rightarrow xn(D) \quad .$$

$n(D)$ cannot be smaller than the number of ordinary gravitons estimated using the Planck constant associated with the detector: $n(D) \geq r(D,G)$. This gives the condition

$$\frac{d}{r} \geq \sqrt{\frac{M(D)}{M(S)}} \times \sqrt{\frac{s(D,G)}{s(G,S)}} \times \frac{1}{x} \quad . \tag{8.4.10}$$

Suppose for simplicity $s(D,G)/s(G,S) = 1$, $M(D) = 10^3$ kg, and $M(S) = 10^{30}$ kg and $r = 200$ MPc $\sim 10^9$ ly, which is a typical distance for binaries. For $x = 1, k = 1$ this gives roughly $d \geq 10^{-4}$ ly $\sim 10^{11}$ m, which is roughly the size of the solar system. From energy conservation condition the entire solar system would be the natural detector in this case. $s(G,S) >> s(D,G)$ would be required to improve the situation. For **Option a)** this would mean that the number of sheets in the covering of CP_2 is reduced by large number. For option b) one has $s(G,S) = 1$ so that the situation cannot be improved. Therefore the direct detection of giant graviton by human made detectors is excluded at least for option b).

Secondary detection

The previous argument leaves only the secondary detection into consideration. Assume that ME results in the primary de-coherence of a giant graviton. Also longer de-coherence sequences are possible and one can deduce analogous conditions for these.

Energy conservation gives

$$\frac{S(D)}{S(ME)} \times q(ME,G) \quad = \quad q(D,ME) \ . \tag{8.4.11}$$

Using the expression for $S(ME)$ from Eq. 8.4.5, this gives an expression for $S(ME)$ for a given detector area:

$$S(ME) \quad = \quad \frac{q(ME,G)}{q(D,ME)} \times S(D) \simeq \frac{E(G)}{M(D)} \times S(D) \ . \tag{8.4.12}$$

From $S(ME) = \frac{E(ME)}{M(S)} 4\pi r^2$ one obtains

$$r \quad = \quad \sqrt{\frac{E(G)M(S)}{E(ME)M(D))}} \times \sqrt{S(D)} \tag{8.4.13}$$

for the distance at which ME is created. The distances of binaries studied in LIGO are of order $D = 10^{24}$ m. Using $E(G) \sim Mv_0^2$ and assuming $M = 10^{30}$ kg and $S(D) = 1$ m^2 (just for definiteness), one obtains $r \sim 10^{25}(kg/E(ME))$ m. If ME is generated at distance $r \sim D$ and if one has $S(ME) \sim 10^6$ m^2 (from the size scale for LIGO) one obtains from the equation for $S(ME)$ the estimate $E(ME) \sim 10^{-25}$ kg $\sim 10^{-8}$ Joule.

Some quantitative estimates for gravitational quantum transitions in planetary system

To get a concrete grasp about the situation it is useful to study the energies of dark gravitons in the case of planetary system assuming Bohr model.

The expressions for the energies of dark gravitons can be deduced from those of hydrogen atom using the replacements $Ze^2 \rightarrow 4\pi GMm$, $\hbar \rightarrow GMm/v_0$. The energies are given by

$$\begin{aligned} E_n &= \frac{1}{n^2} E_1 \ , \\ E_1 &= (Z\alpha)^2 \frac{m}{4} = (\frac{Ze^2}{4\pi\hbar})^2 \times \frac{m}{4} \rightarrow \frac{m}{4} v_0^2 \ . \end{aligned} \tag{8.4.14}$$

E_1 defines the energy scale. Note that v_0 defines a characteristic velocity if one writes this expression in terms of classical kinetic energy using virial theorem $T = -V/2$ for the circular orbits. This gives $E_n = T_n = mv_n^2/2 = mv_0^2/4n^2$ giving

$$v_n = \frac{v_0}{\sqrt{2}n} \ .$$

Orbital velocities are quantized as sub-harmonics of the universal velocity $v_0/sqrt2 = 2^{-23/2}$ and the scaling of v_0 by $1/n$ scales does not lead out from the set of allowed velocities.

Bohr radius scales as

$$r_0 \quad = \quad \frac{\hbar}{Z\alpha m} \rightarrow \frac{GM}{v_0^2} \ . \tag{8.4.15}$$

For $v_0 = 2^{11}$ this gives $r_0 = 2^{22}GM \simeq 4 \times 10^6 GM$. In the case of Sun this is below the value of solar radius but not too much.

The frequency $\omega(n, n-k)$ of the dark graviton emitted in $n \rightarrow n-k$ transition and orbital rotation frequency ω_n are given by

$$\omega(n,n-k) = \frac{v_0^3}{GM}\times(\frac{1}{n^2}-\frac{1}{(n-k)^2}) \simeq k\omega_n \ .$$
$$\omega_n = \frac{v_0^3}{GMn^3} \ . \tag{8.4.16}$$

The emitted frequencies at the large n limit are harmonics of the orbital rotation frequency so that quantum classical correspondence holds true. For low values of n the emitted frequencies differ from harmonics of orbital frequency.

The energy emitted in $n \rightarrow n-k$ transition would be

$$E(n,n-k) = mv_0^2\times(\frac{1}{n^2}-\frac{1}{(n-k)^2}) \ , \tag{8.4.17}$$

and obviously enormous. Single giant (spherical) dark graviton would be emitted in the transition and should decay to gravitons with smaller values of $\hbar$. Bunch like character of the detected radiation might serve as the signature of the process. The bunch like character of liberated dark gravitational energy means coherence and might play role in the coherent locomotion of living matter. For a pair of systems of masses $m = 1$ kg this would mean $Gm^2/v_0 \sim 10^{20}$ meaning that exchanged dark graviton corresponds to a bunch containing about 10^{20} ordinary gravitons. The energies of graviton bunches would correspond to the differences of the gravitational energies between initial and final configurations which in principle would allow to deduce the Bohr orbits between which the transition took place. Hence dark gravitons could make possible the analog of spectroscopy in astrophysical length scales.

8.4.5 Generalization to gauge interactions

The situation is expected to be essentially the same for gauge interactions. The first guess is that one has $r = Q_1Q_2g^2/v_0$, were g is the coupling constant of appropriate gauge interaction. v_0 need not be same as in the gravitational case. The value of $Q_1Q_2g^2$ for which perturbation theory fails defines a plausible estimate for v_0. The naive guess would be $v_0 \sim 1$. In the case of gravitation this interpretation would mean that perturbative approach fails for $GM_1M_2 = v_0$. For $r > 1$ Planck constant is quantized with rational values with ruler-and-compass rationals as favored values. For gauge interactions r would have rather small values. The above criterion applies to the field body connecting two gauge charged systems. One can generalize this picture to self interactions assignable to the "personal" field body of the system. In this case the condition would read as $\frac{Q^2g^2}{v_0} > 1$.

Some applications

One can imagine several applications.

1. A possible application would be to electromagnetic interactions in heavy ion collisions.

2. Gamma ray bursts might be one example of dark photons with very large value of Planck constant. The MEs carrying gravitons could carry also gamma rays and this would amplify the value of Planck constant form them too.

3. Atomic nuclei are good candidates for systems for which electromagnetic field body is dark. The value of $\hbar$ would be $r = Z^2e^2/v_0$, with $v_0 \sim 1$. Electromagnetic field body could become dark already for $Z > 3$ or even for $Z = 3$. This suggest a connection with nuclear string model [F9] in which $A \leq 4$ nuclei (with $Z < 3$) form the basic building bricks of the heavier nuclei identified as nuclear strings formed from these structures which themselves are strings of nucleons.

4. Color confinement for light quarks might involve dark gluonic field bodies.

5. Dark photons with large value of $\hbar$ could transmit large energies through long distances and their phase conjugate variants could make possible a new kind of transfer mechanism [K6] essential in TGD based quantum model of metabolism and having also possible technological applications. Various kinds of sharp pules [67] suggest themselves as a manner to produce dark bosons in

laboratory. Interestingly, after having given us alternating electricity, Tesla spent the rest of his professional life by experimenting with effects generated by electric pulses. Tesla claimed that he had discovered a new kind of invisible radiation, scalar wave pulses, which could make possible wireless communications and energy transfer in the scale of globe (for a possible but not the only TGD based explanation [G3]). This notion of course did not conform with Maxwell's theory, which had just gained general acceptance so that Tesla's fate was to spend his last years as a crackpot. Great experimentalists seem to be able to see what is there rather than what theoreticians tell them they should see. They are often also visionaries too much ahead of their time.

In what sense dark matter is dark?

The notion of dark matter as something which has only gravitational interactions brings in mind the concept of ether and is very probably only an approximate characterization of the situation. As I have been gradually developing the notion of dark matter as a hierarchy of phases of matter with an increasing value of Planck constant, the naivete of this characterization has indeed become obvious.

If the proposed view is correct, dark matter is dark only in the sense that the process of receiving the dark bosons (say gravitons) mediating the interactions with other levels of dark matter hierarchy, in particular ordinary matter, differs so dramatically from that predicted by the theory with a single value of Planck constant that the detected dark quanta are unavoidably identified as noise. Dark matter is there and interacts with ordinary matter and living matter in general and our own EEG in particular provide the most dramatic examples about this interaction. Hence we could consider the dropping of "dark matter" from the glossary altogether and replacing the attribute "dark" with the spectrum of Planck constants characterizing the particles (dark matter) and their field bodies (dark energy).

8.5 New view about black-holes

In TGD framework the imbedding of the interior metric of ordinary black-holes fails and there is a good argument suggesting that horizon is transformed to a "partonic" light-like 3-surface at which the signature of the induced metric changes [D3]. Black-hole would be replaced by a gigantic particle having no electro-weak interactions since the state would be created using super-symplectic generators and generate its mass via p-adic thermodynamics. Scwartschild radius equals to Compton length if the generalization of Nottale formula for Planck constant holds true. Super-symplectic black-holes behave as dark matter and are very natural final states of the star and follow naturally neutron star phase. Also a microscopic description of black-hole as a gigantic hadron emerges.

8.5.1 Anyonic view about blackholes

A new element to the model of black hole comes from the vision that black hole horizon as a light-like 3-surface corresponds to a light-like orbit of light-like partonic 2-surface. This allows two kinds of black holes. Fermion like black hole would correspond to a deformed CP_2 type extremal which Euclidian signature of metric and topologically condensed at a space-time sheet with a Minkowskian signature. Boson like black hole would correspond to a large wormhole contact connecting two space-time sheets with Minkowskian signature. Wormhole contact would be a piece deformed CP_2 type extremal possessing two light-like throats defining two black hole horizons very near to each other. It does not seem absolutely necessary to assume that the interior metric of the black-hole is realized in another space-time sheet with Minkowskian signature.

Second new element relates to the value of Planck constant. For $\hbar_{gr} = 4GM^2$ the Planck length $L_P(\hbar) = \sqrt{\hbar G}$ equals to Schwartschild radius and Planck mass equals to $M_P(\hbar) = \sqrt{\hbar/G} = 2M$. If the mass of the system is below the ordinary Planck mass: $M \leq m_P(\hbar_0)/2 = \sqrt{\hbar_0/4G}$, gravitational Planck constant is smaller than the ordinary Planck constant.

Black hole surface contains ultra dense matter so that perturbation theory is not expected to converge for the standard value of Planck constant but do so for gravitational Planck constant. If the phase transition increasing Planck constant is a friendly gesture of Nature making perturbation theory convergent, one expects that only the black holes for which Planck constant is such that $GM^2/4\pi\hbar < 1$

holds true are formed. Black hole entropy -being proportional to $1/\hbar$- is of order unity so that TGD black holes are not very entropic.

If the partonic 2-surface surrounds the tip of causal diamond CD, the matter at its surface is in anyonic state with fractional charges. Anyonic black hole can be seen as single gigantic elementary particle stabilized by fractional quantum numbers of the constituents preventing them from escaping from the system and transforming to ordinary visible matter. A huge number of different black holes are possible for given value of $\hbar$ since there is infinite variety of pairs (n_a, n_b) of integers giving rise to same value of $\hbar$.

One can imagine that the partonic surface is not exact sphere except for ideal black holes but contains large number of magnetic flux tubes giving rise to handles. Also a pair of spheres with different radii can be considered with surfaces of spheres connected by braided flux tubes. The braiding of these handles can represent information and one can even consider the possibility that black hole can act as a topological quantum computer. There would be no sharp difference between the dark parts of black holes and those of ordinary stars. Only the volume containing the complex flux tube structures associated with the orbits of planets and various objects around star would become very small for black hole so that the black hole might code for the topological information of the matter collapsed into it.

8.5.2 Super-symplectic bosons

TGD predicts also exotic bosons which are analogous to fermion in the sense that they correspond to single wormhole throat associated with CP_2 type vacuum extremal whereas ordinary gauge bosons corresponds to a pair of wormhole contacts assignable to wormhole contact connecting positive and negative energy space-time sheets. These bosons have super-conformal partners with quantum numbers of right handed neutrino and thus having no electro-weak couplings. The bosons are created by the purely bosonic part of super-symplectic algebra [B2, B3, B4], whose generators belong to the representations of the color group and 3-D rotation group but have vanishing electro-weak quantum numbers. Their spin is analogous to orbital angular momentum whereas the spin of ordinary gauge bosons reduces to fermionic spin. Recall that super-symplectic algebra is crucial for the construction of configuration space Kähler geometry. If one assumes that super-symplectic gluons suffer topological mixing identical with that suffered by say U type quarks, the conformal weights would be (5,6,58) for the three lowest generations. The application of super-symplectic bosons in TGD based model of hadron masses is discussed in [F4] and here only a brief summary is given.

As explained in [F4], the assignment of these bosons to hadronic space-time sheet is an attractive idea.

1. Quarks explain only a small fraction of the baryon mass and that there is an additional contribution which in a good approximation does not depend on baryon. This contribution should correspond to the non-perturbative aspects of QCD. A possible identification of this contribution is in terms of super-symplectic gluons. Baryonic space-time sheet with $k = 107$ would contain a many-particle state of super-symplectic gluons with net conformal weight of 16 units. This leads to a model of baryons masses in which masses are predicted with an accuracy better than 1 per cent.

2. Hadronic string model provides a phenomenological description of non-perturbative aspects of QCD and a connection with the hadronic string model indeed emerges. Hadronic string tension is predicted correctly from the additivity of mass squared for $J = 2$ bound states of super-symplectic quanta. If the topological mixing for super-symplectic bosons is equal to that for U type quarks then a 3-particle state formed by 2 super-symplectic quanta from the first generation and 1 quantum from the second generation would define baryonic ground state with 16 units of conformal weight. A very precise prediction for hadron masses results by assuming that the spin of hadron correlates with its super-symplectic particle content.

3. Also the baryonic spin puzzle caused by the fact that quarks give only a small contribution to the spin of baryons, could find a natural solution since these bosons could give to the spin of baryon an angular momentum like contribution having nothing to do with the angular momentum of quarks.

4. Super-symplectic bosons suggest a solution to several other anomalies related to hadron physics. The events observed for a couple of years ago in RHIC [31] suggest a creation of a black-hole like state in the collision of heavy nuclei and inspire the notion of color glass condensate of gluons, whose natural identification in TGD framework would be in terms of a fusion of hadronic space-time sheets containing super-symplectic matter materialized also from the collision energy. In the collision, valence quarks connected together by color bonds to form separate units would evaporate from their hadronic space-time sheets in the collision, and would define TGD counterpart of Pomeron, which experienced a reincarnation for few years ago [30]. The strange features of the events related to the collisions of high energy cosmic rays with hadrons of atmosphere (the particles in question are hadron like but the penetration length is anomalously long and the rate for the production of hadrons increases as one approaches surface of Earth) could be also understood in terms of the same general mechanism.

5. RHIC events have features which suggest that color glass condensate is very much analogous to a black-hole. This analogy has a precise formulation. Super-symplectic matter has no electro-weak interactions and is therefore dark matter in a strict sense. The exchange of super-symplectic $J = 2$ quanta brings in gravitation and string mass formula holds true. The value of the gravitational constant is however determined by hadronic p-adic length scale rather than CP_2 length scale so that strong gravitation is in question. This picture leads naturally to the question whether ordinary black-holes should be replaced by super-symplectic black-holes in TGD Universe as a natural final step of stellar evolution after the neutron star phase during which star already behaving like a gigantic hadron in super-symplectic degrees of freedom.

8.5.3 Are ordinary black-holes replaced with super-symplectic black-holes in TGD Universe?

Some variants of super string model predict the production of small black-holes at LHC. I have never taken this idea seriously but in a well-defined sense TGD predicts black-holes associated with super-symplectic gravitons with strong gravitational constant defined by the hadronic string tension. The proposal is that super-symplectic black-holes have been already seen in Hera, RHIC, and the strange cosmic ray events.

Baryonic super-symplectic black-holes of the ordinary M_{107} hadron physics would have mass 934.2 MeV, very near to proton mass. The mass of their M_{89} counterparts would be 512 times higher, about 478 GeV. "Ionization energy" for Pomeron, the structure formed by valence quarks connected by color bonds separating from the space-time sheet of super-symplectic black-hole in the production process, corresponds to the total quark mass and is about 170 MeV for ordinary proton and 87 GeV for M_{89} proton. This kind of picture about black-hole formation expected to occur in LHC differs from the stringy picture since a fusion of the hadronic mini black-holes to a larger black-hole is in question.

An interesting question is whether the ultrahigh energy cosmic rays having energies larger than the GZK cut-off of 5×10^{10} GeV are baryons, which have lost their valence quarks in a collision with hadron and therefore have no interactions with the microwave background so that they are able to propagate through long distances.

In neutron stars the hadronic space-time sheets could form a gigantic super-symplectic black-hole and ordinary black-holes would be naturally replaced with super-symplectic black-holes in TGD framework (only a small part of black-hole interior metric is representable as an induced metric). This obviously means a profound difference between TGD and string models.

1. Hawking-Bekenstein black-hole entropy would be replaced with its p-adic counterpart given by

$$S_p = (\frac{M}{m(CP_2)})^2 \times log(p) \ , \tag{8.5.1}$$

where $m(CP_2)$ is CP_2 mass, which is roughly 10^{-4} times Planck mass. M is the contribution of p-adic thermodynamics to the mass. This contribution is extremely small for gauge bosons but for fermions and super-symplectic particles it gives the entire mass.

2. If p-adic length scale hypothesis $p \simeq 2^k$ holds true, one obtains

$$S_p = klog(2) \times (\frac{M}{m(CP_2)})^2 , \tag{8.5.2}$$

$m(CP_2) = \hbar/R$, R the "radius" of CP_2, corresponds to the standard value of $\hbar_0$ for all values of $\hbar$.

3. Hawking-Bekenstein area law gives in the case of Schwartschild black-hole

$$S = \frac{A}{4G} \times \hbar = \pi G M^2 \times \hbar \ . \tag{8.5.3}$$

For the p-adic variant of the law Planck mass is replaced with CP_2 mass and $klog(2) \simeq log(p)$ appears as an additional factor. Area law is obtained in the case of elementary particles if k is prime and wormhole throats have M^4 radius given by p-adic length scale $L_k = \sqrt{k}R$ which is exponentially smaller than L_p. For macroscopic super-symplectic black-holes modified area law results if the radius of the large wormhole throat equals to Schwartschild radius. Schwartschild radius is indeed natural: in [D3] I have shown that a simple deformation of the Schwartschild exterior metric to a metric representing rotating star transforms Schwartschild horizon to a light-like 3-surface at which the signature of the induced metric is transformed from Minkowskian to Euclidian.

4. The formula for the gravitational Planck constant appearing in the Bohr quantization of planetary orbits and characterizing the gravitational field body mediating gravitational interaction between masses M and m [D6] reads as

$$\hbar_{gr} = \frac{GMm}{v_0}\hbar_0 \ .$$

$v_0 = 2^{-11}$ is the preferred value of v_0. One could argue that the value of gravitational Planck constant is such that the Compton length $\hbar_{gr}/M$ of the black-hole equals to its Schwartshild radius. This would give

$$\hbar_{gr} = \frac{GM^2}{v_0}\hbar_0 \ , \ \ v_0 = 1/2 \ . \tag{8.5.4}$$

The requirement that $\hbar_{gr}$ is a ratio of ruler-and-compass integers expressible as a product of distinct Fermat primes (only four of them are known) and power of 2 would quantize the mass spectrum of black hole [D6]. Even without this constraint M^2 is integer valued using p-adic mass squared unit and if p-adic length scale hypothesis holds true this unit is in an excellent approximation power of two.

5. The gravitational collapse of a star would correspond to a process in which the initial value of v_0 , say $v_0 = 2^{-11}$, increases in a stepwise manner to some value $v_0 \leq 1/2$. For a supernova with solar mass with radius of 9 km the final value of v_0 would be $v_0 = 1/6$. The star could have an onion like structure with largest values of v_0 at the core as suggested by the model of planetary system. Powers of two would be favored values of v_0. If the formula holds true also for Sun one obtains $1/v_0 = 3 \times 17 \times 2^{13}$ with 10 per cent error.

6. Black-hole evaporation could be seen as means for the super-symplectic black-hole to get rid of its electro-weak charges and fermion numbers (except right handed neutrino number) as the antiparticles of the emitted particles annihilate with the particles inside super-symplectic black-hole. This kind of minimally interacting state is a natural final state of star. Ideal super-symplectic black-hole would have only angular momentum and right handed neutrino number.

7. In TGD light-like partonic 3-surfaces are the fundamental objects and space-time interior defines only the classical correlates of quantum physics. The space-time sheet containing the highly entangled cosmic string might be separated from environment by a wormhole contact with size of black-hole horizon.

   This looks the most plausible option but one can of course ask whether the large partonic 3-surface defining the horizon of the black-hole actually contains all super-symplectic particles so that super-symplectic black-hole would be single gigantic super-symplectic parton. The interior of super-symplectic black-hole would be a space-like region of space-time, perhaps resulting as a large deformation of CP_2 type vacuum extremal. Black-hole sized wormhole contact would define a gauge boson like variant of the black-hole connecting two space-time sheets and getting its mass through Higgs mechanism. A good guess is that these states are extremely light.

8.6 Piece-wise accelerated cosmic expansion as basic prediction of quantum cosmology

Quantum cosmology predicts that astrophysical objects do not follow cosmic expansion except in jerk-wise quantum leaps increasing the value of the gravitational Planck constant. This assumption provides explanation for the apparent cosmological constant. Also planets are predicted to expand in this manner. This provides a new version of Expanding Earth theory originally postulated to explain the intriguing findings suggesting that continents have once formed a connected continent covering the entire surface of Earth but with radius which was one half of the recent one.

8.6.1 Experimental evidence for accelerated expansion is consistent with TGD based model

There are several pieces of evidence for accelerated expansion, which need not mean cosmological constant, although this is the interpretation adopted in [32]. It is interesting to see whether this evidence is indeed consistent with TGD based interpretation.

The four pieces of evidence for accelerated expansion

1. Supernovas of type Ia

Supernovas of type Ia define standard candles since their luminosity varies in an oscillatory manner and the period is proportional to the luminosity. The period gives luminosity and from this the distance can be deduced by using Hubble's law: $d = cz/H_0$, H_0 Hubble's constant. The observation was that the farther the supernova was the more dimmer it was as it should have been. In other words, Hubble's constant increased with distance and the cosmic expansion was accelerating rather than decelerating as predicted by the standard matter dominated and radiation dominated cosmologies.

2. Mass density is critical and 3-space is flat

It is known that the contribution of ordinary and dark matter explaining the constant velocity of distance stars rotating around galaxy is about 25 per cent from the critical density. Could it be that total mass density is critical?

From the anisotropy of cosmic microwave background one can deduce that this is the case. What criticality means geometrically is that 3-space defined as surface with constant value of cosmic time is flat. This reflects in the spectrum of microwave radiation. The spots representing small anisotropies in the microwave background temperature is 1 degree and this correspond to flat 3-space. If one had dark matter instead of dark energy the size of spot would be .5 degrees!

Thus in a cosmology based on general relativity cosmological constant remains the only viable option. The situation is different in TGD based quantum cosmology based on sub-manifold gravity and hierarchy of gravitational Planck constants.

3. The energy density of vacuum is constant in the size scale of big voids

It was observed that the density of dark energy would be constant in the scale of 10^8 light years. This length scale corresponds to the size of big voids containing galaxies at their boundaries.

4. Integrated Sachs-Wolf effect

Also so called integrated Integrated Sachs-Wolf effect supports accelerated expansion. Very slow variations of mass density are considered. These correspond to gravitational potentials. Cosmic expansion tends to flatten them but mass accretion to form structures compensates this effect so that gravitational potentials are unaffected and there is no effect of CMB. Situation changes if dark matter is replaced with dark energy the accelerated expansion flattening the gravitational potentials wins the tendency of mass accretion to make them deeper. Hence if photon passes by an over-dense region, it receives a little energy. Similarly, photon loses energy when passing by an under-dense region. This effect has been observed.

Comparison with TGD

The minimum TGD based explanation for accelerated expansion involves only the fact that the imbeddings of critical cosmologies correspond to accelerated expansion. A more detailed model allows to understand why the critical cosmology appears during some periods.

1. Accelerated expansion in classical TGD

The first observation is that critical cosmologies (flat 3-space) imbeddable to 8-D imbedding space H correspond to negative pressure cosmologies and thus to accelerating expansion. The negativity of the counterpart of pressure in Einstein tensor is due to the fact that space-time sheet is forced to be a 4-D surface in 8-D imbedding space. This condition is analogous to a force forcing a particle at the surface of 2-sphere and gives rise to what could be called constraint force. Gravitation in TGD is sub-manifold gravitation whereas in GRT it is manifold gravitation. This would be minimum interpretation involving no assumptions about what mechanism gives rise to the critical periods.

2. Accelerated expansion and hierarchy of Planck constants

One can go one step further and introduce the hierarchy of Planck constants. The basic difference between TGD and GRT based cosmologies is that TGD cosmology is quantum cosmology. Smooth cosmic expansion is replaced by an expansion occurring in discrete jerks corresponding to the increase of gravitational Planck constant. At space-time level this means the replacement of 8-D imbedding space H with a book like structure containing almost-copies of H with various values of Planck constant as pages glued together along critical manifold through which space-time sheet can leak between sectors with different values of $\hbar$. This process is the geometric correlate for the the phase transition changing the value of Planck constant.

During these phase transition periods critical cosmology applies and predicts automatically accelerated expansion. Neither genuine negative pressure due to "quintessence" nor cosmological constant is needed. Note that quantum criticality replaces inflationary cosmology and predicts a unique cosmology apart from single parameter. Criticality also explains the fluctuations in microwave temperature as long range fluctuations characterizing criticality.

3. Accelerated expansion and flatness of 3-cosmology

Observations 1) and 2) about super-novae and critical cosmology (flat 3-space) are consistent with this cosmology. In TGD dark energy must be replaced with dark matter because the mass density is critical during the phase transition. This does not lead to wrong sized spots since it is the increase of Planck constant which induces the accelerated expansion understandable also as a constraint force due to imbedding to H.

4. The size of large voids is the characteristic scale

The TGD based model in its simplest form model assigns the critical periods of expansion to large voids of size 10^8 ly. Also larger and smaller regions can express similar periods and dark space-time sheets are expected to obey same universal "cosmology" apart from a parameter characterizing the duration of the phase transition. Observation 3) that just this length scale defines the scale below which dark energy density is constant is consistent with TGD based model.

The basic prediction is jerkwise cosmic expansion with jerks analogous to quantum transitions between states of atom increasing the size of atom. The discovery of large voids with size of order 10^8 ly but age much longer than the age of galactic large voids conforms with this prediction. One the other hand, it is known that the size of galactic clusters has not remained constant in very long time scale so that jerkwise expansion indeed seems to occur.

5. Do cosmic strings with negative gravitational mass cause the phase transition inducing accelerated expansion

Quantum classical correspondence is the basic principle of quantum TGD and suggest that the effective antigravity manifested by accelerated expansion might have some kind of concrete space-time correlate. A possible correlate is super heavy cosmic string like objects at the center of large voids which have negative gravitational mass under very general assumptions. The repulsive gravitational force created by these objects would drive galaxies to the boundaries of large voids. At some state the pressure of galaxies would become too strong and induce a quantum phase transition forcing the increase of gravitational Planck constant and expansion of the void taking place much faster than the outward drift of the galaxies. This process would repeat itself. In the average sense the cosmic expansion would not be accelerating.

Does TGD allow description of accelerated expansion in terms of cosmological constant?

The introduction of cosmological constant seems to be the only manner to explain accelerated expansion and related effects in the framework of General Relativity. TGD allows different explanation of these effects. It is however interesting to look whether TGD allows a description based on finite cosmological constant as a small deformation of De Sitter space represented as a vacuum extremal. Before this a clarifying comment about the term "vacuum energy".

The term vacuum energy density is bad use of language since De Sitter space [36] is a solution of field equations with cosmological constant at the limit of vanishing energy momentum tensor carries *vacuum curvature* rather than vacuum energy. Thus theories with non-vanishing cosmological constant represent a family of gravitational theories for which vacuum solution is not flat so that Einstein's basic identification matter = curvature is given up. No wonder, Einstein regarded the introduction of cosmological constant as the biggest blunder of his life.

De Sitter space is representable as a hyperboloid $a^2 - u^2 = -R^2$, where one has $a^2 = t^2 - r^2$ and $r^2 = x^2 + y^2 + z^2$. The symmetries of de Sitter space are maximal but Poincare group is replaced with Lorentz group of 5-D Minkowski space and translations are not symmetries. The value of cosmological constant is $\Lambda = 3/R^2$. The presence of non-vanishing dimensional constant is from the point of view of conformal invariance a feature raising strong suspicions about the correctness of the underlying physics.

1. Imbeddings of De Sitter space

De Sitter space is possible as a vacuum extremal in TGD framework. There exists infinite number of imbeddings as a vacuum extremal into $M^4 \times CP_2$. Take any infinitely long curve X in CP_2 not intersecting itself (one might argue that infinitely long curve is somewhat pathological) and introduce a coordinate u for it such that its induced metric is $ds^2 = du^2$. De Sitter space allows the standard imbedding to $M^4 \times X$ as a vacuum extremal. The imbedding can be written as $u = \pm[a^2 + R^2]^{1/2}$ so that one has $r^2 < t^2 + R^2$. One example is curve in S^2 which spirals around chosen point infinitely many times so that at the vicinity of point it almost fills 2-dimensional region of S^2. One can also combine spirals associated with two distinct points so that u coordinate spans range $[-\infty, \infty]$.

The curve in question can also fill 2-D or higher-dimensional sub-manifold of CP_2 densely. An example is torus densely filled by the curve $\phi = \alpha\psi$ where α is irrational number. Note that even a slightest local deformation of this object induces an infinite number of self-intersections. Space-time sheet fills densely 5-D set in this case. One can ask whether this kind of objects might be analogs of $D > 4$ branes in TGD framework. As a matter fact, CP_2 projections of 1-D vacuum extremals could give rise to both the analogs of branes and strings connecting them if space-time surface contains both regular and "brany" pieces. Perhaps this might provide a new (possibly) approach to the understanding of branes in M-theory context.

It might be that the 2-D Lagrangian manifolds representing CP_2 projection of the most general vacuum extremal, can fill densely $D > 2$-dimensional sub-manifold of CP_2. One can imagine construction of very complex Lagrange manifolds by gluing together pieces of 2-D Lagrangian sub-manifolds by arbitrary 1-D curves. One could also rotate 2-Lagrangian manifold along a 2-torus - just like one rotates point along 2-torus in the above example - to get a dense filling of 4-D volume of CP_2.

The M^4 projection of the imbedding corresponds to the region $a^2 > -R^2$ containing future and past lightcones. If u varies only in range $[0, u_0]$ only hyperboloids with a^2 in the range $[-R^2, -R^2+u_0^2]$ are present in the foliation. In zero energy ontology the space-like boundaries of this piece of De Sitter space, which must have $u_0^2 > R^2$, would be carriers of positive and negative energy states. The boundary corresponding to $u_0 = 0$ is space-like and analogous to the orbit of partonic 2-surface. For $u_0^2 < R^2$ there are no space-like boundaries and the interpretation as a zero energy state is not possible. Note that the restriction $u_0^2 \geq R^2$ plus the choice of the branch of the imbedding corresponding to future or past directed lightcone is natural in TGD framework.

2. Could negative cosmological constant make sense in TGD framework?

The questionable feature of slightly deformed De Sitter metric as a model for the accelerated expansion is that the value of a would be same order of magnitude as the recent age of the Universe. Why should just this value of cosmic time be so special? In TGD framework one could of course consider space-time sheets having De Sitter cosmology characterized by a varying value of R. Also the replacement of one spatial coordinate with CP_2 coordinate implies very strong breaking of translational invariance. Hence the explanation relying on quantization of gravitational Planck constant looks more attractive to me.

It is however always useful to make an exercise in challenging the cherished beliefs.

1. Could the complete failure of the perturbation theory around canonically imbedded M^4 make De Sitter cosmology natural vacuum extremal. De Sitter space appears also in the models of inflation and long range correlations might have something to do with the intersections between distant points of 3-space resulting from very small local deformations. Could both the slightly deformed De Sitter space and quantum critical cosmology represent cosmological epochs in TGD Universe?

2. Gravitational energy defined as a non-conserved Noether charge in terms of Einstein tensor TGD is infinite for De Sitter cosmology (Λ as characterizer of vacuum energy). If one includes to the gravitational momentum also metric tensor gravitational four-momentum density vanishes (Λ as characterizer of vacuum curvature). TGD does not involve Einstein-Hilbert action as fundamental action and gravitational energy momentum tensor should be dictated by finiteness condition so that negative cosmological constant might make sense in TGD.

3. The imbedding of De Sitter cosmology involves the choice of a preferred lightcone as does also quantization of Planck constant. Quantization of Planck constant involves the replacement of the lightcones of $M^4 \times CP_2$ by its finite coverings and orbifolds glued to together along quantum critical sub-manifold. Finite pieces of De Sitter space are obtained for rational values of α and there is a covering of lightcone by CP_2 points. How can I be sure that there does not exist a deeper connection between the descriptions based on cosmological constant and on phase transitions changing the value Planck constant?

Note that Anti de Sitter space [37] having similar imbedding to 5-D Minkowski space with two time like dimensions does not possess this kind of imbedding to H. Very probably no imbeddings exist so that TGD would allow only imbeddings of cosmologies with correct sign of Λ whereas M-theory in its basic form predicts a wrong sign for it. Note also that Anti de Sitter space appearing in AdS-CFT dualities contains closed time-like loops and is therefore also physically questionable.

The mystery of mini galaxies and the hierarchy of Planck constants

New Scientist [38] informs that a team led by Pieter van Dokkum at Yale University measured the light of distant galaxies from around 3 billion years after the big bang. They had the same mass as the Milky Way, but were 10 times smaller (The Astrophysical Journal, vol. 677, p. L5). Peering at younger regions of the sky shows that galaxies this size are no longer around, but it's not clear what happened to them. "This is a very puzzling result," says Simon White of the Max Planck Institute for Astrophysics in Garching, Germany. "Galaxies cannot disappear." Team member Marijn Franx of Leiden Observatory, the Netherlands, suspects they have since merged with extremely massive galaxies. The disappearance of the mini galaxies would be due to this mechanism. From the assumption that this mechanism gives rise to the same outcome as smooth expansion within factor of two at given moment, one could estimate their recent size. If the galaxies are assumed to have roughly the size of Milky Way now, an upwards scaling would be roughly by a factor 8. This would mean that recent age of Universe would be about 24 billion years.

8.6.2 Quantum version of Expanding Earth theory

TGD predicts that cosmic expansion at the level of individual astrophysical systems does not take place continuously as in classical gravitation but through discrete quantum phase transitions increasing gravitational Planck constant and thus various quantum length and time scales. The reason would be that stationary quantum states for dark matter in astrophysical length scales cannot expand. One would have the analog of atomic physics in cosmic scales. Increases of $\hbar$ by a power of two are favored in these transitions but also other scalings are possible.

This has quite far reaching implications.

1. These periods have a highly unique description in terms of a critical cosmology for the expanding space-time sheet. The expansion is accelerating. The accelerating cosmic expansion can be assigned to this kind of phase transition in some length scale (TGD Universe is fractal). There is no need to introduce cosmological constant and dark energy would be actually dark matter.

2. The recently observed void which has same size of about 10^8 light years as large voids having galaxies near their boundaries but having an age which is much higher than that of the large voids, would represent one example of jerk-wise expansion.

3. This picture applies also to solar system and planets might be perhaps seen as having once been parts of a more or less connected system, the primordial Sun. The Bohr orbits for inner and outer planets correspond to gravitational Planck constant which is 5 times larger for outer planets. This suggests that the space-time sheet of outer planets has suffered a phase transition increasing the size scale by a factor of 5. Earth can be regarded either as n=1 orbit for Planck constant associated with outer planets or n= 5 orbit for inner planetary system. This might have something to do with the very special position of Earth in planetary system. One could even consider the possibility that both orbits are present as dark matter structures. The phase transition would also explain why n=1 and n=2 Bohr orbits are absent and one only n=3,4, and 5 are present.

4. Also planets should have experienced this kind of phase transitions increasing the radius: the increase by a factor two would be the simplest situation.

The obvious question - that I did not ask - is whether this kind of phase transition might have occurred for Earth and led from a completely granite covered Earth - Pangeia without seas - to the recent Earth. Neither it did not occur to me to check whether there is any support for a rapid expansion of Earth during some period of its history.

Situation changed when my son visited me last Saturday and told me about a Youtube video [53] by Neal Adams, an American comic book and commercial artist who has also produced animations for geologists. We looked the amazing video a couple of times and I looked it again yesterday. The video is very impressive artwork but in the lack of references skeptic probably cannot avoid the feeling that Neal Adams might use his highly developed animation skills to cheat you. I found also a polemic article [54] of Adams but again the references were lacking. Perhaps the reason of polemic tone was that the concrete animation models make the expanding Earth hypothesis very convincing but geologists refuse to consider seriously arguments by a layman without a formal academic background.

The claims of Adams

The basic claims of Adams were following.

1. The radius of Earth has increased during last 185 million years (dinosaurs [62] appeared for about 230 million years ago) by about factor 2. If this is assumed all continents have formed at that time a single super-continent, Pangeia, filling the entire Earth surface rather than only 1/4 of it since the total area would have grown by a factor of 4. The basic argument was that it is very difficult to imagine Earth with 1/4 of surface containing granite and 3/4 covered by

basalt. If the initial situation was covering by mere granite -as would look natural- it is very difficult for a believer in thermodynamics to imagine how the granite would have gathered to a single connected continent.

2. Adams claims that Earth has grown by keeping its density constant, rather than expanded, so that the mass of Earth has grown linearly with radius. Gravitational acceleration would have thus doubled and could provide a partial explanation for the disappearance of dinosaurs: it is difficult to cope in evolving environment when you get slower all the time.

3. Most of the sea floor is very young and the areas covered by the youngest basalt are the largest ones. This Adams interprets this by saying that the expansion of Earth is accelerating. The alternative interpretation is that the flow rate of the magma slows down as it recedes from the ridge where it erupts. The upper bound of 185 million years for the age of sea floor requires that the expansion period - if it is already over - lasted about 185 million years after which the flow increasing the area of the sea floor transformed to a convective flow with subduction so that the area is not increasing anymore.

4. The fact that the continents fit together - not only at the Atlantic side - but also at the Pacific side gives strong support for the idea that the entire planet was once covered by the super-continent. After the emergence of subduction theory this evidence as been dismissed.

5. I am not sure whether Adams mentions the following objections [57]. Subduction only occurs on the other side of the subduction zone so that the other side should show evidence of being much older in the case that oceanic subduction zones are in question. This is definitely not the case. This is explained in plate tectonics as a change of the subduction direction. My explanation would be that by the symmetry of the situation both oceanic plates bend down so that this would represent new type of boundary not assumed in the tectonic plate theory.

6. As a master visualizer Adams notices that Africa and South-America do not actually fit together in absence of expansion unless one assumes that these continents have suffered a deformation. Continents are not easily deformable stuff. The assumption of expansion implies a perfect fit of *all* continents without deformation.

Knowing that the devil is in the details, I must admit that these arguments look rather convincing to me and what I learned from Wikipedia articles supports this picture.

The critic of Adams of the subduction mechanism

The prevailing tectonic plate theory [55] has been compared to the Copernican revolution in geology. The theory explains the young age of the seafloor in terms of the decomposition of the litosphere to tectonic plates and the convective flow of magma to which oceanic tectonic plates participate. The magma emerges from the crests of the mid ocean ridges representing a boundary of two plates and leads to the expansion of sea floor. The variations of the polarity of Earth's magnetic field coded in sea floor provide a strong support for the hypothesis that magma emerges from the crests.

The flow back to would take place at so called oceanic trenches [56] near continents which represent the deepest parts of ocean. This process is known as subduction. In subduction oceanic tectonic plate bends and penetrates below the continental tectonic plate, the material in the oceanic plate gets denser and sinks into the magma. In this manner the oceanic tectonic plate suffers a metamorphosis returning back to the magma: everything which comes from Earth's interior returns back. Subduction mechanism explains elegantly formation of mountains [58] (orogeny), earth quake zones, and associated zones of volcanic activity [60].

Adams is very polemic about the notion of subduction, in particular about the assumption that it generates steady convective cycle. The basic objections of Adams against subduction are following.

1. There are not enough subduction zones to allow a steady situation. According to Adams, the situation resembles that for a flow in a tube which becomes narrower. In a steady situation the flow should accelerate as it approaches subduction zones rather than slow down. Subduction zones should be surrounded by large areas of sea floor with constant age. Just the opposite is suggested by the fact that the youngest portion of sea-floor near the ridges is largest. The

presence of zones at which both ocean plates bend down could improve the situation. Also jamming of the flow could occur so that the thickness of oceanic plate increases with the distance from the eruption ridge. Jamming could increase also the density of the oceanic plate and thus the effectiveness of subduction.

2. There is no clear evidence that subduction has occurred at other planets. The usual defense is that the presence of sea is essential for the subduction mechanism.

3. One can also wonder what is the mechanism that led to the formation of single super continent Pangeia covering 1/4 of Earth's surface. How probable the gathering of all separate continents to form single cluster is? The later events would suggest that just the opposite should have occurred from the beginning.

Expanding Earth theories are not new

After I had decided to check the claims of Adams, the first thing that I learned is that Expanding Earth theory [57], whose existence Adams actually mentions, is by no means new. There are actually many of them.

The general reason why these theories were rejected by the main stream community was the absence of a convincing physical mechanism of expansion or of growth in which the density of Earth remains constant.

1. 1888 Yarkovski postulated some sort of aether absorbed by Earth and transforming to chemical elements (TGD version of aether could be dark matter). 1909 Mantovani postulated thermal expansion but no growth of the Earth's mass.

2. Paul Dirac's idea about changing Planck constant led Pascual Jordan in 1964 to a modification of general relativity predicting slow expansion of planets. The recent measurement of the gravitational constant imply that the upper bound for the relative change of gravitational constant is 10 time too small to produce large enough rate of expansion. Also many other theories have been proposed but they are in general conflict with modern physics.

3. The most modern version of Expanding Earth theory is by Australian geologist Samuel W. Carey. He calculated that in Cambrian period (about 500 million years ago) all continents were stuck together and covered the entire Earth. Deep seas began to evolve then.

Summary of TGD based theory of Expanding Earth

TGD based model differs from the tectonic plate model but allows subduction which cannot imply considerable back-flow of magma. Let us sum up the basic assumptions and implications.

1. The expansion is or was due to a quantum phase transition increasing the value of gravitational Planck constant and forced by the cosmic expansion in the average sense.

2. Tectonic plates do not participate to the expansion and therefore new plate must be formed and the flow of magma from the crests of mid ocean ridges is needed. The decomposition of a single plate covering the entire planet to plates to create the mid ocean ridges is necessary for the generation of new tectonic plate. The decomposition into tectonic plates is thus prediction rather than assumption.

3. The expansion forced the decomposition of Pangeia super-continent covering entire Earth for about 530 million years ago to split into tectonic plates which began to recede as new non-expanding tectonic plate was generated at the ridges creating expanding sea floor. The initiation of the phase transition generated formation of deep seas.

4. The eruption of plasma from the crests of ocean ridges generated oceanic tectonic plates which did not participate to the expansion by density reduction but by growing in size. This led to a reduction of density in the interior of the Earth roughly by a factor 1/8. From the upper bound for the age of the seafloor one can conclude that the period lasted for about 185 million years after which it transformed to convective flow in which the material returned back to the Earth

interior. Subduction at continent-ocean floor boundaries and downwards double bending of tectonic plates at the boundaries between two ocean floors were the mechanisms. Thus tectonic plate theory would be more or less the correct description for the recent situation.

5. One can consider the possibility that the subducted tectonic plate does not transform to magma but is fused to the tectonic layer below continent so that it grows to an iceberg like structure. This need not lead to a loss of the successful predictions of plate tectonics explaining the generation of mountains, earthquake zones, zones of volcanic activity, etc...

6. From the video of Adams it becomes clear that the tectonic flow is East-West asymmetric in the sense that the western side is more irregular at large distances from the ocean ridge at the western side. If the magma rotates with slightly lower velocity than the surface of Earth (like liquid in a rotating vessel), the erupting magma would rotate slightly slower than the tectonic plate and asymmetry would be generated.

7. If the planet has not experienced a phase transition increasing the value of Planck constant, there is no need for the decomposition to tectonic plates and one can understand why there is no clear evidence for tectonic plates and subduction in other planets. The conductive flow of magma could occur below this plate and remain invisible.

The biological implications might provide a possibility to test the hypothesis.

1. Great steps of progress in biological evolution are associated with catastrophic geological events generating new evolutionary pressures forcing new solutions to cope in the new situation. Cambrian explosion indeed occurred about 530 years ago (the book "Wonderful Life" of Stephen Gould [64] explains this revolution in detail) and led to the emergence of multicellular creatures, and generated huge number of new life forms living in seas. Later most of them suffered extinction: large number of phylae and groups emerged which are not present nowadays.

   Thus Cambrian explosion is completely exceptional as compared to all other dramatic events in the evolution in the sense that it created something totally new rather than only making more complex something which already existed. Gould also emphasizes the failure to identify any great change in the environment as a fundamental puzzle of Cambrian explosion. Cambrian explosion is also regarded in many quantum theories of consciousness (including TGD) as a revolution in the evolution of consciousness: for instance, micro-tubuli emerged at this time. The periods of expansion might be necessary for the emergence of multicellular life forms on planets and the fact that they unavoidably occur sooner or later suggests that also life develops unavoidably.

2. TGD predicts a decrease of the surface gravity by a factor 1/4 during this period. The reduction of the surface gravity would have naturally led to the emergence of dinosaurs 230 million years ago as a response coming 45 million years after the accelerated expansion ceased. Other reasons led then to the decline and eventual catastrophic disappearance of the dinosaurs. The reduction of gravity might have had some gradually increasing effects on the shape of organisms also at microscopic level and manifest itself in the evolution of genome during expansion period.

3. A possibly testable prediction following from angular momentum conservation ($\omega R^2 = constant$) is that the duration of day has increased gradually and was four times shorter during the Cambrian era. For instance, genetically coded bio-clocks of simple organisms during the expansion period could have followed the increase of the length of day with certain lag or failed to follow it completely. The simplest known circadian clock is that of the prokaryotic cyanobacteria. Recent research has demonstrated that the circadian clock of Synechococcus elongatus can be reconstituted in vitro with just the three proteins of their central oscillator. This clock has been shown to sustain a 22 hour rhythm over several days upon the addition of ATP: the rhythm is indeed faster than the circadian rhythm. For humans the average innate circadian rhythm is however 24 hours 11 minutes and thus conforms with the fact that human genome has evolved much later than the expansion ceased.

4. Scientists have found a fossil of a sea scorpion with size of 2.5 meters [65], which has lived for about 10 million years for 400 million years ago in Germany. The gigantic size would conform

nicely with the much smaller value of surface gravity at that time. The finding would conform nicely with the much smaller value of surface gravity at that time. Also the emergence of trees could be understood in terms of a gradual growth of the maximum plant size as the surface gravity was reduced. The fact that the oldest known tree fossil is 385 million years old [66] conforms with this picture.

Did intra-terrestrial life burst to the surface of Earth during Cambrian expansion?

Intra-terrestrial hypothesis [L5] is one of the craziest TGD inspired ideas about the evolution of life and it is quite possible that in its strongest form the hypothesis is unrealistic. One can however try to find what one obtains from the combination of the IT hypothesis with the idea of pre-Cambrian granite Earth. Could the harsh pre-Cambrian conditions have allowed only intra-terrestrial multicellular life? Could the Cambrian explosion correspond to the moment of birth for this life in the very concrete sense that the magma flow brought it into the day-light?

1. Gould emphasizes the mysterious fact that very many life forms of Cambrian explosion looked like final products of a long evolutionary process. Could the eruption of magma from the Earth interior have induced a burst of intra-terrestrial life forms to the Earth's surface? This might make sense: the life forms living at the bottom of sea do not need direct solar light so that they could have had intra-terrestrial origin. It is quite possible that Earth's mantle contained low temperature water pockets, where the complex life forms might have evolved in an environment shielded from meteoric bombardment and UV radiation.

2. Sea water is salty. It is often claimed that the average salt concentration inside cell is that of the primordial sea: I do not know whether this claim can be really justified. If the claim is true, the cellular salt concentration should reflect the salt concentration of the water inside the pockets. The water inside water pockets could have been salty due to the diffusion of the salt from ground but need not have been same as that for the ocean water (higher than for cell interior and for obvious reasons). Indeed, the water in the underground reservoirs in arid regions such as Sahara is salty, which is the reason for why agriculture is absent in these regions. Note also that the cells of marine invertebrates are osmoconformers able to cope with the changing salinity of the environment so that the Cambrian revolutionaries could have survived the change in the salt concentration of environment.

3. What applies to Earth should apply also to other similar planets and Mars [61] is very similar to Earth. The radius is .533 times that for Earth so that after quantum leap doubling the radius and thus Schumann frequency scale (7.8 Hz would be the lowest Schumann frequency) would be essentially same as for Earth now. Mass is .131 times that for Earth so that surface gravity would be .532 of that for Earth now and would be reduced to .131 meaning quite big dinosaurs! have learned that Mars probably contains large water reservoirs in it's interior and that there is an un-identified source of methane gas usually assigned with the presence of life. Could it be that Mother Mars is pregnant and just waiting for the great quantum leap when it starts to expand and gives rise to a birth of multicellular life forms. Or expressing freely how Bible describes the moment of birth: in the beginning there was only darkness and water and then God said: Let the light come!

To sum up, TGD would provide only the long sought mechanism of expansion and a possible connection with the biological evolution. It would be indeed fascinating if Planck constant changing quantum phase transitions in planetary scale would have profoundly affected the biosphere.

8.7 About the anomalies of the cosmic microwave background

Depending on one's attitudes, the anomalies of the fluctuation spectrum of the cosmic microwave background (CMB) can be seen as a challenge for people analyzing the experiments or that of the inflationary scenario. I do not pretend to be deeply involved with CMB. What interests me is whether the replacement of inflation with quantum criticality and $\hbar$ changing phase transitions could provide fresh insights about fluctuations and the anomalies of CMB. In the following I try first to explain to myself what the anomalies are and after that I will consider some TGD inspired crazy (as always) ideas. My motivations for commuting these ideas are indeed strong: the consideration of the anomalies led to a generalization of the notion of conformal QFT to what might be called symplectic QFT having very natural place also in quantum TGD proper.

8.7.1 Background

Consider first some background.

1. The fluctuations of CMB reflect directly the fluctuations of energy density (acoustic waves) responsible for the formation of various structures: this follows from the proportionality $\rho \propto T^4$: one has $\Delta T/T \propto \Delta\rho/\rho \propto \Phi$, Φ is gravitational potential created by the density fluctuations. The spectrum reflects the situation as thermal photons decoupled from matter and the matter became transparent to photons. The radiation comes from the sphere of last scattering S^2, which corresponds to the setting on of transparency and only Thomson scattering can affect the radiation after that time. For short angular distances the 2-point correlation functions at S^2 for the fluctuations are suppressed: this is due to a rapid increase of photon free path during the transition making possible exponential damping of the fluctuations of energy density for angular separation $\theta < 1$ degree at which the amplitude is maximum. Quite generally, at the maxima of correlation function the photons almost decouple from the acoustic fluctuations.

2. The analysis of fluctuation spectrum of CMB in general relativistic context requires a solution of Einstein's equations for small perturbations of Robertson Walker metric in presence of matter. It is convenient to decompose the perturbation of the metric Robertson-Walker coordinates using representations of rotation group [42]. The perturbation of g_{tt} is scalar, the perturbation of g_{ti} decomposes to a gradient of a scalar and rotor of a vector, and the perturbation of g_{ij} corresponds to a scaling of the 3-metric represented by a scalar, double gradient of scalar, and genuinely tensorial part corresponding to classical gravitational radiation. From the four scalar modes two can be eliminated as mere coordinate changes without actual physical content. It is believed that only the scalar perturbations and tensor perturbation are significant. For the WMAP data only scalar perturbations matter.

3. Scalar fluctuations can be divided to two classes. For adiabatic fluctuations the fluctuation of the energy density for a given particle species is proportional to the energy density associated with the species with a common constant of proportionality. When curvature scalar vanishes these fluctuations do not affect the curvature scalar. Inflationary scenario predicts adiabaticity. For iso-curvature fluctuations the sum of the fluctuations associated with different particles vanishes: cosmic strings predict this kind of spectrum. The detailed spectrum of the peaks for 2-point correlation functions is consistent with adiabaticity and excludes cosmic strings in sense of GUTs.

4. The predictions of the inflationary scenario follow from the assumption that fluctuations correspond to primordial quantum fluctuations of inflaton field which expanded with an exponential rate to macroscopic fluctuations during the inflationary period. The spectrum of perturbations is assumed to be Gaussian and to obey approximate scale invariance [39]. Gaussianity holds true in 3-D momentum space and states that correlation function for the fluctuations of the energy density is proportional to 3-D delta function in momentum space. In other words, the Fourier components of the density perturbation are statistically independent. The coefficient of delta function can depend on the magnitude of 3-momentum. For exact scale invariance it would be constant. This invariance is however broken and the multiplying function is a power k^{1-n_s} of the length of the wave vector, where n_s is so called spectral index. Spectral index has been deduced from WMAP data been measured and differs slightly from unity: $n_s = .960 \pm .0014$. Gaussian distribution contains as a free parameter the scale r of the perturbations and the observed amplitude $r = \Delta T/T \simeq 10^{-5}$ of fluctuations would reflect primordial initial conditions in energy scale about 10^{-3} times Planck mass, which has interpretation as gauge unification scale in GUTs. I am not sure whether the theories can really predict the value of r.

8.7.2 Anomalies of CMB

There are several anomalies associated with CMB corresponding to the power spectrum of fluctuations and 2-point correlation function as a function of the angle difference θ between points of the sphere of last scattering. There is also some evidence for the failure of Gaussianity reflecting itself as a non-vanishing of 3-point correlation functions.

Consider first fluctuation spectrum, or formally 1-point correlation functions for what is essentially gravitational potential due to fluctuations in Newtonian gauge.

1. There is dipole term in the spectrum identifiable in terms of motion of the galaxy cluster containing Milky Way relative to the reference frame of the CMB. The cluster appears to be moving with velocity 627 ± 22 km/s in the direction of galactic longitude $(l = 264.4, b = 48.4)$ degrees [40].

2. Hemispherical power asymmetry [44] means that the amplitude of the fluctuations is not same at the opposite sides of the galactic plane (rather near to ecliptic plane): the difference in the amplitude is about 10 per cent. This does not mean that the mean value of temperature would differ at the opposite sides. The anomaly can be parameterized by a deviation of the amplitude from constant by an additive dipole term of amplitude .114 and in the direction (l,b)= (225,-27) degrees in galactic coordinates. Freeman suggest that the asymmetry can be eliminated for $l \leq 8$ by a slight modification of the CMB dipole [43]. In the average sense this might hold true since dipole term has odd parity. The temperature fluctuations are also stronger in southern than northern galactic hemisphere and there is a peculiar cold spot at southern hemisphere. Dipole term cannot eliminate this kind of anomalies. One might hope that the elimination of the galactic foreground - when done properly - might eliminate this asymmetry. The subtraction of the contribution from the galactic plane affects in the first approximation only the even harmonics: this would affect the interference pattern between even and odd harmonics.

3. There is also an anomaly christened as axis of evil.

   i) One can assign to the l:th contribution a unique axis maximizing angular momentum dispersion and these directions turn out to be very near to each other for $l = 2$ and $l = 3$ contributions [47]. De Oliveiro Costa *et al* noticed that this anomaly could be understood if the Universe has a compact direction in this direction of size of order horizon radius. This explanation is ruled out by other tests, including the absence of matched circles. The modification of the contribution from galactic plane would affect the direction assignable to $l = 2$ harmonic but would not affect considerably $l = 3$ contribution. Hence this effect might be due a wrong subtraction.

   ii) The contribution from the harmonics with angular momentum l can be characterized in terms of l unit vectors: what one does is essentially expression of the contribution as a product of the direction cosines between radial unit vector and l unit vectors [45]. $l = 2$ harmonics defined two vectors of this kind and their cross product defines what is called an area vector. For $l = 3$ there are three vectors of this kind and one can define three area vectors. It turns out that the planes defined by $l = 2$ area vector and two $l = 3$ area vectors are very near to each other and nearly orthogonal to the plane of ecliptic (and thus also galactic plane). These vectors are in reasonable approximation in galactic plane and aligned with the direction of CMB dipole whereas the direction. The direction of the third $l = 3$ area vector deviates about 10 degrees from the normal of the galactic plane.

   Again the smallness of $l = 2$ contribution raises the question whether the dipole correction and galactic foreground subtraction are done properly. Freeman and collaborators [43] have proposed that a proper subtraction of CMB dipole might allow to get rid of this anomaly. According to [46] this is probably not possible. In the case of $l = 3$ harmonics galactic subtraction affecting only even harmonics should not have any appreciable effect. The presence of cold spot near Galactic center and hot spot near Gum Nebula, both in the galactic plane, could also relate to the fact that the area vector is aligned with galactic plane.

Consider next two-point correlation functions.

1. The function $C(\theta)$ is obtained by averaging the fluctuations for all pairs of points at the sphere of last scattering separated by angle θ. $C(\theta)$ with galactic cutoff vanishes for $\theta > 60$ degrees the

correlation function vanishes in good approximation [46]. There is also a strange finding[50] suggesting a strong correlation between the fluctuation spectrum and 2-point correlation function. Large scale cutoff of $C(\theta)$ in the full-sky maps without galactic cutoff is absent while cut-sky maps with the galactic contribution masked are anomalous. The galactic cut is also almost equivalent with the masking of the cold and hot spot assignable to the galactic plane. Accepting the hot and cold spots in the galactic plane as real would give large scale correlations of 2-point correlation functions and vice versa. Also the subtraction of the anomalous quadrupole and octopole contributions from the 1-point correlation function brings back the large scale power. It is also essential that the multipole vectors of these contributions are nearly parallel. Hence it seems that one can choose between two evils: either the power cutoff at large scales or the axis of evil.

2. For low l harmonics statistical isotropy assumption fails [46]. This means that the correlation functions $\langle a_{lm}a_{l_1,-m_1}\rangle$ in the expansion of ΔT in terms of spherical harmonics $Y_{l,m}$ taken over temporal ensemble are not of form $C_l\delta_{l,l_1}\delta_{m,m_1}$, where C_l would define coefficients of $C(\theta)$ in terms of $P_l(\theta)$. Quadrupole terms ($l=2$) are also anomalously small.

There are also other anomalous correlations.

1. Unexpectedly high correlation between temperature and E-mode polarization caused by Thomson scattering of CMB photons can be seen as an evidence for a large optical depth and very early star formation [49].

2. Gaussianity predicts that three-point correlation functions for density fluctuations vanish. Hence also three-point correlation functions at the sphere of the last scattering should vanish. There is some evidence that this is not the case [48]: the proposed deviation from Gaussianity is parameterized by writing the perturbation of the gravitational potential in the form $\Phi = \Phi_L + f_{NL}(\Phi_L^2 - \langle\Phi_L^2\rangle)$.

8.7.3 What TGD could say about the anomalies?

TGD cosmology involves several new elements. Super-conformal invariance generalizes in TGD framework and one can wonder whether the fluctuations at the sphere of the last scattering could be described in terms of conformal field theory. It turns out that symplectic QFT based on the analogs of fusion rules is more natural in TGD framework. There are p-adic and dark matter hierarchies realized in terms of book like structure of imbedding space with levels labeled by Planck constant with gravitational Planck constant assignable to flux tubes mediating gravitational interactions and having gigantic values so that quantum coherence in cosmological scales is possible. Zero energy ontology implies that time like entanglement in cosmic time scales assignable to gravitational interaction is possible so that the notion of state function reduction in astrophysical and cosmic time scales might make sense. Hence one can wonder whether the strange correlations between local galactic and solar geometry and density fluctuations at surface of large scattering might be real after all.

Implications of p-adic and dark matter hierarchies

Consider next the possible implications of p-adic and dark matter hierarchies.

1. In TGD framework there are two hierarchies: hierarchy of p-adic space-time sheets and hierarchy of Planck constants. p-Adic length scales are defined as $L_p \propto \sqrt{p}$, where $p \simeq 2^k$ is prime and k is positive integer. $L(151)$ corresponds in good approximation to 10 nm, cell membrane thickness. The hierarchy of Planck constants reflect the book like structure of the generalized imbedding space consisting of almost copies of $M^4 \times CP_2$ glued together like pages of book along common back. The proposed structure of imbedding space can be understood as a geometric correlate for the choice of quantization axes at the imbedding space level inducing it also at the level of configuration space (world of classical worlds). There are preferred quantization axes associated with both M^4 and CP_2 degrees of freedom. In the case of M^4 this means preferred plane M^2 defining a quantization axis of spin and in the case of CP_2 preferred homologically non-trivial geodesic sphere defining quantization axis of color isospin. This means breaking of symmetries at particular sector of the imbedding space but since the "world of classical worlds" is union

over different choices of quantization axes, symmetries remain intact as a whole. It would seem that quantum measurement with new quantization axis means a tunneling from between this kind of sectors.

2. It is important to notice that in TGD Universe the fluctuations emerge during the quantum criticality at the time of decoupling rather than developing from primordial fluctuations as in the case of inflationary cosmology. This kind of periods would be quite general since the smooth cosmic expansion is in TGD Universe replaced by a sequence of quantum leaps during which Planck constant for some relevant space-time sheet increases and implies the increase of the size L of the appropriate space-time sheet scaling like $\hbar$. The same mechanism explains also the accelerated cosmic expansion taking place much later during cosmic expansion and probably corresponding to expansion for large voids of size of order 10^8 ly.

3. In TGD Universe the vanishing of the curvature scalar of 3-space (flatness) corresponds to quantum criticality associated with phase transitions changing the value of Planck constant. Robertson-Walker form of the metric, criticality constraint, and imbeddability as a vacuum extremal to $M^4 \times S^2 \subset M^4 \times CP_2$ fix the critical cosmology highly uniquely. The critical cosmology has a finite temporal duration due to the failure of the global imbedding. During early phases the critical mass density behaves as $1/a^2$ which might be interpreted in terms of dominance of string like objects, which in TGD framework are identified as long magnetic flux tubes.

Can one say anything more quantitative about the situation? In particular, can one predict the scale (variance) of $\Delta T/T$?

1. There are two dimensionless numbers available: the value of the integer k characterizing p-adic length scale $L_p \propto 2^{k/2}$ characterizing the surface of the last scattering and the ratio $\hbar/\hbar_0$ of Planck constants associated with dark and visible sectors of the configuration space.

2. The value of the integer k characterizing p-adic length scale at the time of the transition can be estimated from the radius for the sphere of last scattering identified as radius $R = a(t)$. The transition to matter dominated Universe began in about 400, 000 years old universe. Coupling took about 120,000 years and was finished at the age of 500,000 years. From this one can estimate the p-adic length scale in question as light-cone proper time $a(t)/a_0 = (t/t_0)^{2/3}$ in matter dominated cosmology identifiable as curvature radius R in GRT based RW cosmology. My own estimate $a = 3 \times 10^7$ ly in [D5] gives $k \sim 355$.

3. Identifying $\Delta\rho_i$ for a given particle as the energy density $\rho_{i,d}$ of dark variant of the particle implies adiabaticity if one has $\rho_{i,d}/\rho_i = constant$. This is achieved by assuming that the energy densities scale like ρ_{tot}, that is one has $\rho_{d,i} = (\hbar/\hbar_0)^{-n}\rho_i \propto (\hbar/\hbar_0)^{-n}\ a^{-n}$. $n = 2$ is suggested by the early critical cosmology discussed [D5]. This would give $\Delta\rho_i/\rho_i = (\hbar_0/\hbar)^2$. From $\Delta T/T \simeq 10^{-5}$ one would have $r = \hbar/\hbar_0 \sim 300$. The estimate for r is not too far from $k \sim 355$, which might mean that $r = k$ holds true implying that the r would increase logarithmically with the p-adic length scale of the space-time sheet.

Consider next the anomalies from phenomenological point of view.

1. One cannot exclude the possibility that the vanishing of the two-point correlation functions for $\theta > 60$ degrees reflects the finite size of the space-time sheets. In conformal field theory approach this would mean that conformal field theory applies only inside patches at the sphere of last scattering. Suppose that the size of space-time sheets is typically of order p-adic length scale $L_p \propto \sqrt{p}$, where $p \simeq 2^k$ is prime and k is positive integer. For the surface of last scattering $L_p \equiv L(k)$ could be identified as the radius of the sphere and can be estimated from the value of light-cone proper time a at that time.

   The first guess is that only the points of the sphere for which distance is shorter than $L(k)$ can correlate. Simple elementary geometry shows that this is the case only for $\theta < 60$ degrees! The reduction of the vanishing correlation to almost kinematics must of course be taken with a big grain of salt: if the diameter of the sphere is taken to be L_p, one would have $\theta < 180$ degrees.

The killer prediction is that the non-averaged correlation function for two fixed points of sphere obtained by averaging the fluctuations over ensemble of observations should vanish for smaller values of angular distances when points belong to different patches so that the boundaries of patches should be identifiable from CMB map.

2. As already noticed, the presence of galactic cold and hot spots and axis of evil seem to be the price to be paid for the presence of large scale power [50]. The finite size of the space-time sheets forcing the vanishing of 2-point correlation function for large angular separations could thus conform with the non-CMB explanation of galactic cold and hot spots and allow to get rid of axis of evil. The pair of cold and hot spots indeed gives a large negative contribution to $C(\theta)$. The finite size of space-time sheets could also explain the hemispherical asymmetry and why fluctuations are stronger at the southern galactic hemisphere.

3. The particles at different pages of the "Big Book" can tunnel between the pages so that the presence of dark space-time sheets could affect the spectrum of temperature fluctuations. If dark matter is responsible for the fluctuations, the tunneling of dark photons to visible space-time sheets and vice versa might have something to do with the fluctuations of CMB spectrum. Fractality suggests that dark space-time sheets could induce a modulation of the amplitudes of CMB proposed to explain the hemispherical asymmetries but not why the hemispheres correspond to Nothern and Southern galactic spheres. There would be kind of modulation hierarchy. This might relate to the fluctuations in the amplitude of ΔT, and the related small 10 percent deviation of the fluctuation amplitudes at Northern and Souther hemisphere.

A couple of warnings are in order.

1. The proposed mechanism does not explain the strange correlations of CMB with the local geometry. If one accepts quantum coherence in cosmic length scales predicted by the dark matter hierarchy, the choice of quantization axis in cosmic scale having direct geometric correlate in TGD Universe, could explain the asymmetries as a result of state function reduction in cosmic scale.

2. The decomposition into disjoint space-time sheets is not the only manner to explain the anomalies. It will be found that the approach based on symplectic QFT predicts with very general assumptions about 2-point functions hemispherical asymmetry. Symplectic approach might be also able explain the vanishing of $C(\theta)$ in large scales.

Perturbations of the critical cosmology: the naive approach

Although the naive formal application of perturbation theory around critical cosmology does not make sense in quantum TGD framework, one can start by looking what it would give at classical level.

1. Concerning the perturbations of the critical cosmology, a natural condition would be that only vacuum extremals of Kähler action are allowed. This means that only perturbations giving rise to 4-surfaces belonging to $M^4 \times Y^2 \subset M^4 \times CP_2$, Y^2 Lagrangian sub-manifold of CP_2, are allowed. If all small deformations of the critical cosmology are allowed, curvature scalar cannot vanish in general. In this framework the notion of adiabaticity involving statements about various particles does not have any obvious meaning whereas the notion of iso-curvature fluctuations can be formulated. The vanishing of the curvature scalar makes sense for the perturbations of RW metric representing vacuum extremals but would break the symplectic symmetry in CP_2 degrees of freedom. Note also that many-sheeted space-time and the generalization of imbedding space induced by hierarchy of Planck constants are quite essential piece of TGD vision and are not taken into account in this naive approach.

2. One can express the perturbations of the metric in terms of gradients of CP_2 coordinates and since for the unperturbed RW metric CP_2 coordinates depend on light-cone proper time only, the perturbations are gradients of CP_2 coordinates with respect to spatial coordinates so that a reduction to scalar perturbations modifying only g_{aa} and vector perturbations implying non-vanishing g_{ai} indeed takes place in the first order. Since g_{ij} remains invariant in the first order, also 3-space remains flat in this order. In second order also other modes become possible.

3. The absence of other than scalar modes in the first order means that classical gravitons are absent in this order. Does this mean that also quantal gravitons are not present in the first order so that the B mode polarization would be smaller than expected? Probably not: the basic reason for developing the vision about physics as the geometry of the world of classical worlds was the total failure of the perturbative path integral approach theory in TGD framework. Previous considerations also force to ask whether the phase transitions of dark gravitons to ordinary gravitons could be an an essential element of detection of gravitons and mean that dark graviton with very large energy as compared to the wavelength transforms to a bunch of ordinary gravitons. This might lead to the erratic elimination of the graviton signal as a noise. One can also consider the possibility that dark gravitons with very long wave lengths transform to ordinary gravitons with much shorter wavelengths.

Could super-conformal field theory at sphere of last scattering describe the fluctuations?

I have already earlier [D5] proposed that CMB spectrum might be understood in terms of conformal field theory. If some variant of conformal field theory works, the general prediction is the breaking of conformal invariance meaning the appearance of the counterpart of the spectral index from the breaking of conformal symmetry by the generation of central extension to super-conformal algebra. In this framework $1 - n_s$ corresponds to an anomalous dimension having a discrete spectrum in conformal theories and known once the representation of Super Virasoro algebra is known. It would not be surprising if n_s would depend on the value of $\hbar$, which defines a quantum phase q playing also a key role in conformal field theories. Second important prediction would be that 3-point correlation functions are predictable and non-vanishing unless the conformal field theory in question is not free. This would allow the possibility of non-Gaussian behavior.

It however seems that CQFT need not be quite correct idea. Rather, a symplectic variant of conformal field theory is natural in TGD framework and could be used to characterize the ground state in terms of n-points functions. The basic objection against the use of conformal field theory is that it should apply to the construction of physical states pairs of positive and negative energy states and considering thus non-vacuum fluctuations of space-time surfaces around vacuum extremals. Now one is considering vacuum states with respect to Noether charges expressed as functionals in the space of vacuum extremals. Since symplectic transformations are symmetries of the vacuum extremals, a symplectic analogy of conformal field theory might be a more appropriate approach. In the following this argument is made more precise.

1. One must consider small perturbations of the critical cosmology which are also vacuum extremals. This means that the perturbations correspond to surface $X^4 \subset M^4 \times Y^2$, where Y^2 corresponds to Lagrangian sub-manifold of CP_2 having vanishing induced Kähler form. If one poses no other conditions the vacuum extremals possess symplectic transformations of CP_2 leaving given Y^2 invariant as symmetries. These transformations relate closely to so called super-symplectic symmetries which are basic super-conformal symmetries of quantum TGD besides Kac-Moody type symmetries assignable to light-like 3-surfaces identified as basic dynamical objects. Also symplectic (or rather contact-) transformations of $r_M = constant$ sphere of light-cone boundary act as this kind of symmetries which raises the question whether the analog of conformal field theory based having the symplectic group of light-cone boundary as symmetries might be a proper manner to characterize the vacuum degeneracy in quantum TGD.

2. Could conformal field theory possessing these symmetries defined at the sphere of last scattering (S^2) or - as suggested by basic structure of quantum TGD - at the boundary of 3-D light-cone connecting S^2 to the observer's position - describe the quantum criticality? The hope raised by the fact that critical cosmology is fixed the by the criticality condition without any reference to matter is that the correlation functions could be deduced from universality without any reference to elementary particle physics .

   i) The naive guess would be that the deviations of CP_2 complex coordinates ξ^k from their values at S^2 should be taken as primary dynamical variables. Unfortunately, the assumption that ξ^k are holomorphic functions of the complex coordinate of the sphere of last scattering would not be consistent with the vacuum extremal property. The use of CP_2 coordinates as dynamical variables is not consistent with general coordinate invariance unless one chooses some special coordinates. This is possible since selection of preferred quantization axis selects preferred complex coordinates unique modulo $U(2) \subset SU(3)$ rotations represented linearly. The simplest manner to achieve general coordinate invariance is by using the gravitational potential defined as the perturbation $\Delta g_{aa} = \Delta(s_{k\bar{l}}\partial_a\xi^k\partial_a\overline{\xi}^l)$. All perturbations of R-W metric can be arranged to the representation of rotation group corresponding to two scalars, vector, and traceless tensor. Unfortunately, the deviations of metric do not however define conformal fields in S^2. They could however define symplectic fields. It seems that conformal field theory approach requires the expression of Δg_{aa} in terms of primary conformal fields, say various currents, and this looks too complicated.

iii) The radial light-like coordinate r_M for the light-cone boundary plays a role analogous to that of complex coordinate for Kac-Moody representations at like 3-surfaces and for super-symplectic representations at light-cone boundary. In this case all vacuum extremals are allowed and the symplectic transformations of $S^2 \times CP_2$ localized with respect to r_M would act as analogos of conformal symmetries. In quantum TGD proper this could quite well make sense but in the recent situation only a QFT at S^2 is needed and light-like conformal invariance does not seem to say anything about the behavior of the correlation functions of temperature fluctuations at S^2.

Could a symplectic analog of conformal field theory work?

Symplectic symmetries of $\delta M^4_+ \times CP_2$ (light-cone boundary briefly) inspire the question whether a symplectic analog of conformal field theory at S^2 could dictate the correlation functions. Therefore it makes sense to play with the idea what symplectic QFT could look like and what one could conclude about the predictions of 'symplectic QFT' in the recent situation.

1. In quantum TGD the symplectic transformation of the light-cone boundary would induce action in the "world of classical worlds" (light-like 3-surfaces). In the recent situation it is convenient to regard perturbations of CP_2 coordinates as fields at the sphere of last scattering (call it S^2) so that symplectic transformations of CP_2 would act in the field space whereas those of S^2 would act in the coordinate space just like conformal transformations. The deformation of the metric would be a symplectic field in S^2. The symplectic dimension would be induced by the tensor properties of R-W metric in R-W coordinates: every S^2 coordinate index would correspond to one unit of symplectic dimension. The symplectic invariance in CP_2 degrees of freedom is guaranteed if the integration measure over the vacuum deformations is symplectic invariant. This symmetry does not play any role in the sequel.

2. For a symplectic scalar field $n \geq 3$-point functions with a vanishing anomalous dimension would be functions of the symplectic invariants defined by the areas of geodesic polygons defined by subsets of the arguments as points of S^2. Since n-polygon can be constructed from 3-polygons these invariants can be expressed as sums of the areas of 3-polygons expressible in terms of symplectic form. n-point functions would be constant if arguments are along geodesic circle since the areas of all sub-polygons would vanish in this case. The decomposition of n-polygon to 3-polygons brings in mind the decomposition of the n-point function of conformal field theory to products of 2-point functions by using the fusion algebra of conformal fields (very symbolically $\Phi_k\Phi_l = c^m_{kl}\Phi_m$). This intuition seems to be correct.

3. Fusion rules stating the associativity of the products of fields at different points should generalize. In the recent case it is natural to assume a non-local form of fusion rules given in the case of symplectic scalars by the equation

$$\Phi_k(s_1)\Phi_l(s_2) = \int c^m_{kl} f(A(s_1,s_2,s_3))\Phi_m(s)d\mu_s \quad . \tag{8.7.1}$$

   Here the coefficients c^m_{kl} are constants and $A(s_1,s_2,s_3)$ is the area of the geodesic triangle of S^2 defined by the sympletic measure and integration is over S^2 with symplectically invariant measure $d\mu_s$ defined by symplectic form of S^2. Fusion rules pose powerful conditions on n-point functions and one can hope that the coefficients are fixed completely.

4. The application of fusion rules gives at the last step an expectation value of 1-point function of the product of the fields involves unit operator term $\int c_{kl} f(A(s_1, s_2, s)) I d d\mu_s$ so that one has

$$\langle \Phi_k(s_1)\Phi_l(s_2)\rangle = \int c_{kl} f(A(s_1, s_2, s)) d\mu_s \quad . \tag{8.7.2}$$

Hence 2-point function is average of a 3-point function over the third argument. The absence of non-trivial symplectic invariants for 1-point function means that $n = 1$- an are constant, most naturally vanishing, unless some kind of spontaneous symmetry breaking occurs. Since the function $f(A(s_1, s_2, s_3))$ is arbitrary, 2-point correlation function can have both signs. 2-point correlation function is invariant under rotations and reflections.

CMB data suggest breaking of rotational and reflection symmetries. A possible mechanism of spontaneous symmetry breaking is based on the observation that in TGD framework the hierarchy of Planck constants assigns to each sector of the generalized imbedding space a preferred quantization axes. The selection of the quantization axis is coded also to the geometry of "world of classical worlds", and to the quantum fluctuations of the metric in particular. Clearly, symplectic QFT with spontaneous symmetry breaking would provide the sought-for really deep reason for the quantization of Planck constant in the proposed manner.

1. The coding of angular momentum quantization axis to the generalized imbedding space geometry allows to select South and North poles as preferred points of S^2. To the three arguments s_1, s_2, s_3 of the 3-point function one can assign two squares with the added point being either North or South pole. The difference

$$\Delta A(s_1, s_2, s_3) \equiv A(s_1, s_2, s_3, N) - A(s_1, s_2, s_3, S) \tag{8.7.3}$$

of the corresponding areas defines a simple symplectic invariant breaking the reflection symmetry with respect to the equatorial plane. Note that ΔA vanishes if arguments lie along a geodesic line or if any two arguments co-incide. Quite generally, symplectic QFT differs from conformal QFT in that correlation functions do not possess singularities.

2. The reduction to 2-point correlation function gives a consistency conditions on the 3-point functions

$$\langle (\Phi_k(s_1)\Phi_l(s_2))\Phi_m(s_3)\rangle = c^r_{kl} \int f(\Delta A(s_1, s_2, s))\langle \Phi_r(s)\Phi_m(s_3)\rangle d\mu_s$$
$$= \tag{8.7.4}$$
$$c^r_{kl} c_{rm} \int f(\Delta A(s_1, s_2, s)) f(\Delta A(s, s_3, t)) d\mu_s d\mu_t \quad . \tag{8.7.5}$$

Associativity requires that this expression equals to $\langle \Phi_k(s_1)(\Phi_l(s_2)\Phi_m(s_3))\rangle$ and this gives additional conditions. Associativity conditions apply to $f(\Delta A)$ and could fix it highly uniquely.

3. 2-point correlation function would be given by

$$\langle \Phi_k(s_1)\Phi_l(s_2)\rangle = c_{kl} \int f(\Delta A(s_1, s_2, s)) d\mu_s \tag{8.7.6}$$

4. There is a clear difference between $n > 3$ and $n = 3$ cases: for $n > 3$ also non-convex polygons are possible: this means that the interior angle associated with some vertices of the polygon is larger than π. $n = 4$ theory is certainly well-defined, but one can argue that so are also $n > 4$ theories and skeptic would argue that this leads to an inflation of theories. TGD however allows only finite number of preferred points and fusion rules could eliminate the hierarchy of theories.

5. To sum up, the general predictions are following. Quite generally, for $f(0) = 0$ n-point correlation functions vanish if any two arguments co-incide which conforms with the spectrum of temperature fluctuations. It also implies that symplectic QFT is free of the usual singularities. For symmetry breaking scenario 3-point functions and thus also 2-point functions vanish also if s_1 and s_2 are at equator. All these are testable predictions using ensemble of CMB spectra.

Since number theoretic braids are the basic objects of quantum TGD, one can hope that the n-point functions assignable to them could code the properties of ground states and that one could separate from n-point functions the parts which correspond to the symplectic degrees of freedom acting as symmetries of vacuum extremals and isometries of the 'world of classical worlds'.

1. This approach indeed seems to generalize also to quantum TGD proper and the n-point functions associated with partonic 2-surfaces can be decomposed in such a manner that one obtains coefficients which are symplectic invariants associated with both S^2 and CP_2 Kähler form.

2. Fusion rules imply that the gauge fluxes of respective Kähler forms over geodesic triangles associated with the S^2 and CP_2 projections of the arguments of 3-point function serve basic building blocks of the correlation functions. The North and South poles of S^2 and three poles of CP_2 can be used to construct symmetry breaking n-point functions as symplectic invariants. Non-trivial 1-point functions vanish also now.

3. The important implication is that n-point functions vanish when some of the arguments co-incide. This might play a crucial role in taming of the singularities: the basic general prediction of TGD is that standard singularities should be absent and this mechanism might realize this expectation.

Next some more technical but elementary first guesses about what might be involved.

1. It is natural to introduce the moduli space for n-tuples of points of the symplectic manifold as the space of symplectic equivalence classes of n-tuples. In the case of sphere S^2 convex n-polygon allows $n+1$ 3-sub-polygons and the areas of these provide symplectically invariant coordinates for the moduli space of symplectic equivalence classes of n-polygons (2^n-D space of polygons is reduced to $n+1$-D space). For non-convex polygons the number of 3-sub-polygons is reduced so that they seem to correspond to lower-dimensional sub-space. In the case of CP_2 n-polygon allows besides the areas of 3-polygons also 4-volumes of 5-polygons as fundamental symplectic invariants. The number of independent 5-polygons for n-polygon can be obtained by using induction: once the numbers $N(k,n)$ of independent $k \leq n$-simplices are known for n-simplex, the numbers of $k \leq n+1$-simplices for $n+1$-polygon are obtained by adding one vertex so that by little visual gymnastics the numbers $N(k,n+1)$ are given by $N(k,n+1) = N(k-1,n)+N(k,n)$. In the case of CP_2 the allowance of 3 analogs $\{N,S,T\}$ of North and South poles of S^2 means that besides the areas of polygons (s_1,s_2,s_3), (s_1,s_2,s_3,X), (s_1,s_2,s_3,X,Y), and (s_1,s_2,s_3,N,S,T) also the 4-volumes of 5-polygons (s_1,s_2,s_3,X,Y), and of 6-polygon (s_1,s_2,s_3,N,S,T), $X,Y \in \{N,S,T\}$ can appear as additional arguments in the definition of 3-point function.

2. What one really means with symplectic tensor is not clear since the naive first guess for the n-point function of tensor fields is not manifestly general coordinate invariant. For instance, in the model of CMB, the components of the metric deformation involving S^2 indices would be symplectic tensors. Tensorial n-point functions could be reduced to those for scalars obtained as inner products of tensors with Killing vector fields of $SO(3)$ at S^2. Again a preferred choice of quantization axis would be introduced and special points would correspond to the singularities of the Killing vector fields.

   The decomposition of Hamiltonians of the "world of classical worlds" expressible in terms of Hamiltonians of $S^2 \times CP_2$ to irreps of $SO(3)$ and $SU(3)$ could define the notion of symplectic tensor as the analog of spherical harmonic at the level of configuration space. Spin and gluon color would have natural interpretation as symplectic spin and color. The infinitesimal action of various Hamiltonians on n-point functions defined by Hamiltonians and their super counterparts is well-defined and group theoretical arguments allow to deduce general form of n-point functions in terms of symplectic invariants.

3. The need to unify p-adic and real physics by requiring them to be completions of rational physics, and the notion of finite measurement resolution suggest that discretization of also fusion algebra is necessary. The set of points appearing as arguments of n-point functions could be finite in a given resolution so that the p-adically troublesome integrals in the formulas for the fusion rules would be replaced with sums. Perhaps rational/algebraic variants of $S^2 \times CP_2 = SO(3)/SO(2) \times SU(3)/U(2)$ obtained by replacing these groups with their rational/algebraic variants are involved. Tedrahedra, octahedra, and dodecahedra suggest themselves as simplest candidates for these discretized spaces. Also the symplectic moduli space would be discretized to contain only n-tuples for which the symplectic invariants are numbers in the allowed algebraic extension of rationals. This would provide an abstract looking but actually very concrete operational approach to the discretization involving only areas of n-tuples as internal coordinates of symplectic equivalence classes of n-tuples. The best that one could achieve would be a formulation involving nothing below measurement resolution.

4. This picture based on elementary geometry might make sense also in the case of conformal symmetries. The angles associated with the vertices of the S^2 projection of n-polygon could define conformal invariants appearing in n-point functions and the algebraization of the corresponding phases would be an operational manner to introduce the space-time correlates for the roots of unity introduced at quantum level. In CP_2 degrees of freedom the projections of n-tuples to the homologically trivial geodesic sphere S^2 associated with the particular sector of CH would allow to define similar conformal invariants. This framework gives dimensionless areas (unit sphere is considered). p-Adic length scale hypothesis and hierarchy of Planck constants would bring in the fundamental units of length and time in terms of CP_2 length.

These findings raise the hope that quantum TGD is indeed a solvable theory. Even it one is not willing to swallow any bit of TGD, the classification of the symplectic QFTs remains a fascinating mathematical challenge in itself. A further challenge is the fusion of conformal QFT and symplectic QFT in the construction of n-point functions. One might hope that conformal and symplectic fusion rules can be treated separately.

What symplectic QFT tells about fluctuations?

It is interesting to look what one can say about the CMB assuming symplectic QFT using the proposed poor man's formulation.

The general predictions are that all n-point functions are non-vanishing so that Gaussianity fails to be true. In the symmetric scenario there is no breaking of rotational and reflection symmetries. In symmetric breaking scenario both breakings are present.

Consider first 2-point correlation functions.

1. The averaged 2-point correlation function $C(\theta)$ is obtained as

$$\begin{aligned} C(\theta) &= \langle \Phi(s_1)\Phi(s_2)\rangle = \sum_n f_n \langle \int [\Delta A(s_1,s_2,s)]^n d\mu_s\rangle \ , \\ \Delta A(s_1,s_2,s) &= A(s_1,s_2,s,N) - A(s_1,s_2,s,P) \ . \end{aligned} \tag{8.7.7}$$

2. If $f(\Delta A)$ is odd function of $\Delta A = A(s_1,s_2,s_3,N) - A(s_1,s_2,s_3,P)$, the first order term of the 3-point function changes sign under reflection of the first two arguments with respect to the equatorial plane and same holds true for all odd powers of ΔA as a simple argument shows. Same holds true for the 2-point correlation function so that its average over all points with same angular distance vanishes giving $C(\theta) = 0$. $C(\theta)$ is completely determined by the even part of f and one can write the averaged correlation function as

$$C(\theta) = \sum_n f_{2n} \langle \int [\Delta A(s_1,s_2,s)]^{2n} d\mu_s\rangle \ . \tag{8.7.8}$$

Thus the rotational averages of the numerically calculable even 'moments' $\int [\Delta A(s_1, s_2, s)]^{2n} d\mu_s$ determine $C(\theta)$.

3. Since $C(\theta)$ has also negative values, some of the coefficients f_{2n} must be negative. The variation of the signs of the coefficients is also necessary to explain the presence of positive maxima and negative minima in $C(\theta)$.

4. An open question is whether the smallness of $C(\theta)$ for angle separation larger than 60 degrees could be understood from symplectic invariance alone.

3-point correlation functions are certainly non-trivial and this means means a non-Gaussian behavior. Non-vanishing 2-point functions are averages of the 3-point functions involving identity operator with respect to third argument multiplied by 4π. Hence the non-Gaussian behavior is significant effect. For 3-point functions not involving identity operator the coefficients c_{klm} could be smaller.

Consider next the fluctuations.

1. It would be nice if temperature fluctuations could be interpreted as 1-point functions rather than particular fluctuations. This is not the case since the only reasonable candidate would be obtained in terms of the area of the degenerate geodesic triangle spanned by s and poles. This means that one must interpret the data as fluctuations rather than averages of fluctuations unless one is ready to break the symmetry by shifting slightly the second preferred point, say South Pole.

2. The intuitive notions about distribution for the fluctuations and amplitude of fluctuations are not readily expressible in terms of n-point correlation functions since the moments $\langle \Phi(s)^k \rangle$ vanish identically. One can however perform smoothing out of these quantities and replace the quantity $\langle \Phi(s)^k \rangle$ with $\int \langle \prod_i \Phi(s_i) \rangle \prod_k d\mu_{s_k}/A^n$, where the integrations are over a small disk of area A around point s. This gives a well defined variance and one can speak about fluctuation amplitude in a given resolution defined by A. The moments define in a given resolution what the probability distribution for the fluctuations means.

3. This definition allows to formulate what the evidence for the hemispherical asymmetry for the probability distribution of fluctuations could mean. Hemispherical asymmetry is obtained in the smooth out sense if the two-point correlation functions with arguments differing by a reflection with respect to equatorial plane are not identical: that is if $f(\Delta A)$ contains both even and odd coefficients f_n. The reason is that the sign of ΔA changes in the reflection. This could be tested by considering the counterpart of $C(\theta)$ defined by taking only average with respect to point pairs in upper/lower hemisphere and comparing the results.

To sum ump, the breaking of the rotational symmetry and parity breaking via a selection of a preferred equatorial plane conform with the general properties of the physical correlation functions and it remains to be seen whether fusion rules force f to have both odd and even parts necessary in obtain to obtain the breaking of reflection symmetry. The challenge is to understand whether the correlation between cosmic and local geometries (equatorial plane of S^2 and galactic plane) is a pure accident or whether there is something much deeper involved.

Could cosmic quantum coherence explain the correlation of the quantum fluctuations at surface of last scattering with galactic geometry?

The idea about hierarchy of Planck constants was inspired by the finding that the orbits of inner and outer planets could be regarded in a reasonable approximation as Bohr orbits but with Planck constant which was gigantic and was for outer planets smaller than for inner planets by a factor of 1/5 [D6]. The gigantic value of the Planck constant at the flux tubes mediating gravitational interactions implies quantum coherence in cosmic scales and this could allow a radically new interpretation of CMB anomalies. In particular, it could explain why the preferred equatorial plane of the sphere of last scattering predicted by symplectic QFT with spontaneous symmetry breaking is near to the galactic plane.

1. Gravitational Planck constant associated with the flux tubes mediating gravitational interactions has a gigantic value, which quantum coherence in cosmological scales. This forces to ask whether the measurement of CMB background should be considered as a quantum measurement in cosmic scales and whether its outcome could be analogous to the state function reduction at the level of particle physics as far as dark space-time sheets are considered. If dark matter dictates the behavior of visible matter one must consider the possibility that quantum measurement in dark scales could dramatically affect the geometric past in cosmic scales. On the other hand, the CMB measurements as such are only about distribution of ordinary photons and can only tell which quantum fluctuation pattern has been selected in quantum measurement in dark matter scales.

2. The situation at quantum criticality would correspond to a superposition of quantum fluctuations having in accordance with zero energy ontology time-like entanglement with the "observer". This entanglement correlates the states of observer with the quantum fluctuations. Observer could be a dark matter system assignable to galaxy, say the field body of galactic system with gigantic Plank constant connecting observer with the sphere of last scattering which in turn might be entangled with the solar system. The question is whether the time-like entanglement correlates some geometric properties of the observing system (say various directions like normal of the ecliptic or galactic plane) with the geometric properties of the quantum fluctuation spectrum (say the direction of the quantization axis defining equatorial asymmetry)?

3. Could one imagine that "we" as observers are entangled with the possible states of the galactic gravito-magnetic body in turn entangled gravitationally with the quantum fluctuations at the sphere of last scattering and that the measurement of the state of galactic system telling the direction of galactic plane, etc... selects also the dark quantum fluctuation in the geometric past. If so, the selection of quantization axes for fluctuations would be same for the observer and sphere of last scattering. If the choice is dictated by the observer, the breaking of rotational symmetry and parity symmetry and choice of galactic plane as preferred plane would be induced by quantum measurement. Note that this does not lead to any obvious contradictions since the spheres of last scattering are in principle different for observers at different positions of the Universe. If this interpretation is correct, the strange anomalies of CMB would provide a rather dramatic verification for the Wheeler's idea about participatory Universe.

8.8 Quantum fluctuations in geometry as a new kind of noise?

The motivation for writing this section came from the email of Jack Sarfatti. I learned that gravitational detectors in GEO600 experiment have been plagued by unidentified noise in the frequency range 300-1500 Hz [51]. Craig J. Hogan has proposed an explanation in terms of holographic Universe [52] By reading the paper I learned that assumptions needed are essentially those of quantum TGD. Light-like 3-surfaces as basic objects, holography, effective 2-dimensionality, are some of the terms appearing repeatedly in the article.

8.8.1 The experiment

Consider first the graviton detector used in GEO600 experiment. The detector consists of two long arms (the length is 600 meters)- essentially rulers of equal length. The incoming gravitational wave causes a periodic stretch of the arms: the lengths of the rulers vary. The detection of gravitons means that laser beam is used to keep record about the varying length difference. This is achieved by splitting the laser beam into two pieces using a beam splitter. After this the beams travel through the arms and bounce back to interfere in the detector. Interference pattern tells whether the beam spent slightly different times in the arms due to the stretching of arm caused by the incoming gravitational radiation. The problem of experimenters has been the presence of an unidentified noise in the range 100-1500 Hz.

The prediction of the article *Measurement of quantum fluctuations in geometry* by Craig Hogan [52] is that holographic geometry of space-time should induce fluctuations of classical geometry with a spectrum which is completely fixed . Hogan's prediction is very general and - if I have understood correctly - the fluctuations depend only on the duration (or length) of the laser beam using Planck length as a unit. Note that there is no dependence on the length of the arms and the fluctuations characterize only the laser beam. Although Planck length appears in the formula, the fluctuations need not have anything to with gravitons but could be due to the failure of the classical description of laser beams. The great surprise was that the prediction of Hogan for the noise is of same order of magnitude as the unidentified noise bothering experiments in the range 100-700 Hz.

8.8.2 Hogan's theory

Let us try to understand Hogan's theory in more detail.

1. The basic quantitative prediction of the theory is very simple. The spectral density of the noise for high frequencies is given by $h_H = t_P^{1/2}$, where $t_P = (\hbar G)^{1/2}$ is Planck time. For low frequencies h_H is proportional to 1/f just like 1/f noise. The power density of the noise is given by t_P and a connection with poorly understood 1/f noise appearing in electronic and other systems is suggestive. The prediction depends only Planck scale so that it should very easy to kill the model if one is able to reduce the noise from other sources below the critical level $t_P^{1/2}$. The model predicts also the the distribution characterizing the uncertainty in the direction of arrival for photon in terms of the ratio l_P/L. Here L is the length or beam of equivalently its duration. A further prediction is that the minimal uncertainty in the arrival time of photons is given by $\Delta t = (t_P t)^{1/2}$ and increases with the duration of the beam.

2. Both quantum and classical mechanisms are discussed as an explanation of the noise. Gravitational holography is the key assumption behind both models. Gravitational holography states that space-time geometry has two space-time dimensions instead of three at the fundamental level and that third dimension emerges via holography. A further assumption is that light-like (null) 3-surfaces are the fundamental objects. Sounds familiar!

Heuristic argument

The model starts from an optics inspired heuristic argument.

1. Consider a light ray with length L, which ends to aperture of size D. This gives rise to a diffraction spot of size $\lambda L/D$. The resulting uncertainty of the transverse position of source is minimized when the size of diffraction spot is same as aperture size. This gives for the transverse uncertainty of the position of source $\Delta x = (\lambda L)^{1/2}$. The orientation of the ray can be determined with a precision $\Delta\theta = (\lambda/L)^{1/2}$. The shorter the wavelength the better the precision. Planck length is believed to pose a fundamental limit to the precision. The conjecture is that the transverse indeterminacy of Planck wave length quantum paths corresponds to the quantum indeterminacy of the metric itself. What this means is not quite clear to me.

2. The basic outcome of the model is that the uncertainty for the arrival times of the photons after reflection is proportional to

$$\Delta t = t_P^{1/2} \times (sin(\theta))^{1/2} \times sin(2\theta) \ ,$$

   where θ denotes the angle of incidence on beam splitter. In normal direction Δt vanishes. The proposed interpretation is in terms of Brownian motion for the distance between beam splitter and detector the interpretation being that each reflection from beam splitter adds uncertainty. This is essentially due to the replacement of light-like surface with a new one orthogonal to it inducing a measurement of distance between detector and bean splitter.

This argument has some aspects which I find questionable.

1. The assumption of Planck wave length waves is certainly questionable. The underlying is that it lead to the classical formula involving the aperture size which is eliminated from the basic formula by requiring optimal angular resolution. One might argue that a special status of waves with Planck wave length breaks Lorentz invariance but since the experimental apparatus defines a preferred coordinate system this ned not be a problem.

2. Unless one is ready to forget the argument leading to the formula for $\Delta\theta$, one can argue that the description of the holographic interaction between distant points induced by these Planck wave length waves in terms of aperture with size $D = (l_P L)^{1/2}$ should have some more abstract physical counterpart. Could elementary particles as extended 2-D objects (as in TGD) play the role of ideal apertures to which a radiation with Planck wave length arrives? If one gives up the assumption about Planck wave radiation the uncertainty increases as λ. To my opinion one should be able to deduced the basic formula without this kind of argument.

Argument based on uncertainty principle for waves with Planck wave length

Second argument can do without diffraction but still uses Planck wave length waves.

1. The interactions of Planck wave length radiation at null surface at two different times corresponding to normal coordinates z_1 and z_2 at these times are considered. From the standard uncertainty relation between momentum and position of the incoming particle one deduces uncertainty relation for transverse position operators $x(z_i)$, i=1,2. The uncertainty comes from uncertainty of $x(z_2)$ induced by uncertainty of the transverse momentum $p_x(z_i)$. The uncertainty relation is deduced by assuming that $(x(z_2) - x(z_1)/(z_2 - z_1)$ is the ratio of transversal and longitudinal wave vectors. This relates $x(z_2)$ to $p_x(z_i)$ and the uncertainty relation can be deduced. The uncertainty increases linearly with $z_2 - z_1$. Geometric optics is used to describing the propagating between the two points and this should certainly work for a situation in which wavelength is Planck wavelength if the notion of Planck wave length wave makes sense. From this formula the basic predictions follow.

2. Hogan emphasizes that the basic result is obtained also classically by assuming that light-like surfaces describing the propagation of light between ends points of arm describe Brownian like random walk in directions transverse to the direction of propagation. I understand that this means that Planck wave length wave is not absolutely necessary for this approach.

Description in terms of equivalent gravitonic wave packet

Hogan discusses also an effective description of holographic noise in terms of gravitational wave packet passing through the system.

1. The holographic noise at frequency f has equivalent description in terms of a gravitational wave packet of frequency f and duration $T = 1/f$ passing through the system. In this description the variance for the length difference of arms using standard formula for gravitational wave packet is given by

$$\frac{\Delta l^2}{l^2} = h^2 f \quad ,$$

where h characterizes the spectral density of gravitational wave.

2. For high frequencies one obtains

$$h = h_P = (t_P)^{1/2} \quad .$$

3. For low frequencies the model predicts

$$h = \frac{(f_{res}}{f}(t_P)^{1/2}.$$

Here f_{res} characterized the inverse residence time in detector and is estimated to be about 700 Hz in GEO600 experiment.

4. The predictions of the theory are compared to the unidentified noise in the frequency range 100-600 Hz which introduces amplifying factor varying from 7 to 1. The orders of magnitude are same.

8.8.3 TGD based model

In TGD based model for the claimed noise on can avoid the assumption about waves with Planck wave length. Rather Planck length corresponds to the transversal cross section of so called massless extremals (MEs) assignable to MEs and orthogonal to the direction of propagation. Further elements are so called number theoretic braids leading to the discretization of quantum TGD at fundamental level. The mechanism inducing the distribution for the travel times of reflected photon is due to the transverse extension of MEs, discretization in terms of number theoretic braids. Note that also in Hogan's model it is essential that one can speak about position of particle in the beam.

Some background

Consider first the general picture behind the TGD inspired model.

1. What authors emphasize can be condensed to the following statement: *The transverse indeterminacy of Planck wave length seems likely to be a feature of 3+1 D space-time emerge is as a dual of quantum theory on a 2+1-D null surface.* In TGD light-like 3-surfaces indeed are the fundamental objects and 4-D space-time surface is in a holographic relation to these light-like 3-surfaces. The analog of conformal invariance in light-like radial direction implies that partonic 2-surfaces are actually basic objects in short scales in the sense that one 3-dimensionality only in discretized sense.

2. Both the interpretation as almost topological quantum field theory, the notion of finite measurement resolution, number theoretical universality making possible p-adicization of quantum TGD, and the notion of quantum criticality lead to a fundamental description in terms of discrete points sets. These are defined as intersections of what I call number theoretic braids with partonic 2-surfaces X^2 at the boundaries of causal diamonds identified as intersections of future and paste directed light-cones forming a fractal hierarchy. These 2-surfaces X^2 correspond to the ends of light-like three surfaces. Only the data from this discrete point set is used in the definition of M-matrix: there is however continuum of selections of this data set corresponding to different directions of light-like ray at the boundary of light-cone, and in detection one of these direction is selected and corresponds to the direction of beam in the recent case.

3. Fermions correspond to CP_2 type vacuum extremal with Euclidian signature of induced metric condensed to space-time sheet with Minkowskian signature and light-like wormhole throat for which 4-metric is degenerate carries the quantum numbers. Bosons correspond to wormhole contacts consisting of a piece of CP_2 vacuum extremal connecting two two space-time sheets with Minkowskian signature of induced metric. The strands of number theoretic braids carry fermionic quantum numbers and discretization is interpreted as a space-time correlate for the finite measurement resolution implying the effective grainy nature of 2-surfaces.

The model

Consider now the TGD inspired model for a laser beam of fixed duration T.

1. In TGD framework the beams of photons and perhaps also photons themselves would have so called massless extremals as space-time correlates. The identification of gauge bosons as wormhole contacts means that there is a pair of MEs connected by a pieces of CP_2 type vacuum extremal and carrying fermion and antifermion at the wormhole throats defining light-like 3-surfaces. The intersection of ME with light-cone boundary would represent partonic 2-surface and any transverse cross section of the M^4 projection of ME is possible.

2. The reflection of ME has description in terms of generalized Feynman diagrams for which the incoming lines correspond to the light-like three surfaces and vertices to partonic 2-surfaces at which the MEs are glued together. In this simplest model this surface defines transverse cross section of both incoming and outgoing ME. The incoming and outgoing braid strands end to different points of the cross section because if two points coincide the N-point correlation function vanishes. This means that in the reflection the distribution for the positions of braid points representing exact positions of photon change in non-deterministic manner. This induces a

quantum distribution of transverse coordinates associated with braid strands and in the detection state function reduction occurs fixing the position of braid strands.

3. The transversal cross section has maximum area when it is parallel to ME. In this case the area is apart from a numerical constant equal to $d \times L$, L the length defined by the duration of laser beam defining the length of ME and d the diameter of orthogonal cross section of ME. This makes natural the assumption about Gaussian distribution for the positions of points in the cross section as Gaussian with variance equal to $d \times L$. The distribution proposed by Hogan is obtained if d is given by Planck length. This would mean that the minimum area for a cross section of ME is very small, about $S = \hbar \times G$. This might make sense if the ME represents laser beam.

4. The assumption susceptible to criticism is that for the primordial ME representing photon the area of cross section orthogonal to the direction of propagation is assumed to be always given by Planck length. This assumption of course replaces Hogan's Planck wave. Note that the classical four-momentum of ME is massless. One could however argue that in quantum situation transverse momentum square is well defined quantum number and of order Planck mass mass squared.

5. In TGD Universe single photon would differ from infinitely narrow ray by having thickness defined by Planck length. There would be just single braid strand and its position would change in the reflection. The most natural interpretation indeed is that the pair of space-time sheets associated with photon consists of MEs with different transversal size scales: larger ME could represent laser beam. The noise would come from the lowest level in the hierarchy. One could argue that the natural size for M^4 projection of wormhole throat is of order CP_2 size R and therefore roughly 10^4 Planck lengths. If the cross section has area of order R^2, where R is CP_2 size, the spectral density would be roughly by a factor 100 larger than for Planck length and this might predict too large holographic noise in GEO600 experiment if the value of f_{res} is correct. The assumption that the Gaussian characterizing the position distribution of the wormhole throat is very strongly concentrated near the center of ME with transverse size given by R looks un-natural.

6. It is important to notice that single reflection of primordial ME corresponds to a minimum spectral noise. Repeated reflections of ME in different directions gradually increase the transversal size of ME so that the outcome is cylindrical ME with radius of order $L = cT$, where T is the duration of ME. At this limit the spectral density of noise would be $T^{1/2}$ meaning that the uncertainty in the frequency assignable to the arrival time of photons would of same order as the oscillation period $f = 1/T$ assignable to the original ME. The interpretation is that the repeated reflections gradually generate noise and destroy the coherence of the laser beam. This would however happen at single particle level rather than for a member of fictive ensemble. Quite literally, photon would get old! This interpretation conforms with the fact that in TGD framework thermodynamics becomes part of quantum theory and thermodynamical ensemble is represented at single particle level in the sense and time like entanglement coefficients between positive and negative energy parts of zero energy state define M-matrix as a product of square root of diagonal density matrix and of S-matrix.

7. The notion of number theoretic braid is essential for the interpretation for what happens in detection. In detection the positions of ends of number theoretic braid are measured and this measurement fixes the exact time spent by photons during the travel. Similar position measurement appears also in Hogan's argument. Thus the overall picture is more or less same as in the popular representation where also the grainy nature of space-time is emphasized.

8. I already mentioned the possible connection with poorly understood 1/f noise appearing in very many systems. The natural interpretation would be in terms of MEs.

The relationship with hierarchy of Planck constants

It is interesting to combine this picture with the vision about the hierarchy of Planck constants (I am just now developing in detail the representation of the ideas involved from a perspective given by the intense work during last five years).

1. If one accepts that dark matter corresponds to a hierarchy of phases of matter labeled by a hierarchy of Planck constants with arbitrarily large values, one must conclude that Planck length l_P proportional to $\hbar^{1/2}$, has also spectrum. Primordial photons would have transversal size scalings as $\hbar^{1/2}$. One can consider the possibility that for large values of $\hbar$ the transversal size saturates to CP_2 length $R \simeq 10^4 \times l_P$. The spectral density of the noise would scale as $\hbar^{1/4}$ at least up to the critical value $\hbar_{cr} = R^2/G$, which is in the range $[2.3683, 2.5262] \times 10^7$. The preferred values of $\hbar$ number theoretically simple integers expressible as product of distinct Fermat primes and power of 2. $\hbar_{cr}/\hbar_0 = 3 \times 2^{23}$ is integer of this kind and belongs to the allowed range of critical values.

2. The order of magnitude for gravitational Planck constant assignable to the space-time sheets mediating gravitational interaction is gigantic - of order $\hbar_{gr} \simeq GM^2$ for ideal black holes - so that the noise assignable to gravitons would be gigantic in astrophysical scales unless R serves as the upper bound for the transverse size of both primordial gauge bosons and gravitons.

3. If ordinary photonic space-time sheets are in question $\hbar$ has its standard value. For dark photons which I have proposed to play a key role in living matter, the situation changes and $\Delta l^2/l^2$ would scale like $\hbar^{1/2}$ at least up to critical value of Planck constant. Above this value of Planck constant spectral density would be given by R and $\Delta l^2/l^2$ would scale like R/l and $\Delta\theta$ like $(R/l)^{1/2}$.

8.9 Appendix

In this appendix the generalization of the notion of imbedding space realizing mathematically the hierarchy of Planck constants is discussed. Also orbital radii of exo-planets as test of the theory are considered.

8.9.1 Generalization of the notion of imbedding space

In the following the recent view about structure of imbedding space forced by the quantization of Planck constant is described. This view has developed much before the original version of this chapter was written.

The original idea was that the proposed modification of the imbedding space could explain naturally phenomena like quantum Hall effect involving fractionization of quantum numbers like spin and charge. This does not however seem to be the case. $G_a \times G_b$ implies just the opposite if these quantum numbers are assigned with the symmetries of the imbedding space. For instance, quantization unit for orbital angular momentum becomes n_a where Z_{n_a} is the maximal cyclic subgroup of G_a.

One can however imagine of obtaining fractionization at the level of imbedding space for space-time sheets, which are analogous to multi-sheeted Riemann surfaces (say Riemann surfaces associated with $z^{1/n}$ since the rotation by 2π understood as a homotopy of M^4 lifted to the space-time sheet is a non-closed curve. Continuity requirement indeed allows fractionization of the orbital quantum numbers and color in this kind of situation.

Both covering spaces and factor spaces are possible

The observation above stimulates the question whether it might be possible in some sense to replace H or its factors by their multiple coverings.

1. This is certainly not possible for M^4, CP_2, or H since their fundamental groups are trivial. On the other hand, the fixing of quantization axes implies a selection of the sub-space $H_4 = M^2 \times S^2 \subset M^4 \times CP_2$, where S^2 is a geodesic sphere of CP_2. $\hat{M}^4 = M^4 \backslash M^2$ and $\hat{CP}_2 = CP_2 \backslash S^2$ have fundamental group Z since the codimension of the excluded sub-manifold is equal to two and homotopically the situation is like that for a punctured plane. The exclusion of these sub-manifolds defined by the choice of quantization axes could naturally give rise to the desired situation.

2. Zero energy ontology forces to modify this picture somewhat. In zero energy ontology causal diamonds (CDs) defined as the intersections of future and past directed light-cones are loci for zero energy states containing positive and negative energy parts of state at the two light-cone

boundaries. The location of CD in M^4 is arbitrary but p-adic length scale hypothesis suggests that the temporal distances between tips of CD come as powers of 2 using CP_2 size as unit. Thus M^4 is replaces by CD and $\hat{M}^4$ is replaced with $\hat{CD}$ defined in obvious manner.

3. H_4 represents a straight cosmic string inside CD. Quantum field theory phase corresponds to Jones inclusions with Jones index $\mathcal{M}:\mathcal{N}<4$. Stringy phase would by previous arguments correspond to $\mathcal{M}:\mathcal{N}=4$. Also these Jones inclusions are labeled by finite subgroups of $SO(3)$ and thus by Z_n identified as a maximal Abelian subgroup.

   One can argue that cosmic strings are not allowed in QFT phase. This would encourage the replacement $\hat{CD}\times \hat{CP_2}$ implying that surfaces in $CD\times S^2$ and $(M^2\cap CD)\times CP_2$ are not allowed. In particular, cosmic strings and CP_2 type extremals with M^4 projection in M^2 and thus light-like geodesic without zitterwebegung essential for massivation are forbidden. This brings in mind instability of Higgs=0 phase.

4. The covering spaces in question would correspond to the Cartesian products $\hat{CD}_{n_a}\times \hat{CP}_{2n_b}$ of the covering spaces of $\hat{CD}$ and $\hat{CP_2}$ by Z_{n_a} and Z_{n_b} with fundamental group is $Z_{n_a}\times Z_{n_b}$. One can also consider extension by replacing $M^2\cap CD$ and S^2 with its orbit under G_a (say tedrahedral, octahedral, or icosahedral group). The resulting space will be denoted by $\hat{CD}\hat{\times}G_a$ *resp.* $\hat{CP_2}\hat{\times}G_b$.

5. One expects the discrete subgroups of $SU(2)$ emerge naturally in this framework if one allows the action of these groups on the singular sub-manifolds $M^2\cap CD$ or S^2. This would replace the singular manifold with a set of its rotated copies in the case that the subgroups have genuinely 3-dimensional action (the subgroups which corresponds to exceptional groups in the ADE correspondence). For instance, in the case of $M^2\cap CD$ the quantization axes for angular momentum would be replaced by the set of quantization axes going through the vertices of tedrahedron, octahedron, or icosahedron. This would bring non-commutative homotopy groups into the picture in a natural manner.

6. Also the orbifolds $\hat{CD}/G_a\times \hat{CP_2}/G_b$ can be allowed as also the spaces $\hat{CD}/G_a\times(\hat{CP_2}\hat{\times}G_b)$ and $(\hat{CD}\hat{\times}G_a)\times\hat{CP_2}/G_b$. Hence the previous framework would generalize considerably by the allowance of both coset spaces and covering spaces.

There are several non-trivial questions related to the details of the gluing procedure and phase transition as motion of partonic 2-surface from one sector of the imbedding space to another one.

1. How the gluing of copies of imbedding space at $(M^2\cap CD)\times CP_2$ takes place? It would seem that the covariant metric of M^4 factor proportional to $\hbar^2$ must be discontinuous at the singular manifold since only in this manner the idea about different scaling factor of M^4 metric can make sense. This is consistent with the identical vanishing of Chern-Simons action in $M^2\times S^2$.

2. One might worry whether the phase transition changing Planck constant means an instantaneous change of the size of partonic 2-surface in CD degrees of freedom. This is not the case. Light-likeness in $(M^2\cap CD)\times S^2$ makes sense only for surfaces $X^1\times D^2\subset(M^2\cap CD)\times S^2$, where X^1 is light-like geodesic. The requirement that the partonic 2-surface X^2 moving from one sector of H to another one is light-like at $(M^2\cap CD)\times S^2$ irrespective of the value of Planck constant requires that X^2 has single point of $(M^2\cap CD)$ as M^2 projection. Hence no sudden change of the size X^2 occurs.

3. A natural question is whether the phase transition changing the value of Planck constant can occur purely classically or whether it is analogous to quantum tunneling. Classical non-vacuum extremals of Chern-Simons action have two-dimensional CP_2 projection to homologically non-trivial geodesic sphere S^2_I. The deformation of the entire S^2_I to homologically trivial geodesic sphere S^2_{II} is not possible so that only combinations of partonic 2-surfaces with vanishing total homology charge (Kähler magnetic charge) can in principle move from sector to another one, and this process involves fusion of these 2-surfaces such that CP_2 projection becomes single homologically trivial 2-surface. A piece of a non-trivial geodesic sphere S^2_I of CP_2 can be deformed to that of S^2_{II} using 2-dimensional homotopy flattening the piece of S^2 to curve. If this homotopy cannot be chosen to be light-like, the phase transitions changing Planck constant take

place only via quantum tunnelling. Obviously the notions of light-like homotopies (cobordisms) and classical light-like homotopies (cobordisms) are very relevant for the understanding of phase transitions changing Planck constant.

Do factor spaces and coverings correspond to the two kinds of Jones inclusions?

What could be the interpretation of these two kinds of spaces?

1. Jones inclusions appear in two varieties corresponding to $\mathcal{M}:\mathcal{N}<4$ and $\mathcal{M}:\mathcal{N}=4$ and one can assign a hierarchy of subgroups of $SU(2)$ with both of them. In particular, their maximal Abelian subgroups Z_n label these inclusions. The interpretation of Z_n as invariance group is natural for $\mathcal{M}:\mathcal{N}<4$ and it naturally corresponds to the coset spaces. For $\mathcal{M}:\mathcal{N}=4$ the interpretation of Z_n has remained open. Obviously the interpretation of Z_n as the homology group defining covering would be natural.

2. $\mathcal{M}:\mathcal{N}=4$ should correspond to the allowance of cosmic strings and other analogous objects. Does the introduction of the covering spaces bring in cosmic strings in some controlled manner? Formally the subgroup of $SU(2)$ defining the inclusion is $SU(2)$ would mean that states are $SU(2)$ singlets which is something non-physical. For covering spaces one would however obtain the degrees of freedom associated with the discrete fiber and the degrees of freedom in question would not disappear completely and would be characterized by the discrete subgroup of $SU(2)$.

   For anyons the non-trivial homotopy of plane brings in non-trivial connection with a flat curvature and the non-trivial dynamics of topological QFTs. Also now one might expect similar non-trivial contribution to appear in the spinor connection of $\hat{CD}\hat{\times}G_a$ and $\hat{CP}_2\hat{\times}G_b$. In conformal field theory models non-trivial monodromy would correspond to the presence of punctures in plane.

3. For factor spaces the unit for quantum numbers like orbital angular momentum is multiplied by n_a *resp.* n_b and for coverings it is divided by this number. These two kind of spaces are in a well defined sense obtained by multiplying and dividing the factors of $\hat{H}$ by G_a *resp.* G_b and multiplication and division are expected to relate to Jones inclusions with $\mathcal{M}:\mathcal{N}<4$ and $\mathcal{M}:\mathcal{N}=4$, which both are labeled by a subset of discrete subgroups of SU(2).

4. The discrete subgroups of $SU(2)$ with fixed quantization axes possess a well defined multiplication with product defined as the group generated by forming all possible products of group elements as elements of $SU(2)$. This product is commutative and all elements are idempotent and thus analogous to projectors. Trivial group G_1, two-element group G_2 consisting of reflection and identity, the cyclic groups Z_p, p prime, and tedrahedral, octahedral, and icosahedral groups are the generators of this algebra.

By commutativity one can regard this algebra as an 11-dimensional module having natural numbers as coefficients ("rig"). The trivial group G_1, two-element group G_2¡ generated by reflection, and tedrahedral, octahedral, and icosahedral groups define 5 generating elements for this algebra. The products of groups other than trivial group define 10 units for this algebra so that there are 11 units altogether. The groups Z_p generate a structure analogous to natural numbers acting as analog of coefficients of this structure. Clearly, one has effectively 11-dimensional commutative algebra in 1-1 correspondence with the 11-dimensional "half-lattice" N^{11} (N denotes natural numbers). Leaving away reflections, one obtains N^7. The projector representation suggests a connection with Jones inclusions. An interesting question concerns the possible Jones inclusions assignable to the subgroups containing infinitely manner elements. Reader has of course already asked whether dimensions 11, 7 and their difference 4 might relate somehow to the mathematical structures of M-theory with 7 compactified dimensions. One could introduce generalized configuration space spinor fields in the configuration space labeled by sectors of H with given quantization axes. By introducing Fourier transform in N^{11} one would formally obtain an infinite-component field in 11-D space.

The question how do the Planck constants associated with factors and coverings relate is far from trivial and I have considered several options.

1. If one assumes that $\hbar^2(X)$, $X=M^4$, CP_2 corresponds to the scaling of the covariant metric tensor g_{ij} and performs an over-all scaling of metric allowed by Weyl invariance of Kähler action

by dividing metric with $\hbar^2(CP_2)$, one obtains $r^2 \equiv \hbar^2/\hbar_0^2\hbar^2(M^4)/\hbar^2(CP_2)$. This puts M^4 and CP_2 in a very symmetric role and allows much more flexibility in the identification of symmetries associated with large Planck constant phases.

2. Algebraist would argue that Planck constant must define a homomorphism respecting multiplication and division (when possible) by G_i. This requires $r(X) = \hbar(X)\hbar_0 = n$ for covering and $r(X) = 1/n$ for factor space or vice versa. This gives two options.

3. Option I: $r(X) = n$ for covering and $r(X) = 1/n$ for factor space gives $r \equiv \hbar/\hbar_0 = r(M^4)/r(CP_2)$. This gives $r = n_a/n_b$ for $\hat{H}/G_a \times G_b$ option and $r = n_b/n_a$ for $\hat{Htimes}(G_a \times G_b)$ option with obvious formulas for hybrid cases.

4. Option II: $r(X) = 1/n$ for covering and $r(X) = n$ for factor space gives $r = r(CP_2)/r(M^4)$. This gives $r = n_b/n_a$ for $\hat{H}/G_a \times G_b$ option and $r = n_a/n_b$ for $\hat{Htimes}(G_a \times G_b)$ option with obvious formulas for the hybrid cases.

5. At quantum level the fractionization would come from the modification of fermionic anti-commutation (bosonic commutation) relations involving $\hbar$ at the right hand side so that particle number becomes a multiple of $1/n$ or n. If one postulates that the total number states is invariant in the transition, the increase in the number of sheets is compensated by the increase of the fundamental phase space volume proportional to $\hbar$. This would give $r(X) \to r(X)/n$ for factor space and $r(X) \to nr(X)$ for the covering space to compensate the n-fold reduction/increase of states. This would favor Option II.

6. The second manner to distinguish between these two options is to apply the theory to concrete physical situations. Since G_a and G_b act as symmetries in CD and CP_2 degrees of freedom, one might of being able to distinguish between the two options if it is possible to distinguish between the action of G as symmetry of quantum states associated with covering and factor space. Also the quantization of the orbital spin quantum number at single particle level as multiples of n can be distinguished from that in multiples of $1/n$.

Phase transitions changing the value of Planck constant

There are two basic kinds of phase transitions changing the value of Planck constant inducing a leakage between sectors of imbedding space. There are three cases to consider corresponding to

1. leakage in M^4 degrees of freedom changing G_a: the critical manifold is $R_+ \times CP_2$;

2. leakage in CP_2 degrees of freedom changing G_b: the critical manifold is $\delta M^4_+ \times S^2_{II}$;

3. leakage in both degrees of freedom changing both G_a and G_b: the critical manifold is $R_+ \times S^2_{II}$. This is the non-generic case

For transitions of type 2) and 3) X^2 must go through vacuum extremal in the classical picture about transition.

Covering space can also change to a factor space in both degrees of freedom or vice versa and in this case G can remain unchanged as a group although its interpretation changes.

The phase transitions satisfy also strong group theoretical constraints. For the transition $G_1 \to G_2$ either $G_1 \subset G_2$ or $G_2 \subset G_1$ must hold true. For maximal cyclic subgroups Z_n associated with quantization axes this means that n_1 must divide n_2 or vice versa. Hence a nice number theoretic view about transitions emerges.

One can classify the points of critical manifold according to the degree of criticality. Obviously the maximally critical points corresponds to fixed points of G_i that its points $z = 0, \infty$ of the spheres S^2_r and S^2_{II}. In the case of δM^4_+ the points $z = 0$ and ∞ correspond to the light-like rays R_+ in opposite directions. This ray would define the quantization direction of angular momentum. Quantum phase transitions changing the value of M^4 Planck constant could occur anywhere along this ray (partonic 2-surface would have 1-D projection along this ray). At the level of cosmology this would bring in a preferred direction. Light-cone dip, the counterpart of big bang, is the maximally quantum critical point since it remains invariant under entire group $SO(3,1)$.

Interesting questions relate to the groups generated by finite discrete subgroups of $SO(3)$. As noticed the groups generated as products of groups leaving R_+ invariant and three genuinely 3-D groups are infinite discrete subgroups of SO(3) and could also define Jones inclusions. In this case orbifold is replaced with orbifold containing infinite number of rotated versions of R_+. These phases could be important in elementary particle length scales or in early cosmology.

As already explained, the original too restricted view about generalization of imbedding space led to the idea about p-adic fractal hierarchy of Josephson junctions. Although this vision can criticized as unrealistic I decided to keep the original section discussing this idea in detail.

Fractal hierarchy of Josephson junctions is not new in TGD framework. The development of quantitative models based on this notion has been however plagued by the absence of concrete idea about what these Josephson junctions look like. The dark matter hierarchy based on hierarchy of scaled up values of Planck constant when combined with the p-adic length scale hierarchy might allow to circumvent the problem.

An essential boost for the development of ideas have been the effects of ELF em fields in living matter explainable in terms of quantum cyclotron transitions in Earth's magnetic field. Especially the fact that these effects appear only in narrow temperature and amplitude windows has provided the key hints concerning the model for the hierarchy of Josephson junctions and EEGs. The discussion of these effects is left to a separate section.

8.9.2 Orbital radii of exoplanets as a test for the theory

Orbital radii of exoplanets serve as a test for the theory. Hundreds of them are already known and in [28] tables listing basic data for for 136 exoplanets can be found. Tables provide also references and links to sources giving data about stars, in particular star mass M using solar mass M_S as a unit. Hence one can test the formula for the orbital radii given by the expression

$$\begin{aligned} \frac{r}{r_E} &= \frac{n^2}{5^2}\frac{M}{M_S}X \ , \\ X &= (\frac{n_1}{n_2})^2 \ , \\ n_i &= 2^{k_i}\times\prod_{s_i} F_{s_i} \ , \quad F_{s_i}\in\{3,5,17,257,2^{16}+1\} \ . \end{aligned} \tag{8.9.1}$$

Here a given Fermat prime F_{s_i} can appear only once.

It turns out that the simplest option assuming $X=1$ fails badly for some planets: the resulting deviations of order 20 per cent typically but in the worst cases the predicted radius is by factor of $\sim .5$ too small. The values of X used in the fit correspond to $X\in\{(2/3)^2,(3/4)^2,(4/5)^2,(5/6)^2,(15/17)^2,(15/16)^2,(16/17)^2\}\simeq\{.44,.56,.64,.69,.78,.88,.89\}$ and their inverses. The tables summarizing the resulting fit using both $X=1$ and value giving optimal fit are given below. The deviations are typically few per cent and one must also take into account the fact that the masses of stars are deduced theoretically using the spectral data from star models. I am not able to form an opinion about the real error bars related to the masses.

In the tables R denotes the value of minor semiaxis of the planetary orbit using AU as a unit and M the mass of star using solar mass M_S as a unit. n is the value of the principal quantum number and R_1 the radius assuming $X=(r/s)^2=1$ and R_2 the value for the best choice of X as ratio of "ruler and compass integers". The data about radii of planets are from tables at http://exoplanets.org/almanacframe.html and star masses from the references contained by the tables.

Star Name	R	M	n	R1	R1/R	r	s	R2/R
HD73256	0.037	1.05	1	0.042	1.14	16	15	1.00
HD83443	0.040	0.79	1	0.032	0.79	15	17	1.01
HD46375	0.040	1.00	1	0.040	1.00	1	1	1.00
HD179949	0.040	1.24	1	0.050	1.24	17	15	0.97
HD187123b	0.040	1.06	1	0.042	1.06	1	1	1.06
HD120136	0.050	1.30	1	0.052	1.04	1	1	1.04
HD330075	0.046	0.70	1	0.028	0.61	4	5	0.95
BD-103166	0.050	1.10	1	0.044	0.88	15	16	1
HD209458	0.050	1.05	1	0.042	0.84	16	17	0.95
HD76700	0.050	1.00	1	0.040	0.8	15	17	1.03
HD217014	0.050	1.06	1	0.042	0.85	15	16	0.96
HD9826b	0.059	1.30	1	0.052	0.88	15	16	1.00
HD49674	0.060	1.00	1	0.040	0.67	5	6	0.96
HD68988	0.070	1.20	1	0.048	0.69	5	6	0.99
HD168746	0.065	0.88	1	0.035	0.54	3	4	0.96
HD217107	0.070	0.98	1	0.039	0.56	3	4	1
HD162020	0.074	0.75	1	0.030	0.41	2	3	0.91
HD130322	0.088	0.79	1	0.032	0.36	3	5	1
HD108147	0.102	1.27	1	0.051	0.50	3	4	0.89
HD38529b	0.129	1.39	1	0.056	0.43	2	3	0.97
HD75732b	0.115	0.95	1	0.038	0.33	3	5	0.92
HD195019	0.140	1.02	2	0.163	1.17	16	15	1.02
HD6434	0.150	0.79	2	0.126	0.84	15	16	0.96
HD192263	0.150	0.79	2	0.126	0.84	15	16	0.96
GJ876c	0.130	0.32	3	0.115	0.89	15	16	1.01
HD37124b	0.181	0.91	2	0.146	0.80	15	17	1.03
HD143761	0.220	0.95	2	0.152	0.69	5	6	0.99
HD75732c	0.240	0.95	2	0.152	0.63	4	5	0.99
HD74156b	0.280	1.27	2	0.203	0.73	5	6	1.05
HD168443b	0.295	1.01	2	0.162	0.55	3	4	0.97
GJ876b	0.210	0.32	4	0.205	0.98	1	1	0.98
HD3651	0.284	0.79	3	0.284	1.00	1	1	1
HD121504	0.320	1.18	2	0.189	0.59	3	4	1.05
HD178911	0.326	0.87	3	0.313	0.96	1	1	0.96
HD16141	0.350	1.00	3	0.360	1.03	1	1	1.03
HD114762	0.350	0.82	3	0.295	0.84	15	16	0.96
HD80606	0.469	1.10	3	0.396	0.84	15	16	0.96
HD117176	0.480	1.10	3	0.396	0.83	15	16	0.94
HD216770	0.460	0.90	3	0.324	0.70	5	6	1.01

Star Name	R	M	n	R1	R1/R	r	s	R2/R
HD52265	0.49	1.13	3	0.41	0.83	15	16	0.94
HD73526	0.65	1.02	4	0.65	1	1	1	1.00
HD82943c	0.73	1.05	4	0.67	0.92	16	17	1.04
HD8574	0.77	1.17	4	0.75	0.97	1	1	0.97
HD169830	0.82	1.40	4	0.90	1.09	17	16	0.97
HD9826c	0.83	1.30	4	0.83	1.00	1	1	1.00
HD202206	0.83	1.15	4	0.74	0.89	15	16	1.01
HD89744	0.89	1.40	4	0.9	1.01	1	1	1.01
HD134987	0.81	1.05	4	0.67	0.83	15	16	0.94
HD12661b	0.82	1.07	4	0.68	0.84	15	16	0.95
HD150706	0.82	0.98	5	0.98	1.20	16	15	1.05
HD40979	0.81	1.08	4	0.69	0.85	15	16	0.97
HD92788	0.95	1.06	5	1.06	1.12	16	15	0.98
HD142	0.97	1.10	5	1.1	1.13	16	15	1.00
HD28185	1.03	0.99	5	0.99	0.96	1	1	0.96
HD142415	1.07	1.03	5	1.03	0.96	1	1	0.96
HD108874b	1.06	1.00	5	1.00	0.94	1	1	0.94
HD4203	1.09	1.06	5	1.06	0.97	1	1	0.97
HD177830	1.14	1.17	5	1.17	1.03	1	1	1.03
HD128311b	1.02	0.80	6	1.15	1.13	1	1	1.13
HD27442	1.18	1.20	5	1.20	1.02	1	1	1.02
HD210277	1.12	0.99	5	0.99	0.88	15	16	1.01
HD82943b	1.16	1.05	5	1.05	0.91	15	16	1.03
HD20367	1.25	1.17	5	1.17	0.94	1	1	0.94
HD114783	1.19	0.92	6	1.32	1.11	1	1	1.11
HD137759	1.28	1.05	5	1.05	0.82	15	17	1.05
HD19994	1.42	1.34	5	1.34	0.94	1	1	0.94
HD147513	1.26	1.11	5	1.11	0.88	15	16	1.00
HD222582	1.35	1.00	6	1.44	1.07	1	1	1.07
HD65216	1.31	0.92	6	1.32	1.01	1	1	1.01
HD141937	1.52	1.10	6	1.58	1.04	1	1	1.04
HD41004A	1.31	0.70	7	1.37	1.05	1	1	1.05
HD160691b	1.87	1.08	7	2.12	1.13	16	15	0.99

Star Name	R	M	n	R1	R1/R	r	s	R2/R
HD52265	0.49	1.13	3	0.41	0.83	15	16	0.94
HD73526	0.65	1.02	4	0.65	1	1	1	1.00
HD82943c	0.73	1.05	4	0.67	0.92	16	17	1.04
HD8574	0.77	1.17	4	0.75	0.97	1	1	0.97
HD169830	0.82	1.40	4	0.90	1.09	17	16	0.97
HD9826c	0.83	1.30	4	0.83	1.00	1	1	1.00
HD202206	0.83	1.15	4	0.74	0.89	15	16	1.01
HD89744	0.89	1.40	4	0.9	1.01	1	1	1.01
HD134987	0.81	1.05	4	0.67	0.83	15	16	0.94
HD12661b	0.82	1.07	4	0.68	0.84	15	16	0.95
HD150706	0.82	0.98	5	0.98	1.20	16	15	1.05
HD40979	0.81	1.08	4	0.69	0.85	15	16	0.97
HD92788	0.95	1.06	5	1.06	1.12	16	15	0.98
HD142	0.97	1.10	5	1.1	1.13	16	15	1.00
HD28185	1.03	0.99	5	0.99	0.96	1	1	0.96
HD142415	1.07	1.03	5	1.03	0.96	1	1	0.96
HD108874b	1.06	1.00	5	1.00	0.94	1	1	0.94
HD4203	1.09	1.06	5	1.06	0.97	1	1	0.97
HD177830	1.14	1.17	5	1.17	1.03	1	1	1.03

HD128311b	1.02	0.80	6	1.15	1.13	1	1	1.13
HD27442	1.18	1.20	5	1.20	1.02	1	1	1.02
HD210277	1.12	0.99	5	0.99	0.88	15	16	1.01
HD82943b	1.16	1.05	5	1.05	0.91	15	16	1.03
HD20367	1.25	1.17	5	1.17	0.94	1	1	0.94
HD114783	1.19	0.92	6	1.32	1.11	1	1	1.11
HD137759	1.28	1.05	5	1.05	0.82	15	17	1.05
HD19994	1.42	1.34	5	1.34	0.94	1	1	0.94
HD147513	1.26	1.11	5	1.11	0.88	15	16	1.00
HD222582	1.35	1.00	6	1.44	1.07	1	1	1.07
HD65216	1.31	0.92	6	1.32	1.01	1	1	1.01
HD141937	1.52	1.10	6	1.58	1.04	1	1	1.04
HD41004A	1.31	0.70	7	1.37	1.05	1	1	1.05
HD160691b	1.87	1.08	7	2.12	1.13	16	15	0.99

Star Name	R	M	n	R1	R1/R	r	s	R2/R
HD23079	1.65	1.10	6	1.58	0.96	1	1	0.96
HD186427	1.67	1.01	6	1.45	0.87	15	16	0.99
HD4208	1.67	0.93	7	1.82	1.09	16	15	0.96
HD114386	1.62	0.68	8	1.74	1.07	17	16	0.95
HD213240	2.03	1.22	6	1.76	0.87	15	16	0.98
HD10647	2.10	1.07	7	2.10	1.00	1	1	1
HD10697	2.13	1.10	7	2.16	1.01	1	1	1.01
HD95128b	2.09	1.03	7	2.02	0.97	1	1	0.97
HD190228	2.00	0.83	8	2.12	1.06	1	1	1.06
HD114729	2.08	0.93	7	1.82	0.88	15	16	1
HD111232	1.97	0.78	8	2.00	1.01	1	1	1.01
HD2039	2.19	0.98	7	1.92	0.88	15	16	1
HD136118	2.40	1.24	7	2.43	1.01	1	1	1.01
HD50554	2.32	1.07	7	2.09	0.9	15	16	1.02
HD9826d	2.53	1.30	7	2.55	1.01	1	1	1.01
HD196050	2.43	1.10	7	2.16	0.89	15	16	1.01
HD216437	2.43	1.07	8	2.74	1.13	17	15	0.88
HD216435	2.70	1.25	7	2.45	0.91	1	1	0.91
HD169830c	2.75	1.40	7	2.74	1	1	1	1
HD106252	2.54	0.96	8	2.46	0.97	1	1	0.97
HD12661c	2.60	1.07	8	2.74	1.05	1	1	1.05
HD23596	2.86	1.30	7	2.55	0.89	15	16	1.01
HD168443c	2.87	1.01	8	2.59	0.9	15	16	1.03
HD145675	2.85	1.00	8	2.56	0.9	15	16	1.02
HD11964b	3.10	1.10	8	2.82	0.91	16	17	1.03
HD39091	3.29	1.10	9	3.56	1.08	17	16	0.96
HD38529c	3.71	1.39	8	3.56	0.96	1	1	0.96
HD70642	3.30	1.00	9	3.24	0.98	1	1	0.98
HD33636	3.56	0.99	9	3.21	0.9	15	16	1.03
HD95128c	3.73	1.03	10	4.12	1.1	16	15	0.97
HD190360	3.65	0.96	10	3.84	1.05	1	1	1.05
HD74156c	3.82	1.27	9	4.11	1.08	1	1	1.08
HD22049	3.54	0.80	11	3.87	1.09	16	15	0.96
HD30177	3.86	0.95	10	3.80	0.98	1	1	0.98
HD89307	4.15	0.95	10	3.80	0.92	1	1	0.92
HD72659	4.50	0.95	11	4.60	1.02	1	1	1.02
HD75732d	5.90	0.95	13	6.42	1.09	16	15	0.96

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Part III

TOPOLOGICAL FIELD QUANTIZATION AND GENERATION OF STRUCTURES

Chapter 9

Hydrodynamics and CP_2 Geometry

9.1 Introduction

In this chapter the basic notions related to many-sheeted space-time is briefly described.

The understanding of the turbulence is a longstanding problem in hydrodynamics [23, 22]. This problem is acute also in astrophysics [21], where the proper understanding of the turbulence associated with the astrophysical systems, such as the mass accretion in a binary star, is lacking. A generally accepted point of view is that Navier-Stokes equations provide a correct description of the hydrodynamics and that the problems are of purely technical nature, being analogous to the difficulties encountered in the understanding of the color confinement.

9.1.1 Basic ideas and concepts

TGD approach to the description of the fundamental interactions suggests a fresh approach to the basic problems of the hydrodynamics. The new physical ideas are the following ones.

The notion of topological condensate

The concept of topological condensate: the criticality of the Kähler function and topological arguments suggest that 3-space has many-sheeted, fractal like, hierarchical structure consisting of 3-surfaces with boundary, topological field quanta, condensed on larger topological field quanta. The n:th level of the topological condensate is characterized by a length scale $L(n)$ giving lower bound for the size of the topological quanta at this level.

Various gauge fluxes and gravitational flux associated with a given topological field quantum flow to the lower condensate level via # contacts near the boundaries of the topological field quanta, whose microscopic description in terms of partons is discussed in [F6]. The outer surfaces of the macroscopic bodies are identified as the boundaries of the topological field quanta condensed in the background 3-space.

Topological field quanta are characterized by certain vacuum quantum numbers and the space-time in the astrophysical length scales corresponds to the large vacuum quantum number limit of TGD. In the present situation hydrodynamic vortex provides a good candidate for a topological field quantum condensed on the background 3-space and at a given level vortices must have size not smaller than the length scale $L(n)$. Actually this picture of the space-time requires the generalization of the ordinary hydrodynamics to a hierarchy of hydrodynamics, one for each condensate level and also the modelling of the energy transfer between various condensate levels. In this chapter only the modifications of the hydrodynamics associated with a given condensate level are considered.

The join along boundaries bond makes it possible to glue topological field quanta together to form a larger coherent quantum systems from simpler basic units. Since dissipation corresponds to a loss of the quantum coherence, the formation of the join along boundaries bonds should play a key role in the understanding of the dissipation, in particular hydrodynamic dissipation.

A concrete topological description for the dissipation is following. The basic mechanism of the dissipation at condensate level n are the inelastic collisions of the condensed topological field quanta involving the formation and splitting of the join along boundaries bonds and leading to the transfer of the kinetic energy to the kinetic energy of the topological field quanta at higher condensate level n_1 with $L(n_1) < L(n)$. Eventually the kinetic energy of the flow ends up to the atomic condensate levels, where the collisions of atoms take care of the dissipation. The modelling of this mechanism requires a model for the coupling between hydrodynamics associated with two different condensate levels.

Long range color and electroweak gauge fields created by dark matter

TGD predicts classical long ranged color and weak forces, in particular Z^0 force. The study of the imbeddings for various metrics [D3] suggests strongly that at long length scales matter is accompanied by long range electro-weak gauge fields. For vacuum extremals em field can vanish while Z^0 field is non-vanishing: this requires that Weinberg angle satisfies $sin^2(\theta_W) = 0$ in this phase. In the astrophysical length scales Z^0 charge is proportional to the gravitational mass of the system, when Planck mass is used as unit: $Q_Z = \epsilon_1 m/m_{Pl}$, where ϵ_1 is numerical factor smaller.

Also long ranged classical W fields are possible as well as classical long ranged color fields. The proper interpretation is in terms of scaled down hierarchy of weak and color physics assignable to a hierarchy of dark matters coupling to ordinary matter only via gravitation directly. These physics manifest themselves already in nuclear physics [F8] and condensed matter physics [F9], in particular in the physics of living matter. The appearance of classical Z^0 fields in the bio-systems could explain chirality selection in the living matter.

TGD based model for atomic nuclei predicts that nucleons are connected by color bonds connecting exotic quarks with mass of order MeV. These quarks couple to light variants of weak bosons with Compton length of order atomic radius so that the range of these exotic weak forces would be about atomic radius. These color bonds can have also net em and weak charges so that nucleus develops an anomalous weak charge. More generally, a hierarchy of scaled up variants of weak and color physics is predicted and the range 10 nm-2.5 μm containing the p-adic length scales defined by four Gaussian Mersennes is especially interesting in this respect.

As a consequence, the dark matter part of condensed matter system serves as a source of Z^0 electric and magnetic fields. These fields are vacuum screened above the relevant weak length scale L_w. This means that the space-time sheets of weak bosons are of size L_w and weak gauge fluxes are not conserved in # contacts to larger space-time sheets. The outcome is randomness and loss of coherence in length scales longer than L_w.

In particular, moving matter at given dark space-time sheet creates Z^0 magnetic field

$$\nabla \times B_Z \simeq g_Z N\beta \ , \tag{9.1.1}$$

where N is the density of weak isospin of dark matter using neutrino isospin as a unit. This formula makes sense below the appropriate weak length scale determined by the mass of dark weak bosons in question. Above this length scale vacuum screening occurs. Z^0 electric field satisfies also the appropriate source equation.

Although the Z^0 fields as such are extremely weak, the topological obstructions caused by the CP_2 topology for the imbeddings of the Z^0 magnetic fields are nontrivial. CP_2 topology generates structures: the hydrodynamical flow decomposes into what could be called flux quanta of the Z^0 magnetic field. It will be later found that under rather natural assumptions the sizes of the flux quanta are indeed of the same order of magnitude as the sizes of the typical structures associated with the hydrodynamic flow. In particular, for large systems typically encountered in astrophysics, the geometry of CP_2 is bound to become important.

9.1.2 Z^0 magnetic fields and hydrodynamics

In [F8] long ranged color and weak forces associated with the color bonds between nucleons inside atomic nuclei are proposed as an explanation for the basic properties of the ordinary liquid phase and for the anomalous characteristics of liquid water. The mathematical similarity between incompressible hydrodynamical flow and Maxwell equations for magnetic field forces to ask whether Z^0 magnetic fields created by the dark matter component of condensed matter system might provide deeper insights into the physics of hydrodynamical flow. The general study of solutions of field equations [D1] indeed leads to very general mathematical insights in this respect providing a classification of asymptotic flow patterns in terms of the dimension of CP_2 projection varying in the range $2 \leq D \leq 4$.

Z^0 magnetic fields and transition to turbulence

The concept of the Z^0 magnetic field suggests a new approach to the problem of understanding how the transition to turbulence takes place. The transition to a turbulence might be understood simply as a spontaneous Z^0 magnetization. Flow decomposes into eddies carrying a Z^0 magnetic field in the direction of the rotation axis of the eddy. Due to the viscosity, the size of the eddy grows until its size becomes critical. Vortices dissipate their energy and angular momentum by the emission of daughter vortices: the emission is a generalization of the process known as a phase slippage in super fluidity [23]. This mechanism suggests fractal like structure for the development of the hydrodynamic turbulence. In fact, it will be found CP_2 geometry implies naturally fractal like structures [17] and the model for the turbulence relies heavily on the assumption that the sizes of the daughter eddies are related to the size of the mother eddy by a discrete scaling transformation.

Turbulence and Z^0 magnetization

TGD suggests a first principle explanation for the occurrence of a spontaneous Z^0 (and Kähler) magnetization and therefore of turbulence. The probability of the configuration is proportional to the exponent of the Kähler function. Kähler function corresponds to the absolute minimum of the Kähler action and Kähler magnetic (electric) fields give a positive (negative) contribution to the Kähler action so that a transition to a configuration containing Kähler magnetic fields can take place provided the configuration is energetically possible and corresponds to the minimum of Kähler action.

It turns out that for a certain critical values of the flow parameters, Kähler magnetization takes place and implies the generation of the eddies and turbulence. The mechanism leading to the increase of the Kähler action is however not the generation of magnetic Kähler action but the decrease of the magnitude of the Kähler electric contribution as is understandable from the fact that Kähler magnetic fields of the flow are in general by a factor β (β is the typical flow velocity) weaker than the Kähler electric fields. The decrease of the Kähler electric contribution follows from the fact that the Kähler electric field of the vortex becomes small near the core of the vortex. It should be noticed that a similar explanation might apply to other types of phase transitions, say spontaneous magnetization.

9.1.3 Topics of the chapter

The topics of the chapter are following.

1. The chapter begins with an updated review of the basic aspects of the many-sheeted space-time concept.

2. Hydrodynamical and thermodynamical hierarchies associated with the p-adic length scale hierarchy are considered. A generalization of hydrodynamics to a p-adic hierarchy of hydrodynamics is performed and a mechanism of energy transfer between condensate levels is identified. Mary Selvam has found a fascinating connection between the distribution of primes and the distribution of vortex radii in turbulent flow in atmosphere. These observations provide new insights into p-adic length scale hypothesis and suggest that TGD based generalization of Hawking-Bekenstein law holds even in macroscopic length scales and that hydrodynamical vortices behave in some aspects like elementary particles.

3. General ideas about the description of phase transitions in terms of configuration space geometry (configuration space understood as the space of 3-surfaces, the "world of classical worlds") are considered. The new element is the presence of several condensate levels.

4. Some simple cylindrically symmetric flows are studied and it is shown that the sizes of the flux structures are of a correct order of magnitude under rather natural assumptions about the vacuum parameters characterizing electrovac neutral space-time.

5. A detailed model for the generation of turbulence as a spontaneous Kähler (implying both em and Z^0 magnetization) magnetization in the case of the channel flow is discussed.

An encouraging result is the prediction for the size distribution of the vortices: the prediction is practically identical with that obtained from the model of Heisenberg but on rather different physical grounds. The model is rather insensitive to the p-adic scaling of vortices in the transition as long as it is smaller than $\lambda = 2^{-5}$. The model is also consistent with the assumption that the decay of a vortex to smaller vortices corresponds to a phase transition from a given level of dark matter hierarchy to a lower level so that the value of $\hbar$ is reduced by a factor $\lambda = v_0/n \simeq 2^{-11}/n$, $n = 1, 2, ...$ so that Compton length scales as well as sizes of vortices are reduced by this factor.

9.2 Many-sheeted space-time concept

In this section the basic phenomenology related to the many-sheeted space-time concept is introduced. In [F6] a more refined and more up-to-date review of these notions relying on number theoretic vision can be found. The vision about the role of dark matter in condensed matter and living matter is summarized in [F9].

9.2.1 Basic concepts related to topological condensation and evaporation

The most up-to-date discussion of the notions such as topological condensation and evaporation, gauge charges, transfer of gauge field between different space-time sheets,... can be found in [F6].

CP_2 type vacuum extremals

CP_2 type extremals behave like elementary particles (in particular, light-likeness of M^4 projection gives rise to Virasoro conditions). CP_2 type vacuum extremals have however vanishing four-momentum although they carry classical color charges. This raises the question how they can gain elementary particle quantum numbers.

In topological condensation of CP_2 type vacuum extremal a light-like causal horizon is created. Number theoretical considerations strongly suggest that the horizon carries elementary particle numbers and can be identified as a parton. The quantum numbers or parton would serve as sources of the classical gauge fields created by the causal horizon.

In topological evaporation CP_2 type vacuum extremal carrying only classical color charges is created. This would suggest that the scattering of CP_2 type vacuum extremals defines a topological quantum field theory resulting as a limit of quantum gravitation (CP_2 is gravitational instanton) and that CP_2 type extremals define the counterparts of vacuum lines appearing in the formulation of generalized Feynman diagrams.

contacts as parton pairs

The earlier view about # contacts as passive mediators of classical gauge and gravitational fluxes is not quite correct. The basic modification is due to the fact that one can assign parton or parton pair to the # contact so that it becomes a particle like entity. This means that an entire p-adic hierarchy of new physics is predicted.

1. Formally # contact can be constructed by drilling small spherical holes S^2 in the 3-surfaces involved and connecting the spherical boundaries by a tube $S^2 \times D^1$. For instance, CP_2 type extremal can be glued to space-time sheet with Minkowskian signature or space-time sheets with Minkowskian signature can be connected by # contact having Euclidian signature of the induced metric. Also more general contacts are possible since S^2 can be replaced with a 2-surface of arbitrary genus and family replication phenomenon can be interpreted in terms of the genus.

   The # contact connecting two space-time sheets with Minkowskian signature of metric is accompanied by two "elementary particle horizons", which are light-like 3-surfaces at which the induced 4-metric becomes degenerate. Since these surfaces are causal horizons, it is not clear whether # contacts can mediate classical gauge interactions. If there is an electric gauge flux associated with elementary particle horizon it tends to be either infinite by the degeneracy of the induced metric. It is not clear whether boundary conditions allow to have finite gauge fluxes of electric type. A similar difficulty is encountered when one tries to assign gravitational flux to the # contact: in this case even the existence of flux in non-singular case is far from obvious. Hence the naive extrapolation of Newtonian picture might not be quite correct.

2. Number theoretical considerations suggests that the two light-like horizons associated with # contacts connecting space-time sheets act as dynamical units analogous to shock waves or light fronts carrying quantum numbers so that the identification as partons is natural. Quantum holography would suggest itself in the sense that the quantum numbers associated with causal horizons would determine the long range fields inside space-time sheets involved.

3. # contacts can be modelled in terms of CP_2 type extremals topologically condensed simultaneously to the two space-time sheets involved. The topological condensation of CP_2 type extremal creates only single parton and this encourages the interpretation as elementary particle. The gauge currents for CP_2 type vacuum extremals have a vanishing covariant divergence so that there are no conserved charges besides Kähler charge. Hence electro-weak gauge charges are not conserved classically in the region between causal horizons whereas color gauge charges are. This could explain the vacuum screening of electro-weak charges at space-time level. This is required since for the known solutions of field equations other than CP_2 type extremals vacuum screening does not occur.

4. In the special case space-time sheets have opposite time orientations and the causal horizons carry opposite quantum numbers (with four-momentum included) the # contact would serve the passive role of flux mediator and one could assign to the contact generalized gauge fluxes as quantum numbers associated with the causal horizons. This is the case if the contact is created from vacuum in topological condensation so that the quantum numbers associated with the horizons define naturally generalized gauge fluxes. Kind of generalized quantum dipoles living in two space-times simultaneously would be in question. # contacts in the ground state for space-time sheets with opposite time orientation can be also seen as zero energy parton-antiparton pairs bound together by a piece of CP_2 type extremal.

5. When space-time sheets have same time orientation, the two-parton state associated with the # contact has non-vanishing energy and it is not clear whether it can be stable.

$\#_B$ contacts as bound parton pairs

Besides # contacts also join along boundaries bonds (JABs, $\#_B$ contacts) are possible. They can connect outer boundaries of space-time sheets or the boundaries of small holes associated with the interiors of two space-time sheets which can have Minkowskian signature of metric and can mediate classical gauge fluxes and are excellent candidates for mediators of gauge interactions between space-time sheet glued to a larger space-time sheet by topological sum contacts and join along boundaries contacts. The size scale of the causal horizons associated with parton pairs can be arbitrary whereas the size scale of # contacts is given by CP_2 radius.

The existence of the holes for real space-time surfaces is a natural consequence of the induced gauge field concept: for sufficiently strong gauge fields the imbeddability of gauge field as an induced gauge field fails and hole in space-time appears as a consequence. The holes connected by $\#_B$ contacts obey field equations, and a good guess is that they are light-like 3-surfaces and carry parton quantum numbers. This would mean that both # and $\#_B$ contacts allow a fundamental description in terms of pair of partons.

Magnetic flux tubes provide a representative example of $\#_B$ contact. Instead of $\#_B$ contact also more descriptive terms such as join along boundaries bond (JAB), color bond, and magnetic flux tube are used. $\#_B$ contacts serve also as a space-time correlate for bound state formation and one can even consider the possibility that entanglement might have braiding of bonds defined by # contacts as a space-time correlate [E9].

The formation of join along boundaries contacts could become important at the quantum limit, when the thermal de Broglie wave length $\lambda_{th} = \frac{2\pi}{\sqrt{2Tm}}$ (roughly the minimal size for the p-adic 3-surface at which particle with thermal momentum $p = \sqrt{2Tm}$ can condense) is of same order of magnitude as average separation between particles. A tempting identification for the formation of the join along boundaries bonds is as Bose-Einstein condensation taking place at same temperature range.

For solids join along boundaries binding energy E_{join} can be, at least partially, regarded as the reduction of kinetic energy resulting from the elimination of translational degrees of freedom in the join along boundaries bond. Also the delocalization energy of particles, say conduction electrons contributes to E_{join} (delocalization is made possible by the formation of bridges between p-adic blocks).

Topological condensation and evaporation

Topological condensation corresponds to a formation of # or $\#_B$ contacts between space-time sheets. Topological evaporation means the splitting of # or $\#_B$ contacts. In the case of elementary particles the process changes almost nothing since the causal horizon carrying parton quantum numbers does not disappear. The evaporated CP_2 type vacuum extremal having interpretation as a gravitational instanton can carry only color quantum numbers.

As # contact splits partons are created at the two space-time sheets involved. This process can obviously generate from vacuum space-time sheets carrying particles with opposite signs of energies and other quantum numbers. Positive energy matter and negative energy anti-matter could be thus created by the formation of # contacts with zero net quantum numbers which then split to produce pair of positive and negative energy particles at different space-time sheets having opposite time orientations. This mechanism would allow a creation of positive energy matter and negative energy antimatter with an automatic separation of matter and antimatter at space-time sheets having different time orientation. This might resolve elegantly the puzzle posed by matter-antimatter asymmetry.

The creation of # contact leads to an appearance of radial gauge field in condensate and this seems to be impossible at the limit of infinitely large space-time sheet since it involves a radical instantaneous change in field line topology. The finite size of the space-time sheet can however resolve the difficulty.

If all quantum numbers of elementary particle are expressible as gauge fluxes, the quantum numbers of topologically evaporated particles should vanish. In the case of color quantum numbers and Poincare quantum numbers there is no obvious reason why this should be the case. Despite this the cancellation of the interior quantum numbers by those at boundaries or light-like causal determinants could occur and would conform with the effective 2-dimensionality stating that quantum states are characterized by partonic boundary states associated with causal determinants. This could be also seen as a holographic duality of interior and boundary degrees of freedom [A2].

9.2.2 Can one regard # *resp.* $\#_B$ contacts as particles *resp.* string like objects?

#-contacts have obvious particle like aspects identifiable as either partons or parton pairs. $\#_B$ contacts in turn behave like string like objects. Using the terminology of M-theory, $\#_B$ contacts connecting the boundaries of space-time sheets could be also seen as string like objects connecting two branes. Again the ends holes at the ends of $\#_B$ contacts carry well defined gauge charges.

contacts as particles and $\#_B$ contacts as string like objects?

The fact that # contacts correspond to parton pairs raises the hope that it is possible to apply p-adic thermodynamics to calculate the masses of # contact and perhaps even the masses of the partons. If this the case, one has an order of magnitude estimate for the first order contribution to the mass of the parton as $m \sim 1/L(p_i)$, $i = 1, 2$. It can of course happen that the first order contribution vanishes: in this case an additional factor $1/\sqrt{p_i}$ appears in the estimate and makes the mass extremely small.

For # contacts connecting space-time sheets with opposite time orientations the vanishing of the net four-momentum requires $p_1 = p_2$. According to the number theoretic considerations below it is possible to assign several p-adic primes to a given space-time sheet and the largest among them, call it p_{max}, determines the p-adic mass scale. The milder condition is that p_{max} is same for the two space-time sheets.

There are some motivations for the working hypothesis that # contacts and the ends of $\#_B$ contacts feeding the gauge fluxes to the lower condensate levels or vice versa tend to be located near the boundaries of space-time sheets. For gauge charges which are not screened by vacuum charges (em and color charges) the imbedding of the gauge fields created by the interior gauge charges becomes impossible near the boundaries and the only possible manner to satisfy boundary conditions is that gauge fluxes flow to the larger space-time sheet and space-time surface becomes a vacuum extremal of the Kähler action near the boundary.

For gauge bosons the density of boundary $\#_B$ contacts should be very small in length scales, where matter is essentially neutral. For gravitational $\#_B$ contacts the situation is different. One might well argue that there is some upper bound for the gravitational flux associated with single # or $\#_B$ contact (or equivalently the gravitational mass associated with causal horizon) given by Planck mass or CP_2 mass so that the number of gravitational contacts is proportional to the mass of the system.

The TGD based explanation for Podkletnov effect [29] is based on the assumption that magnetically charged # contacts are carries of gravitational flux equal to Planck mass and predicts effect with correct order of magnitude. The model generalizes also to the case of $\#_B$ contacts. The lower bound for the gravitational flux quantum must be rather small: the mass $1/L(p)$ determined by the p-adic prime associated with the larger space-time sheet is a first guess for the unit of flux.

Could # and $\#_B$ contacts form Bose-Einstein condensates?

The description as # contact as a parton pair suggests that it is possible to assign to # contacts inertial mass, say of order $1/L(p)$, they should be describable using d'Alembert type equation for a scalar field. # contacts couple dynamically to the geometry of the space-time since the induced metric defines the d'Alembertian. There is a mass gap and hence # contacts could form a Bose-Einstein (BE) condensate to the ground state. If # contacts are located near the boundary of the space-time surface, the d'Alembert equation would be 3-dimensional. One can also ask whether # contacts define a particular form of dark matter having only gravitational interactions with the ordinary matter.

Also the probability amplitudes for the positions of the ends of $\#_B$ contacts located at the boundary of the space-time sheet could be described using an order parameter satisfying d'Alembert equation with some mass parameter and whether the notion of Bose-Einstein condensate makes sense also now. The model for atomic nucleus assigns to the ends of the $\#_B$ contact realized as a color magnetic flux tube quark and anti-quark with mass scale given by $k = 127$ (MeV scale) [F8].

This inspires the question whether # and $\#_B$ contacts could be essential for understanding bio-systems as macroscopic quantum systems [I3]. The BE condensate associated with the # contacts behaves in many respects like super conductor: for instance, the concept of Josephson junction generalizes. As a matter fact, it seems that $\#_B$ contacts, join along boundaries, or magnetic flux tubes could indeed be a key element of not only living matter but even nuclear matter and condensed matter in TGD Universe. One application of the concept is the TGD based explanation [J5] of Comorosan effect [27, 28] in terms of # contact Josephson currents appearing at molecular level.

The transfer of fields between space-time sheets and # and $\#_B$ contacts

The penetration of the external electric and magnetic fields from external world to subsystem (from larger space-time sheet to a smaller one) and vice versa must take place via the creation and rearrangement of the # and $\#_B$ contacts and also by the generation of # and $\#_B$ contact currents. The unique coupling of the wormhole BE condensate to the geometry of the boundary of the space-time sheet together with the classical electromagnetic interaction between wormholes and electrons implies coupling between electrons and the shape and size of the 3-surface. This coupling might make it possible to understand how bio-systems are able to control their size and shape.

Exotic effects related to the many-sheeted space-time

The hopping of electrons (most probably unpaired valence electrons) from the atomic space-time sheet to non-atomic space-time sheets might be energetically favorable under some circumstances and would lead to the formation of 'exotic atoms' and effective electronic alchemy since the chemical properties of the atom are presumably determined by the electronic properties of the atomic space-time sheet [J6]. The 'exotic' electrons on non-atomic space-time sheets provide an ideal mechanism for energy and charge transfer since dissipative effects are small and even the temperature at these space-time sheets might be much smaller than the temperature at the atomic space-time sheet. In this respect bio-systems are especially interesting.

The interaction of the exotic electrons with the wormhole BE condensate takes place via the classical electromagnetic interaction generating excitations of the # contact BE condensate. The mechanism is completely analogous to the ordinary mechanism of super conductivity in which electromagnetic interaction of electrons with nuclei excites phonons. Since the gap energy is of order

$1/L(p)$ characterizing the size of the p-adic space-time sheet, one can consider the possibility of high temperature super conductivity.

One can even consider the possibility that the presence of electrons on 'wrong' space-time sheets makes if favorable for some atomic nuclei to feed their electromagnetic charges to non-atomic space-time sheets. This would in principle make possible Trojan horse mechanism of cold nuclear fusion since two nuclei feeding their electromagnetic gauge fluxes on different space-time sheets do not see the Coulomb wall [F8].

Also ions can drop to larger space-time sheets. In [J1, J2, J3] a model of ionic high T_c super conductivity explaining certain peculiar effects of the em radiation on living matter is considered. These effects actually provide support for the view that living systems are macroscopic quantum systems.

9.2.3 Number theoretical considerations

Number theoretical considerations allow to develop more quantitative vision about the how p-adic length scale hypothesis relates to the ideas just described.

How to define the notion of elementary particle?

p-Adic length scale hierarchy forces to reconsider carefully also the notion of elementary particle. p-Adic mass calculations led to the idea that particle can be characterized uniquely by single p-adic prime characterizing its mass squared. It however turned out that the situation is probably not so simple.

The work with modelling dark matter suggests that particle could be characterized by a collection of p-adic primes to which one can assign weak, color, em, gravitational interactions, and possibly also other interactions. It would also seem that only the space-time sheets containing common primes in this collection can interact. This leads to the notions of relative and partial darkness. An entire hierarchy of weak and color physics such that weak bosons and gluons of given physics are characterized by a given p-adic prime p and also the fermions of this physics contain space-time sheet characterized by same p-adic prime, say M_{89} as in case of weak interactions. In this picture the decay widths of weak bosons do not pose limitations on the number of light particles if weak interactions for them are characterized by p-adic prime $p \neq M_{89}$. Same applies to color interactions.

The p-adic prime characterizing the mass of the particle would perhaps correspond to the largest p-adic prime associated with the particle. Graviton which corresponds to infinitely long ranged interactions, could correspond to the same p-adic prime or collection of them common to all particles. This might apply also to photons. Infinite range might mean that the join along boundaries bonds mediating these interactions can be arbitrarily long but their transversal sizes are characterized by the p-adic length scale in question.

The natural question is what this collection of p-adic primes characterizing particle means? The hint about the correct answer comes from the number theoretical vision, which suggests that at fundamental level the branching of boundary components to two or more components, completely analogous to the branching of line in Feynman diagram, defines vertices [C2, E3].

1. If space-time sheets correspond holographically to multi-p p-adic topology such that largest p determines the mass scale, the description of particle reactions in terms of branchings indeed makes sense. This picture allows also to understand the existence of different scaled up copies of QCD and weak physics. Multi-p p-adicity could number theoretically correspond to q-adic topology for $q = m/n$ a rational number consistent with p-adic topologies associated with prime factors of m and n ($1/p$-adic topology is homeomorphic with p-adic topology).

2. One could also imagine that different p-adic primes in the collection correspond to different space-time sheets condensed at a larger space-time sheet or boundary components of a given space-time sheet. If the boundary topologies for gauge bosons are completely mixed, as the model of hadrons forces to conclude, this picture is consistent with the topological explanation of the family replication phenomenon and the fact that only charged weak currents involve mixing of quark families. The problem is how to understand the existence of different copies of say QCD. The second difficult question is why the branching leads always to an emission of

gauge boson characterized by a particular p-adic prime, say M_{89}, if this p-adic prime does not somehow characterize also the particle itself.

What effective p-adic topology really means?

The need to characterize elementary particle p-adically leads to the question what p-adic effective topology really means. p-Adic mass calculations leave actually a lot of room concerning the answer to this question.

1. The naivest option is that each space-time sheet corresponds to single p-adic prime. A more general possibility is that the boundary components of space-time sheet correspond to different p-adic primes. This view is not favored by the view that each particle corresponds to a collection of p-adic primes each characterizing one particular interaction that the particle in question participates.

2. A more abstract possibility is that a given space-time sheet or boundary component can correspond to several p-adic primes. Indeed, a power series in powers of given integer n gives rise to a well-defined power series with respect to all prime factors of n and effective multi-p-adicity could emerge at the level of field equations in this manner.

One could say that space-time sheet or boundary component corresponds to several p-adic primes through its effective p-adic topology in a hologram like manner. This option is the most flexible one as far as physical interpretation is considered. It is also supported by the number theoretical considerations predicting the value of gravitational coupling constant [E3].

An attractive hypothesis is that only space-time sheets characterized by integers n_i having common prime factors can be connected by join along boundaries bonds and can interact by particle exchanges and that each prime p in the decomposition corresponds to a particular interaction mediated by an elementary boson characterized by this prime.

Do infinite primes code for q-adic effective space-time topologies?

Besides the hierarchy of space-time sheets, TGD predicts, or at least suggests, several hierarchies such as the hierarchy of infinite primes [E3], hierarchy of Jones inclusions [C6], hierarchy of dark matters with increasing values of $\hbar$ [F9, J6], the hierarchy of extensions of given p-adic number field, and the hierarchy of selves and quantum jumps with increasing duration with respect to geometric time. There are good reasons to expect that these hierarchies are closely related.

1. Some facts about infinite primes

The hierarchy of infinite primes can be interpreted in terms of an infinite hierarchy of second quantized super-symmetric arithmetic quantum field theories allowing a generalization to quaternionic or perhaps even octonionic context [E3]. Infinite primes, integers, and rationals have decomposition to primes of lower level.

Infinite prime has fermionic and bosonic parts having no common primes. Fermionic part is finite and corresponds to an integer containing and bosonic part is an integer multiplying the product of all primes with fermionic prime divided away. The infinite prime at the first level of hierarchy corresponds in a well defined sense a rational number $q = m/n$ defined by bosonic and fermionic integers m and n having no common prime factors.

2. Do infinite primes code for effective q-adic space-time topologies?

The most obvious question concerns the space-time interpretation of this rational number. Also the question arises about the possible relation with the integers characterizing space-time sheets having interpretation in terms of multi-p-adicity. On can assign to any rational number $q = m/n$ so called q-adic topology. This topology is not consistent with number field property like p-adic topologies. Hence the rational number q assignable to infinite prime could correspond to an effective q-adic topology.

If this interpretation is correct, arithmetic fermion and boson numbers could be coded into effective q-adic topology of the space-time sheets characterizing the non-determinism of Kähler action in the relevant length scale range. For instance, the power series of $q > 1$ in positive powers with integer coefficients in the range $[0, q)$ define q-adically converging series, which also converges with respect to the prime factors of m and can be regarded as a p-adic power series. The power series of q in negative powers define in similar converging series with respect to the prime factors of n.

I have proposed earlier that the integers defining infinite rationals and thus also the integers m and n characterizing finite rational could correspond at space-time level to particles with positive *resp.* negative time orientation with positive *resp.* negative energies. Phase conjugate laser beams would represent one example of negative energy states. With this interpretation super-symmetry exchanging the roles of m and n and thus the role of fermionic and bosonic lower level primes would correspond to a time reversal.

1. The first interpretation is that there is single q-adic space-time sheet and that positive and negative energy states correspond to primes associated with m and n respectively. Positive (negative) energy space-time sheets would thus correspond to p-adicity ($1/p$-adicity) for the field modes describing the states.

2. Second interpretation is that particle (in extremely general sense that entire universe can be regarded as a particle) corresponds to a pair of positive and negative energy space-time sheets labelled by m and n characterizing the p-adic topologies consistent with $m-$ and n-adicities. This looks natural since Universe has necessary vanishing net quantum numbers. Unless one allows the non-uniqueness due to $m/n = mr/nr$, positive and negative energy space-time sheets can be connected only by $\#$ contacts so that positive and negative energy space-time sheets cannot interact via the formation of $\#_B$ contacts and would be therefore dark matter with respect to each other.

Positive energy particles and negative energy antiparticles would also have different mass scales. If the rate for the creation of $\#$ contacts and their CP conjugates are slightly different, say due to the presence of electric components of gauge fields, matter antimatter asymmetry could be generated primordially.

These interpretations generalize to higher levels of the hierarchy. There is a homomorphism from infinite rationals to finite rationals. One can assign to a product of infinite primes the product of the corresponding rationals at the lower level and to a sum of products of infinite primes the sum of the corresponding rationals at the lower level and continue the process until one ends up with a finite rational. Same applies to infinite rationals. The resulting rational $q = m/n$ is finite and defines q-adic effective topology, which is consistent with all the effective p-adic topologies corresponding to the primes appearing in factorizations of m and n. This homomorphism is of course not 1-1.

If this picture is correct, effective p-adic topologies would appear at all levels but would be dictated by the infinite-p p-adic topology which itself could refine infinite-P p-adic topology [E3] coding information too subtle to be catched by ordinary physical measurements.

Obviously, one could assign to each elementary particle infinite prime, integer, or even rational to this a rational number $q = m/n$. q would associate with the particle q-adic topology consistent with a collection of p-adic topologies corresponding to the prime factors of m and n and characterizing the interactions that the particle can participate directly. In a very precise sense particles would represent both infinite and finite numbers.

Under what conditions space-time sheets can be connected by $\#_B$ contact?

Assume that particles are characterized by a p-adic prime determining it mass scale plus p-adic primes characterizing the gauge bosons to which they couple and assume that $\#_B$ contacts mediate gauge interactions. The question is what kind of space-time sheets can be connected by $\#_B$ contacts.

1. The first working hypothesis that comes in mind is that the p-adic primes associated with the two space-time sheets connected by $\#_B$ contact must be identical. This would require that particle is many-sheeted structure with no other than gravitational interactions between various sheets. The problem of the multi-sheeted option is that the characterization of events like electron-positron annihilation to a weak boson looks rather clumsy.

2. If the notion of multi-p p-adicity is accepted, space-time sheets are characterized by integers and the largest prime dividing the integer might characterize the mass of the particle. In this case a common prime factor p for the integers characterizing the two space-time sheets could

be enough for the possibility of $\#_B$ contact and this contact would be characterized by this prime. If no common prime factors exist, only $\#$ contacts could connect the space-time sheets. This option conforms with the number theoretical vision. This option would predict that the transition to large $\hbar$ phase occurs simultaneously for all interactions.

9.2.4 Physically interesting p-adic length scales in condensed matter systems

The following table lists the p-adic length scales L_p. p near prime power of 2, which might be interesting as far as condensed matter is considered. It must be emphasized that the definition of length scale is bound to contain some unkown numerical factor and numbers should not be taken too literally.

k	127	131	137	139	149
L_p/m	$2.04E-12$	$8.19E-12$	$6.53E-11$	$1.31E-10$	$4.18E-9$
k	151	157	163	167	173
L_p/m	$8.33E-9$	$6.69E-8$	$5.34E-7$	$2.13E-6$	$1.71E-5$
k	179	181	191	193	
L_p/m	$1.37E-4$	$2.74E-4$	$8.85E-3$	$1.75E-2$	

Table 1. p-Adic length scales $L_p = 2^{k-127}L_{127}$, $p \simeq 2^k$, $L_{127} \equiv \frac{\pi\sqrt{5+Y}}{m_e}$, $Y = .0317$, k prime, possibly relevant to condensed matter physics.

Notice that the length scales $L(137)$ and $L(139)$ are quite near to the typical atomic length scale and this suggests that the lattice structures of solid state physics might be understood in terms of structures formed by gluing together p-adic cubes with size $L(137)$ by join along boundaries contacts.

9.3 Hydrodynamical and thermodynamical hierarchies

The existence of p-adic length scale hierarchy suggests a new approach to hydrodynamics. There is hydrodynamic flow associated with each condensate level h. The particles at level are condensate blocks of the previous level having typically size $L_{upper}(k)$ larger than $L(k)$ and hydrodynamic approximation fails at this length scale. It will be found that the phenomenon of sono-luminescence can be interpreted as evidence for the hydrodynamical hierarchy. The masses of these particles are just the masses of condensate blocks. The energy dissipation at given level takes place via the collisions of condensate blocks and one can get an order of magnitude estimate for the viscosity $\nu(k)$ and other transport coefficients at level k using kinetic gas theory for condensate blocks.

There must exist also energy transfer mechanism transporting energy and angular momentum to higher condensate levels and eventually to atomic condensation level and this mechanism should be work at length scales $L < L_{upper}(k)$, at which hydrodynamic approximation fails at level k. The mechanism to be proposed is completely analogous with the penetration of magnetic fields into super conductor and should be possible in sufficiently long length scales: the convective zone of Sun provides a possible realization of the mechanism. The hierarchy means quite rich possibilities for flows: the fluid need not be in same phase at all levels, the temperatures (temperature distributions) at different levels need not be identical. The character of the flow need not be same at different levels (turbulent/non-turbulent, rotational/irrotational, etc).

9.3.1 Dissipation by the collisions of condensate blocks

Collisions of condensate blocks at level k provide one possible dissipation mechanism and just as in molecular case the mechanism can be characterized viscosity coefficient. One can generalize kinetic gas theory estimate for the kinetic viscosity at level k in straightforward manner.

$$\begin{aligned}
\nu(k) &= \lambda(k)\beta \ , \\
\lambda(k) &= \frac{1}{N(block)\sigma(k)} \ , \\
\sigma(k) &\sim 4\pi L^2_{upper}(k) \ , \\
N(block) &\sim \frac{1}{L_{upper}(k)^3} \ , \\
\beta &\sim \beta_{th} \sim \sqrt{\frac{T(k)}{M(block)}} \ , \\
M(block) &\sim N(nucleus)ML^3_{upper}(k) \ ,
\end{aligned} \tag{9.3.1}$$

where the average velocity β is replaced with thermal velocity to obtain order of magnitude estimate. More explicitly,

$$\begin{aligned}
\nu(k) &= \sqrt{\frac{L(139)}{L_{upper}(k)}}\nu(139) \ , \\
\nu(139) &= \frac{1}{4\pi N(nucleus,139)}\sqrt{\frac{T}{M}}L(139) \ .
\end{aligned} \tag{9.3.2}$$

The order of magnitude $\nu(139)$ is roughly the same as the order of magnitude for ordinary viscosity at room temperatures determined by the size of the atom. From formula it is clear that $\nu(k)$ scales as $\sqrt{1/L(k)}$. This means that the importance of the collisions of the condensate blocks as dissipation mechanism decreases rapidly in long p-adic length scales. This does not necessarily mean the absence of dissipation since mechanisms of energy transfer between condensate levels must exist. Reynolds number criterion implies that the flow is in sufficiently long p-adic length scales always turbulent.

The collisions of the condensate block need not be elastic and the collision at level k in general involves simultaneous collisions at levels $k_1 < k$ up to atomic condensate levels so that it leads to energy dissipation at all condensate levels $k_1 \geq k$. An interesting challenge is the description of shock waves in this picture. A shock wave at level k corresponds to 'traffic jam' in shock front involving the collisions of the condensate blocks at level k. This in turn is expected to lead to shock waves propagating inside condensate blocks at level $k_{prev} < k$ and so on. Shock wave hierarchy ends up to the atomic condensate level $k = 131$.

9.3.2 Energy transfer between different condensate levels in turbulent flow

The model for the generation of hydrodynamic turbulence is based on the idea that hydrodynamic vortices correspond to topological field quanta, that is cylindrical 3-surfaces with finite radius carrying Kähler electric and magnetic fields. The completely new feature is the presence of ordinary or Z^0 magnetic fields determining the size of the hydrodynamic vortices. Even the Reynolds number criterion could be formulated in terms of these fields. The naive expectation would be that the vortices could be characterized as either em or Z^0 vortices. This is actually not the case since induced gauge field concept implies that em fields are accompanied by Z^0 fields and vice versa for extremals of Kähler action. The study of the imbeddings for Kähler electric and magnetic fields led to the conclusion that vorticities are specified by two frequency type parameters ω_i and by two integers n_i related to the space-time dependence of the phases of the two complex CP_2 coordinates plus and integer m: the vortices with different value of fractal quantum number m were related by a power of a discrete scaling transformation to each other. The decay of vortices to smaller vortices leading to a cascade was suggested to be the basic mechanism for the generation of turbulence. The model led to estimates for Reynolds number for the transition to turbulence in channel flow and for the exponent Δ appearing in the Fourier transform $T(k) \propto k^{\Delta}$ of the kinetic energy density of the flow. In recent context the model for the decay of vortices can be regarded as a kinetic model for the vortices of level k appearing as particles at the level k_{next}.

p-Adic picture of condensed matter suggests a considerable generalization of this model. Of course, a lot of work is needed to construct a detailed quantitative model but some general features of the model are evident.

1. The proposed cascade mechanism as such works at single condensate level for vortices having size larger than $L_{upper}(k)$: below this length scale the hydrodynamic approximation fails. The lower bound for the vortex size was assumed to be some scale not much above atomic size so that description might apply as such at condensate level $k = k_Z$.

2. The idea already due to Kolmogorov [18] is that the generation of turbulence involves the interaction between many length scales: in turbulent situation constant power ϵ is feeded to the system of size l and the rate of the energy flow between any subsequent levels in the hierarchy of length scales is constant and dissipation becomes important at the highest levels of the hierarchy, which correspond to the shortest length scales $L_0 \sim l/Re^{3/4}$ related by to the length scale of the entire flow. This idea leads directly to important dimensional estimates making possible to deduce the form of the velocity correlation function in length scales at which dissipation is not important. It is perhaps worth of recalling that the turbulence model gives slightly different value for the exponent Δ associated with the energy density.

This interaction between different scales corresponds to the decay of vortices to smaller vortices with scaled down values of the vorticity and critical radius: this picture probably still applies at single condensate level down to the vortex radii of order $L_{upper}(k)$, where the hydrodynamical approximation fails. If the size of the block is much larger than the size λ_0 of eddies important for energy dissipation (having Reynolds number of order one) collisions of the condensate blocks at level k cannot take care of energy dissipation. Using the standard order of magnitude estimate for λ_0 [18] the criterion for dissipation via collisions to be possible reads as

$$\begin{aligned} L_{upper}(k) &< \lambda_0(k) \ , \\ \lambda_0(k) &= \frac{l}{Re^{3/4}(k)} = (\frac{L(139)}{L(k)})^{3/8}\lambda_0(139) \ . \end{aligned} \tag{9.3.3}$$

$\lambda_0(139)$ is roughly of same order of magnitude as the estimate based on molecular viscosity and it is clear that in long p-adic length scales the condition cannot be met. One has $\lambda_0(k) \sim 2^{-(k-139)/2}10^{-3}l$ (assuming for definiteness $R \sim 10^4$ in turbulent flow) and L is bound to be smaller than $L_{upper}(k)$ unless l is very large as compared with $L(k)$. Since constant energy dissipation is taking place there must exist some mechanism of energy and angular momentum transfer between condensate levels and this mechanism is expected to be at work below the length scales below, at which hydrodynamic approximation works.

The structure of the topological condensate suggests much more general realization for the idea about interacting length scales: besides vortices related by powers of discrete scaling transformation also different levels k of topological condensate correspond to the levels of the hierarchy. The external source of energy and angular momentum is at some level $k >> 131$ (a concrete example is provided by channel flow) and the flow of energy occurs first from large to smaller eddies at level k in accordance with the standard picture and continues to the higher level k_{prev} via some energy transfer mechanism and repeats itself at level k_{prev}.

If condensate has hierarchical structure the flow occurs in good approximation only between two subsequent condensate levels. The previous work suggests that the mechanism is based on generation of vortices at level k_{cr} and that ordinary and Z^0 magnetic fields might play key role in the mechanism. The length scale $L(k_Z)$ means clearly a borderline in the generation of turbulence. For levels with $k > k_Z$ the electro-weak gauge fields are of Z^0 and em type and there is no motion in atomic length scales. At level $k = k_Z$ the motion is transferred to atomic level since nuclei feed their Z^0 charges directly at $k = k_Z$ level. At levels $k > k_Z$ ordinary magnetic vortices should take the role of Z^0 and em vortices. $k = k_Z$ level is special in the sense that the entire fluid motion at length scales $k > k_Z$ is seen in the flow pattern of Z^0 # throats at this level. It should be also noticed that p-adic quantized version of hydrodynamics (whatever it might mean!) is in principle involved at level $k = k_Z$.

p-Adic TGD suggests a detailed mechanisms for the flow of energy, angular momentum and magnetic flux from level k to level k_{prev}.

1. In the simplified description there are two kind of lumps of rotational energy at level k. The rigid body rotation of the condensate blocks of level k_{prev} condensed on level k and the vortices formed by the condensate blocks, each block rotating according to the law $\beta(\rho) = K/\rho$, where K is vorticity (essentially the total angular momentum) and ρ the distance from the vortex axis. The basic energy transfer process must take place at the level of single condensate block of size not very much larger than $L(k)$ produced as the end result of the cascade process. The block is in rigid body rotation and the destruction of the super fluidity by rigid body rotation of the vessel containing super fluid suggests the mechanism. When the approximately constant magnetic field created by vortex motion at level k is sufficiently strong at the position of the block it penetrates to the level k_{prev}.

2. According to the previous proposal this mechanism is following. For $\Omega < \Omega_{crit}$ the Z^0 and/or em magnetic fields created by the rotation of the # throats on the boundary of the block at level k are those of an extended magnetic dipole: inside the vortex the field lines run in the direction of vortex. For $\Omega = \Omega_{cr}$ something very peculiar happens: the magnetic field created by the rotational flow penetrates to the higher condensate level via # contacts formed at the upper and lower end of the vortex, which behave as magnetic dipoles at levels k and k_{prev}. This means that the magnetic flux runs from the level k to k_{prev} and vice versa at the opposite ends of the vortex and the conservation of magnetic flux implies that average magnetic fluxes are identical on the two levels. The field inside the vortex cylinder disappears at level k and only the field lines of the return flux outside the vortex are preserved. Since magnetic flux and angular momentum are closely related this requires that the rotating block is set in rigid body motion with angular momentum opposite to the angular momentum of the entire block in vortex motion. There blocks in vortex would rotate in opposite direction as compared to the vortex and angular momentum is indeed transferred from level k to k_{prev}.

3. The analogy with super conduticity/super fluidity suggests that the process cannot take place for too small value of magnetic field/rotational velocity at level k. Since the vorticity can be written as $K = \beta\rho$ the condition $K > K_{cr}$ is analogous (but not equivalent) with the Reynolds number criterion $ud > Re_{cr}\nu$. The criterion $K > K_{cr}$ translates into the condition $B > B_{cr}$. The physical content of the condition is probably the following. In the absence of the vortices liquid at level k_{prev} tends to form large join along boundaries blocks: for dense liquids only very few large join along boundaries block are present whereas for the gases there are only few join along boundaries bonds present. The formation of vortices splits join along boundaries bonds at the boundaries of the vortices and some energy $E_{join}(k)$ must be taken from the flow to split single join along boundaries bonds if present.

4. The criterion for the penetration of magnetic field must be local in the sense that only the energetics of a single join along boundaries bond is involved. A natural guess is that the magnetic energy contained in the volume of the bond is larger than the binding energy of the bond: $E_B > E(join)$. Since B is proportional to the vorticity K, the criterion gives critical vorticity K_{cr}. The dependence of $E_B \propto b/L^3(k)$ with b integer implies that the dependence of E_B and $E(join)$ on $L(k)$ is same and K_{cr} does not depend on condensate level. In this case $K_{cr} < K_{Re} \equiv ud = Re \cdot \nu$ holds true unless b is very large integer of order 10^{39} and criterion is identically satisfied for turbulent flow. If b is rational number with small denominator, one has effectively $E_{join} = b/L(k)$ for the real counter part of the energy and one obtains $K_{cr} \propto L(k)$, which is probably the correct alternative. In sufficiently long length scales (perhaps all physically interesting length scales) one has $K_{cr} > K_{Re} \equiv ud = Re \cdot \nu$, which implies a lower bound for the size of the vortices of the turbulent flow in the range $K_{Re} < K < K_{cr}$. This means that for liquids the energy transfer mechanism comes into play for very large Reynolds numbers only and should manifest itself in long (perhaps astrophysical) length scales only. For gases the situation is different since the criterion makes sense only provided the density of the join along boundaries bonds is large (incompressible flow) and in ordinary gas flow the criterion is not needed.

5. The disappearance of the vortices at the highest condensation levels can be regarded as resulting from the annihilation of magnetic monopoles associated with the upper and lower ends of the vortices. One possibility is self destruction, when the mopoles and upper and lower ends annihilate. Second possibility is the annihilation of two different vortices. At lower level the process implies the recombination of the magnetic field lines at positions of monopoles.

6. A possible astrophysical example of the proposed energy transfer process is provided by the convective zone of the Sun, where the presence of the magnetized vortex like structures of all sizes is directly visible. Only observational limitations set lower bound for the radii of the vortices. The ends of the magnetic dipoles are visible and also the recombination of field lines of magnetic fields (this can be regarded as annihilation of magnetic monopoles!) occurs frequently [19].

7. The assumption that the flow consists of vortices carrying almost constant magnetic fields, is not necessary. What is important is the behavior of the magnetic field created by the main flow in the region of single condensate block participating in the flow. If the magnetic field does not vary much in the region of the block, the penetration can take place via the same mechanism into the block. A possible test for the proposed scenario is the flow in the external magnetic field at level $k < k_Z$: for some critical value of field (probably rather high) the flow should become turbulent. One can also consider creating external Z^0 magnetic fields in the interior of, say rotating cylinder, and finding whether they affect the properties of the non-turbulent flow inside the cylinder.

9.3.3 The magnetic fields associated with vortex and rigid body flows

The magnetic field associated with vortex flow $\beta = K/\rho$ (ρ is the distance from the axis of vortex) is given by

$$\begin{aligned} B_C &= A_C K ln(\frac{\rho}{\rho_0}),\ C = em, Z \ , \\ A_C &= \frac{g_C q_C}{\sqrt{\epsilon_C(k)}} n(nucleus) \ , \\ Q_Z &= (A-Z)Q_Z(n) \quad Q_{em} = Z \ , \end{aligned} \tag{9.3.4}$$

where ρ_0 is some finite radius at which the flow ceases to be vortex flow and is expected to change to rigid body flow (single condensate block rotates as rigid body). ϵ_C will be assumed to satisfy the simple scaling law $\epsilon_C(k) \propto L(k)^6$. The field is in good approximation constant in region of vortex so that critical field condition leading to the penetration of the field to higher level occurs almost simultaneously in vortex but proceeds from boundary to interior.

The magnetic field associated with rigid body flow $\beta = \Omega\rho$ is given by

$$B_C = A_C \Omega \frac{\rho^2}{2} \ , \tag{9.3.5}$$

where the parameter A_C defined in previous formula. At critical value of vortex magnetic field condensate blocks rotating in vortex flow like rigid bodies begin to rotate counterclockwise with regard to the vortex flow and the angular rotation velocity is such that

i) the magnetic fluxes created by rigid body flow and vortex flow cancel each other or

ii) angular momentum in the region of condensate block is transferred to higher condensate level.

Denoting the radius of a rigidly rotating block in the vortex flow by ρ_{rig} and by ρ_1 the distance of the block from the axis of vortex flow one obtains for the value of the angular velocity parameter Ω

$$\begin{aligned} \Omega &\simeq \frac{2K}{\rho_{rig}^2} X \ , \\ X &= ln(\rho_1/rho_0) \ . \end{aligned} \tag{9.3.6}$$

An almost identical condition

$$\Omega \simeq \frac{2K}{\rho_{rig}^2} \ , \tag{9.3.7}$$

is obtained if one requires that entire angular momentum of the rigidly rotating block in vortex flow is transferred to higher condensate level so that the two models are equivalent with logarithmic accuracy.

9.3.4 Criticality condition

Consider next the criticality condition for vortex magnetic field or equivalently vorticity $K \sim ud$ to derive the analog of Reynolds number criterion $ud > Re \cdot \nu$ for single vortex. The condition states that magnetic field energy in the volume of join along boundaries contact is larger than join along boundaries bonding energy E_{join}.

$$E_B(bond) \quad > \quad E_{join} \ , \tag{9.3.8}$$

to derive more quantitative criterion one must make some additional assumptions. The volume of join along boundaries bond at level k is assumed to be of order $L^3(k)$ since bond should consist of few p-adic cubes glued together along their walls. E_{join} is of form $bp^{3/2}$ p-adically. If b is integer the real counterpart of the energy behaves as $1/L(k)^3$ and if b is rational number with small denominator the real counterpart of energy behaves as $a/L(k)$, $a < 1$.

The following argument suggests that b must be a genuine rational number. The radius ρ_{cr} of the condensate block determined from the imbeddability requirement of the magnetic field as induced gauge field must be equal to the radius $L_{upper}(k) \propto L(k)$ of the block determined by the stability against topological evaporation. This is possible only provided $\rho_{cr} \propto L(k)$ holds true. It will be later found that the dependence of ρ_{cr} on p-adic length scales is as follows

$$\rho_{cr} \quad \propto \quad \frac{\epsilon_C^{1/4}}{K^{1/2}} \propto \frac{L(k)^{3/2}}{b^{1/2}} \ . \tag{9.3.9}$$

For integer b this gives $\rho_{cr} \propto L(k)^{3/2}$ so that the critical radius is larger than $L_{upper}(k)$ at large length scales. If b is rational number one indeed has $\rho_{cr} \propto L(k)$ and ρ_{cr}. In this case both K_{cr} and ρ_{cr} are proportional to $L(k)$ as suggested by fractality.

If Z^0 magnetic fields dominate at levels $k > k_Z$ levels the condition reduces for $E_{join} = b/L(k)$ to the form

$$\begin{aligned} K \quad &> \quad K_{cr}(k) \ , \\ K_{cr}(Z,k) \quad &= \quad K_Z L(k) \ , \\ K_Z \quad &= \quad b^{1/2} 2^{-41} \frac{\sqrt{\epsilon_Z(k_Z)}}{g_Z(A-Z)} B \ , \\ B \quad &= \quad \frac{\sqrt{2}}{N(nucleus,139)} \frac{1}{ln(\frac{\rho_1}{\rho_0})} \ , \end{aligned} \tag{9.3.10}$$

which gives $K_{cr}(k) \sim \sqrt{b} \cdot 5 \cdot 10^{-2} L(k)$ for $\epsilon_Z(k_Z) \sim 10^{24}$. At condensate levels $k < k_Z$, where ordinary magnetic fields are in question, the condition reads

$$\begin{aligned} K_{cr}(em,k) \quad &= \quad K_{em} L(k) \ , \\ K_{em} \quad &= \quad b^{1/2} 2^{12} \frac{\sqrt{\epsilon_Z(131)}}{Ze} B L(k) \ . \end{aligned} \tag{9.3.11}$$

B is given by the previous formula. This gives $K_{cr}(k) \sim \sqrt{b} 10^4 L(k)$ $(b < 1)$. The value of $K_{Re} = Re \cdot \nu$ is of order 10^{-10} m for typical values $Re = 10^4$ and $\nu \sim 10^{-14}$ m so that K_{cr} is always larger than K_{Re} unless b is very small. This means that below the length scale $L(k_Z)$ the proposed energy transfer mechanism comes into play at very large Reynolds numbers of order

$$Re \sim \frac{K_{cr}(em,k)}{\nu} \sim 10^5 b^{1/2}\frac{L(k)}{L(107)} \ , \tag{9.3.12}$$

whereas for gas phase the situation is different. When $L_{upper}(k)$ is much larger than the size $L_0 \sim l/Re^{3/4}$ for dissipative eddies with $Re \sim 1$ and $K < K_{cr}$ so that the collisions of the join along boundaries blocks nor the proposed energy transfer mechanism cannot take care of the dissipation and some other mechanisms of dissipation must be active: one possibility is heating leading to the splitting of the join along boundaries bonds.

The assumption that the mechanism is at work in the convective zone of Sun gives information on the value value of the parameter b. Assuming $\beta \sim 10^{-5}$ and $L_{upper}(k) \sim 10^7\ m$ one obtains from $K \sim L_{upper}\beta \sim 10^2\ m$. The criterion gives $b^{1/2}L(k) \leq 2\cdot 10^2\ m$. An estimate for b is obtained using the relation $L_{upper}(k) \leq AL(k)$,$A \sim 10^2$: for $L_{upper} \sim 10^2 L(k)$ one obtains $b \sim 4\cdot 10^{-6}$. $L(k)$ and therefore b can be estimated if one has some idea about the value of B_Z: this together with estimate for K gives grasp on the value of $\epsilon_Z(k)$ and scaling law gives estimate for $L(k)$.

The condition implies that typical angular velocities Ω for rigid body rotation behave as $\Omega(k) \propto 1/L(k)$ and that average rotation velocities $\beta(k)$ are identical for all condensate levels. This implies that the frequency spectrum associated with the flow is superposition of form

$$F_{tot}(\omega) = \sum_{k\ prime} a_k F(\omega\frac{L(k_0)}{L(k)}) \ , \tag{9.3.13}$$

and the general form of the spectrum in principle provides a test for p-adic length scale hypothesis. $\beta(k) = constant$ suggests that spatial correlation function for velocity is constant and its Fourier spectrum corresponds to white noise spectrum.

For completeness it is useful to give the values of K_{cr} also for the $E_{join} = bL_0^2/L^3(k)$ ($L_0 \sim 10^4\sqrt{G}$ being the fundamental p-adic length scale) case.

$$K_{cr}(C) = k_C L_0 \ . \tag{9.3.14}$$

The only difference with respect to previous formulas is the replacement $L(k) \rightarrow L_0$. For small values of b the condition is automatically satisfied for reasonable values of K and the sizes of vortices should have no lower bound above atomic length scales: this is not in accordance with the estimate $\lambda_0 \sim l/Re^{3/4}$ of Kolmogorov theory.

9.3.5 Sono-luminescence, Z^0 plasma waves, and hydrodynamic hierarchy

Sono-luminescence [24] is a peculiar phenomenon, which might provide an application for the hydrodynamical hierarchy. The radiation pressure of a resonant sound field in a liquid can trap a small gas bubble at a velocity node. At a sufficiently high sound intensity the pulsations of the bubble are large enough to prevent its contents from dissolving in the surrounding liquid. For an air bubble in water, a still further increase in intensity causes the phenomenon of sono-luminescence above certain threshold for the sound intensity. What happens is that the minimum and maximum radii of the bubble decrease at the threshold and picosecond flash of broad band light extending well into ultraviolet is emitted. Rather remarkably, the emitted frequencies are emitted simultaneously during very short time shorter than 50 picoseconds, which suggests that the mechanism involves formation of coherent states of photons. The transition is very sensitive to external parameters such as temperature and sound field amplitude.

A plausible explanation for the sono-luminescence is in terms of the heating caused by shock waves launched from the boundary of the adiabatically contracting bubble [24]. The temperature jump across a strong shock is proportional to the square of Mach number and increases with decreasing bubble radius. After the reflection from the minimum radius $R_s(min)$ the outgoing shock moves into the gas previously heated by the incoming shock and the increase of the temperature after focusing is approximately given by $T/T_0 = M^4$, where M is Mach number at focusing and $T_0 \sim 300\ K$ is the temperature of the ambient liquid. The observed spectrum of sono-luminescence is explained as a brehmstrahlung radiation emitted by plasma at minimum temperature $T \sim 10^5\ K$. There is a fascinating possibility that sono-luminescence relates directly to the classical Z^0 force: this point is discussed in [F8].

Even standard model reproduces nicely the time development of the bubble and sono-luminescence spectrum and explains sensitivity to the external parameters [24]. The problem is to understand how the length scales are generated and explain the jump-wise transition to sono-luminescence and the decrease of the bubble radius at sono-luminescence: ordinary hydrodynamics predicts continuous increase of the bubble radius. The length scales are the ambient radius R_0 (radius of the bubble, when gas is in pressure of 1 atm) and the minimum radius $R_s(min)$ of the shock wave determining the temperature reached in shock wave heating. Zero radius is certainly not reached since shock front is susceptible to instabilities.

Since p-adic length scale hypothesis introduces a hierarchy of hydrodynamics with each hydrodynamics characterized by a p-adic cutoff length scale there are good hopes of achieving a better understanding of these length scales in TGD. The change in bubble size in turn could be understood as a change in the 'primary' condensation level of the bubble.

1. The bubble of air is characterized by its primary condensation level k. The minimum size of the bubble at level k must be larger than the p-adic length scale $L(k)$. This suggests that the transition to photo-luminesence corresponds to the change in the primary condensation level of the air bubble. In the absence of photo-luminesence the level can be assumed to be $k = 163$ with $L(163) \sim .76\ \mu m$ in accordance with the fact that the minimum bubble radius is above $L(163)$. After the transition the primary condensation level of the air bubble is $k = 157$ with $L(157) \sim .07\ \mu m$. In the transition the minimum radius of the bubble decreases below $L(163)$ but should not decrease below $L(157)$: this hypothesis is consistent with the experimental data [24].

2. The particles of hydrodynamics at level k have minimum size $L(k_{prev})$. For $k = 163$ one has $k_{prev} = 157$ and for $k = 157$ $k_{prev} = 151$ with $L(151) \sim 11.8\ nm$. It is natural to assume that the minimum size of the particle at level k gives also the minimum radius for the spherical shock wave since hydrodynamic approximation fails below this length scale. This means that the minimum radius of the shock wave decreases from $R_s(min, 163) = L(157)$ to $R_s(min, 157) = L(151)$ in the transition to sono-luminescence. The resulting minimum radius is 11 nm and much smaller than the radius .1 $\mu\ m$ needed to explain the observed radiation if it is emitted by plasma.

A quantitative estimate goes along lines described in [24].

1. The radius of the spherical shock is given by

$$R_s = At^{\alpha} , \tag{9.3.15}$$

where t is the time to the moment of focusing and α depends on the equation of state (for water one has $\alpha \sim .7$).

2. The collapse rate of the adiabatically compressing bubble obeys

$$\frac{dR}{dt} = c_0(\frac{2}{3\gamma}\frac{\rho_0}{\rho}(\frac{R_m}{R_0})^3)^{1/2} , \tag{9.3.16}$$

where c_0 is the sound velocity in gas, γ is the heat capacity ratio and ρ_0/ρ is the ratio of densities of the ambient gas and the liquid.

3. Assuming that the shock is moving with velocity c_0 of sound in gas, when the radius of the bubble is equal to the ambient radius R_0 one obtains from previous equations for the Mach number M and for the radius of the shock wave

$$\begin{aligned} M &= \frac{\frac{dR_s}{dt}}{c_0} = (t_0/t)^{\alpha-1} \ , \\ R_s &= R_0(t/t_0)^{\alpha} \ , \\ t_0 &= \frac{\alpha R_0}{c_0} \ . \end{aligned} \tag{9.3.17}$$

where t_0 is the time that elapses between the moment, when the bubble radius is R_0 and the instant, when the shock would focus to zero radius in the ideal case. For $R_0 = L(167)$ (order of magnitude is this) and for $R_s(min) = L(151)$ one obtains $R_0/R_s(min) = 256$ and $M \simeq 10.8$ at the minimum shock radius.

4. The increase of the temperature immediately after the focusing is approximately given by

$$\frac{T}{T_0} \simeq M^4 = (\frac{R_0}{R_s})^{\frac{4(1-\alpha)}{\alpha}} \simeq 1.3 \cdot 10^4 \ . \tag{9.3.18}$$

For $T_0 = 300\ K$ this gives $T \simeq 4 \cdot 10^6\ K$: the temperature is far below the temperature needed for fusion.

In principle the further increase of the temperature can lead to further transitions. The next transition would correspond to the transition $k = 157 \rightarrow k = 151$ with the minimum size of particle changing as $L(k_{prev}) \rightarrow L(149)$. The next transition corresponds to the transition to $k = 149$ and $L(k_{prev}) \rightarrow L(141)$. The values of the temperatures reached depend on the ratio of the ambient size R_0 of the bubble and the minimum radius of the shock wave. The fact that R_0 is expected to be of the order of $L(k_{next})$ suggests that the temperatures achieved are not sufficiently high for nuclear fusion to take place.

9.3.6 p-Adic length scale hypothesis, hydrodynamic turbulence, and distribution of primes

The work of Indian meteorologists Mary Selvam [31] related to the turbulent atmospheric flows provides additional very interesting insight to p-adic length scale hypothesis and suggests that n-ary p-adic length scales corresponding to very large values of n are realized in hydrodynamical turbulence, and that hydrodynamical vortices could be regarded as elementary particle like objects on the space-time sheets at which they are condensed topologically.

1. The distribution of vortex sizes is same as distribution of primes

Selvam studies the distribution for the ratio $z = R/r$ of large vortex radius R to smallest vortex radius r, and finds that this distribution is the same as the distribution of primes in region of rather small primes. This could be understood if vortex radii are prime multiples of r

$$R = kr \ , \ k \ \text{prime} \ ,$$

and if each prime appears with the same probability. This assumption can be actually loosened: one can also interpret r as the p-adic length scale associated with minimum size vortex interpreted as space-time sheet. Selvam also argues that vortex dynamics has quantal features and that vortices could in some aspects be regarded as quantum objects.

2. p-Adic length scale hypothesis from elementary particle blackhole analogy

One can try to understand results on basis of the p-adic length scale hypothesis $p \simeq 2^{k^m}$, k prime, m positive integer.

1. At quantum level p-Adic length scale hypothesis follows from the generalization of Hawking-Bekenstein law for the radius of elementary particle horizon defined as the surface at which the Euclidian signature of the induced metric of the space-time sheet containing topologically condensed particle changes to Minkowskian signature of the metric in regions faraway from particle. Ordinary elementary particles corresponds to CP_2 type extremals condensed on larger space-time sheet with size of order $L_p = \sqrt{p}l$, $l \simeq 10^4$ Planck lengths. Generalized Hawking-Bekenstein law implies that the p-adic entropy of elementary particle characterized by p-adic prime p is proportional to the surface area of the elementary particle horizon. Since entropy is proportional to $log(p)$, the radius r of the elementary particle horizon satisfies $r^2 \propto log(p)$.

2. The idea is to require that the radius of the elementary particle horizon itself is m-ary p-adic length scale. For $p \simeq 2^{k^m}$ this is indeed the case if generalized Hawking-Bekenstein law holds and one has

$$r = \sqrt{k^m} \times l \ , \ \ k \ \text{prime} \ .$$

For $m = 2$ one has

$$r = kl \ .$$

This is the same law as holds true for the vortex radii except that l corresponds to Planck length scale rather than macroscopic size of the minimal vortex. Therefore a generalization replacing l with the size of the minimal vortex is needed.

3. Does generalization of Hawking-Bekenstein hold true also for vortices regarded as elementary particles?

One must be able to generalize the notion of elementary particle by allowing also larger space-time surfaces than CP_2 extremals as models of particle and to assume that the metric of the space-time sheet at which particle is condensed has Euclidian metric signature inside the particle region, now inside the region covered by vortex.

1. A more general situation allowed by the p-adic length scale hypothesis corresponds to vortices topologically condensed at space-time sheets with size of order of n-ary p-adic length scale

$$L_p(n) = p^{n/2} L_p \ , \quad p \simeq 2^{k^m} \ .$$

In this case generalized Hawking-Bekenstein law implies that the radius of the elementary particle horizon is given by

$$r = k^m \times L \ , \quad L = \frac{n}{2} \times l \ .$$

$m = 2$ applies in the situation studied by Mary Selvam. Also the values of k can be small in this case. What is important is that the fundamental p-adic length scale l has been effectively replaced by $L = nl/2$. This is in accordance with the idea of fractality.

2. The requirement that r is also now p-adic length scale would imply that the length scale $k^m \times \frac{n}{2} \times l$ is p-adic length scale. This does not make sense except possibly as an approximation. p-Adic length scale hypothesis however suggests that the new fundamental length scale L itself is some n-ary p-adic length scale. The simplest possibility is that $n/2$ is large prime p_1 so that one has

$$n = 2p_1 \ , \quad r = p_1 l \ .$$

$L = p_1 l$ and clearly corresponds to the secondary p-adic length scale associated with p_1 satisfying itself p-adic length scale hypothesis $p_1 \simeq 2^{k_1^{m_1}}$. This assumption provides the scenario with strong predictive power since the number of the secondary p-adic length scales is not very high.

3. Does atmospheric turbulence provide a fractally scaled version of elementary particle physics?

In the length scale range between .1 meters and Earth circumference the following p-adic primes $p_1 = n/2$ are possible:

$$p_1 \simeq 2^{k_1^{m^1}} ,$$
$$k_1^{m^1} = 101, 103, 107, 109, 113, 11^2 = 121, 5^3 = 125, 127 .$$

There would be only 8 minimal vortex sizes in this length scale range, which is very strong and testable prediction. What is fascinating is that these secondary length scales correspond to the p-adic primes associated with quarks, atomic nuclei, and leptons so that the physics of vortices in atmosphere might in some sense be regarded as a fractal copy of elementary particle and nuclear physics! Note that the length scale $L(n,k)$ giving the size of the space-time sheet at which vortex is condensed, is given by

$$L(n,k^2) \simeq 2^{2^{k_1-1}\times k^2} ,$$

and is completely super-astronomical already for small values of k.

4. Does the space-time region at which vortex is condensed have Euclidian metric signature?
What this model implies is that the induced metric at the space-time sheet at which vortex is condensed, should have Euclidian signature inside radius r. TGD indeed allows huge number of vacuum extremals with Euclidian signature: signature becomes Euclidian if the dependence of the CP_2 coordinates on M^4_+ coordinates is too fast. The simplest situation is encountered when the angle coordinate ϕ associated with CP_2 geodesic circle satisfies the condition $\phi = \omega t$, $\omega \geq 1/R$, where $2\pi R$ is the length of the CP_2 geodesic circle and t is Minkowski time coordinate. From this it is clear that time gradients must be typically larger than $1/R$, where R is CP_2 size, for Euclidization to happen. Also absolute minimization of the Kähler action is consistent with the formation of Euclidian regions. Thus field equations support the idea that space-time sheets can contain Euclidian regions of even macroscopic size. Inside the region covered by the vortex light would not propagate at all and Euclidian regions would be in some respects analogous to black holes. Vortex space-time sheets itself would obey good old Minkowskian physics.

5. Connection with dark matter hierarchy

The remarks above were written much before the realization that TGD "predicts" a dark matter hierarchy with the values of Planck constant $\hbar(n) = \lambda^n \hbar(1)$, $\lambda = n/v_0 \simeq n \times 2^{11}$, $n = 1, 2, ...$ λ is predicted to be integer and also sub-harmonics could be allowed. This means that also the scaled up variants of the p-adic length scale hierarchy appears. For the preferred value of $\lambda \simeq 2^{11}$ precise predictions of preferred time and length scales corresponding to small values of p-adic primes follow. In particular, the TGD based interpretation [D6, J6] of Nottale's proposal [30] for the quantization of planetary orbits in terms of a gigantic value of gravitational Planck constant means that huge scalings are possible so that quantum effects are present in astrophysical and even cosmological length scales. The proposed picture might be consistent with this view since also $\hbar(1)$ is predicted to have a discrete spectrum varying by a factor 2.

9.3.7 Thermodynamical hierarchy

p-Adic TGD suggests the replacement of the ordinary thermodynamic description of the condensed matter with a hierarchy of p-adic thermodynamics, one for each p-adic level. Above the p-adic length scale $L(k)$ this thermodynamics is ordinary real thermodynamics. Below the length scale $L(k)$ p-adic thermodynamics is probably needed (assuming that thermodynamic description makes sense at all).

The general formulation might look like follows.

1. There is thermodynamics associated with each p-adic level of the condensate (in analogy with p-adic conformal field theory limit of TGD). The order parameters for ordinary condensed matter are particle densities at each level of the condensate. Besides this block densities describing the density of $p_1 < p_2$-adic blocks of matter at level $p_2 > p_1$ are present. Join along boundaries gives rise to bound state formation and corresponding densities can also be present. In spin systems also block densities for spin are present and can be identified as densities for magnetic domains with preferred sizes given by the p-adic cutoff length scales $L(k)$ given by prime powers of two.

2. The basic variational principle is the absolute minimization of free energy subject to certain constraints such as the constraint fixing total pressure: absolute minimization is in accordance with the absolute minimization of Kähler action and implies the so called Maxwell rule for phase transitions. Free energy contains three parts: the 'ordinary' free energy F_{ord}, TGD based contribution to free energy and constraint term

$$F = F_{TGD} + F_{ord} + F_{constraint} \ . \tag{9.3.19}$$

The 'ordinary' free energy F_{ord} at level p is sum of single particle free energies for p_1-adic blocks with $p_1 < p$ and the block-block interaction energies plus higher order interaction energies

$$F_{ord} = \sum_i F_i + \sum_{ij} F_{ij} + ... \ . \tag{9.3.20}$$

The index $p_1 \simeq 2^k$, k prime, labelling different p_1-blocks is included in the index i. Ordinary thermodynamics suggests general forms for these terms. By fractality the various parameters appearing in free energies associated with different p-adic levels should be related by simple scaling laws. For instance, van der Waals type form should be appropriate for the free energy associated with a given block density of fluid at a given level of condensate. Also the general form for the block-block interaction terms can be guessed on general grounds.

The free energy has the general form

$$F_{TGD} = \sum_i N_i(-E_{cond} - E_{join}) + \sum_{ij} E^{ij}_{int} + F_{gr} \ . \tag{9.3.21}$$

The energy decomposes into a sum of the condensation energies $E_{cond} = \frac{b(k)}{L(k)}$ and join along boundaries binding energies E_{join} for blocks and of Kähler interaction energy and gravitational binding energy. According to the previous arguments, gravitational binding energy becomes important only in length scales $L(k) > \frac{1}{T}$. Depending on whether the condensate level is of electromagnetic or Z^0 type Kähler interaction energy corresponds either to electromagnetic or Z^0 Coulombic energy. Also magnetic interaction energies are possible. The general order of magnitude estimate for Kähler interaction energy is obtained if one accepts the previously proposed general picture of the electromagnetically neutral topological condensate.

One can understand these terms as coming from the Boltzmann weight $exp(E_{cond} + E_{join} + E_{gr} - E_K)$ appearing in the partition function associated with p:th level of the condensate. Kähler interaction energy is actually thermal average of the Kähler interaction energy and contains small temperature dependence. Due to its smallness it seems however safe to neglect this dependence. There is also a second reason for separating the ordinary contributions and those present only in TGD framework. Ordinary free energy is related to short range interactions and is not sensitive to the finite size of the p-adic surface whereas Kähler interaction energy corresponds to long range interaction and depends strongly on the size of the p-adic surface.

Besides these terms also Lagrange multiplier terms, such as a term

$$F_{const} = \lambda(p_{ext} - \frac{\partial F}{\partial V}) \ . \tag{9.3.22}$$

fixing the pressure to the external pressure at the highest level of the condensate, are present. The condensation level at which the constraint term appears corresponds naturally to the length scale $L(k) \sim \frac{1}{T}$ determined by the temperature: above this length scales gravitational interaction dominates. At the lower levels of the condensate this kind of pressure term is not present and the minimization of free energy fixes completely the various densities at these levels of the condensate. The important consequence is that the density of say, fluid, at short length scales should be fixed completely by the minimization conditions and should not depend on the external pressure at all. The external pressure changes the density of blocks but the not the density inside blocks. An exception is provided by solid phases, for which join along boundaries implies the formation of lattice so that only single block density is present for an ideal solid.

At high temperatures and in long length scales Kähler interaction energy and condensation energy are completely negligible in general. At low temperatures and short length scales as well as in critical systems the situation is different. The formation of supra phases and also of ordinary solids by join along boundaries operation provide examples of the situation, where the Kähler energy probably must be taken into account.

9.4 Configuration space geometry and phase transitions

The definition of the configuration space Kähler geometry has beautiful catastrophe theoretic interpretation. As a matter fact, catastrophe theory enters at two levels. First, Kähler function $K(X^3)$ is defined as the absolute minimum of Kähler action and associates a unique space-time surface $X^4(X^3)$ to a given 3-surface X^3. It can quite well happen that the absolute minimum of the Kähler action as a function of the varied parameters changes in discontinuous manner. Secondly, 'quantum average effective space-times' correspond to the absolute minimum space-time surfaces $X^4(X^3_{max})$ associated with the maxima of Kähler function as function of 3-surface and has so called zero modes as external control parameters and also now catastrophes are possible.

9.4.1 Basic ideas of the catastrophe theory

To understand the connection consider first the definition of the ordinary catastrophe theory [16]. In catastrophe theory one considers the extrema of a potential function depending on dynamical variables x as function of external parameters c. The basic space decomposes locally into cartesian product $E = C \times X$ of control variables c, appearing as parameters in the potential function $V(c, x)$ and of state variables x appearing as dynamical variables. Equilibrium states of the system correspond to the extrema of the potential $V(x, c)$ with respect to the variables x and in the absence of symmetries they form a sub-manifold of M with dimension equal to that of the parameter space C. In some regions of C there are several extrema of potential function and the extremum value of x as a function of c is multi-valued. These regions of $C \times X$ are referred to as catastrophes. The simplest example is cusp catastrophe (see Fig. 9.4.2) with two control parameters and one state variable.

In catastrophe regions the actual equilibrium state must be selected by some additional physical requirement. If system obeys flow dynamics defined by first order differential equations the catastrophic jumps take place along the folds of the cusp catastrophe (delay rule). On the other hand, the Maxwell rule obeyed by the thermodynamic phase transitions, states that the equilibrium state corresponds to the absolute minimum of the potential function and the state of the system changes in discontinuous manner along the Maxwell line in the middle between the folds of the cusp (see Fig. 9.4.2). As far as discontinuous behavior is considered fold catastrophe is the basic catastrophe: all catastrophes contain folds as there 'satellites' and one aim of the catastrophe theory is to derive all possible manners for the stable organization of folds into higher catastrophes. The fundamental result of the catastrophe theory is that for dimensions d of C smaller than 5 there are only 7 basic catastrophes and polynomial potential functions provide a canonical representation for the catastrophes: fold catastrophe corresponds to a third order polynomial (in the fold the two real roots become a pair of complex conjugate roots), cusp to fourth order polynomial, etc.. The development of the fold catastrophe means that the minimum of a potential function decomposes to two minima so that previous minimum becomes local maximum.

9.4.2 Configuration space geometry and catastrophe theory

Consider now how catastrophe theory emerges from the definition of the Kähler function. The most obvious identification for the parameter space C would be as the space of all 3-surfaces in $H = M^4_+ \times CP_2$. In order to get rid of the difficulties related to $Diff^4$ invariance one must however restrict the consideration to 3-surfaces belonging to H_a : the set of 3-surfaces of $M^4_+ \times CP_2$ with constant M^4_+ proper time coordinate. The counterpart of the total space $E = C \times X$ can be identified as the space of the solutions of the Euler Lagrange equations associated with Kähler action (one could consider all 4-surfaces but this is not necessary) and decomposes only locally into Cartesian product. Intuitively the space X corresponds to the time derivatives for the variables specifying the space X and in Hamiltonian formalism to the canonical momenta. If the initial value problem is well defined, the values of C and X coordinates specify the extremum uniquely. In TGD this is not in general true as the extremely large vacuum degeneracy of the Kähler action strongly suggests.

Potential function corresponds to the Kähler action restricted to the solution space of the Euler Lagrange equations. Catastrophe surface corresponds to the four-surfaces found by extremizing Kähler action with respect to the variables of X (time derivatives of coordinates of C specifying X^3 in H_a) keeping the variables of C specifying 3-surface X^3 fixed. Extremization with respect to time derivatives implies a phenomenon analogous to the Bohr quantization since canonical momenta cannot be chosen freely as in the ordinary initial value problems of the classical physics. When catastrophe occurs there are several extremizing 4-surfaces going through the given 3-surface: otherwise one obtains just the sought for absolute minimum surface.

The requirement that Kähler function corresponds to absolute minimum is just Maxwell's rule in infinite dimensional context and implies that phase transition type catastrophic quantum jumps are typical for TGD Universe. Cusp catastrophe provides a simple concretization of the situation (see Fig. 9.4.2) The set M ('Maxwell set') of the critical 3-surfaces corresponds to the Maxwell line of the cusp catastrophe and forms codimension one set in configuration space. For 3-surfaces near to the Maxwell set M small one parameter deformation in the direction normal to it can induce large deformation of the 4-surface associated with it. This implies initial value sensitivity with respect to the coordinate X_n associated with the normal direction. Kähler function itself is continuous on Maxwell surface and mathematical consistency requires that also Kähler metric is continuous on Maxwell surface. A good example of a catastrophic jump is provided by a topology changing quantum jump (3-surface decays to two disjoint 3-surfaces) identifiable as 3-particle vertex.

The present situation differs from the ordinary catastrophe theory in several respects.

1. The parameter space C is infinite dimensional so that there seems to be no hope of having finite classification for catastrophes in TGD Universe. Of course, all lower dimensional catastrophes are expected to be present in TGD, too.

2. Kähler action possesses vacuum degeneracy and one cannot exclude the possibility that the absolute minima of the Kähler action are degenerate: this implies further modifications to the standard picture of catastrophe theory.

3. Maxwell rule follows as a theorem in Quantum TGD whereas in ordinary catastrophe theory delay rule (jumps takes place along the folds) follows as a theorem. The latter implies that the description of phase transitions is not possible using the catastrophe theory associated with flows. These observations suggests that classical dynamics (for instance the classical dynamics associated with Kähler action) obeys delay rule whereas quantum dynamics obeys Maxwell rule and that the phenomena of super cooling and super heating are related to classical dynamics and ordinary phase transitions are induced by quantum fluctuations.

The existence of the catastrophes is implied by the vacuum degeneracy of the Kähler action. For example, for pieces of Minkowski space in $M^4_+ \times CP_2$ the second variation of the Kähler action vanishes identically and only the fourth variation is non-vanishing: these 4-surfaces correspond to the dip of the cusp catastrophe. There are also space-time surfaces for which second variation is non-vanishing but degenerate and a hierarchy of subsets in the space of extremal 4-surfaces with decreasing degeneracy of the second variation defines the boundaries of the projection of the catastrophe surface to the space of 3-surfaces. The space-times for which the second variation is degenerate contain as subset the critical and initial value sensitive absolute minimum space-times. By p-adic fractality there are good reasons to expect that there are catastrophes in all length scales so that the increase in p-adic resolution leads to emergence of new smaller catastrophes on a given portion of the catastrophe surface.

9.4.3 Quantum TGD and catastrophe theory

Catastrophes appear also in a second manner in TGD. As explained in the second part of the book, configuration space allows an infinite number of zero modes. Zero modes characterize the size and

Figure 9.1: Cusp catastrophe

shape of the 3-surface but do not appear in the line element of the configuration space metric. In good approximation configuration space functional integrals associated with the S-matrix elements can in principle be calculated using perturbation theory around the maxima of the Kähler function and one can define 'quantum average effective space-times' as the space-time surfaces $X^4(X^3_{max})$ associated with the maxima. Since the vacuum functional of the theory is the exponent of the Kähler function, the ill-defined Gaussian and metric determinants cancel each other and what remains is an integral over the zero modes. In general, for given values of the zero modes there are several maxima of the Kähler function and zero modes are in the role of the control parameters whereas the coordinates fixing the maximum of Kähler function for given values of the zero modes are in the role of the state variables. Also now infinite-dimensional catastrophe theory is in question.

The values of the vacuum functional at the Maxwell line of the cusp catastrophe same at the two sheets of the catastrophe but when one moves away from the Maxwell line, the second sheet begins to dominate due to the exponential dependence of the vacuum functional on Kähler function. One can also consider quantum jumps associated with the catastrophes: if the states represented by the points of the catastrophe surface are quantum entangled with the states of the external world or measurement apparatus E, one has, in the case of a cusp catastrophe, entanglement of the two sheets of the catastrophe with the states of E.

According to the strong form of Negentropy Maximization Principle, the quantum jumps selecting ond of the sheets can occur when the quantum entanglement/entanglement entropy is large, actually largest in the set of all possible quantum subsystems. This is indeed the case at the Maxwell line, where the values of the Kähler function defining the entanglement probabilities at two sheets are identical so that entanglement entropy is maximized. Hence the region near the Maxwell line is predicted to be the region, where macroscopic phase transition like quantum jumps can occur and it is an intriguing possibility that thermal phase transitions basically correspond to this kind of quantum jumps. Strong form of NMP actually suggests that large number of nearly degenerate maxima must be involved so that the entanglement entropy becomes large.

9.4.4 TGD based description of phase transitions

The above described mathematical structure should somehow reflect its presence also in the quantum description of the ordinary condensed matter phase transitions. Quantum criticality means that quantum states in TGD Universe are analogous to the states of a critical system and long range quantum correlations are predicted in all length scales. In principle, all quantum states are predicted to be critical in some time and length scale. The appearance of the join along boundaries condensates provides a concrete realization for quantum criticality. Spin glass analogy is in turn related to the enormous vacuum degeneracy of the Kähler action. This means the appearance of infinite number of zero modes of the Kähler function, which characterize the size and shape of the 3-surface as well as the classical induced Kähler field and play the role of universal control parameters in the catastrophe theory. Zero modes are the quantum counterparts of macroscopic state variables, to which thermodynamical variables should reduce at quantum level, and clearly they have no counterpart in the ordinary quantum field theories.

The strong form of Negentropy Maximization Principle states that the quantum jump in a given quantum state is performed by a subsystem for which the quantum jump to an eigenstate of the density matrix gives maximum negentropy gain. There are good arguments suggesting that the second law of thermodynamics follows from the strong form of Negentropy Maximization Principle [H2].

1. State function reductions increase the negentropy of the subsystem in ensemble but only the subsystem for which negentropy gain is maximal, can make the quantum jump and reduce its entanglement entropy. In order to get the possibility to make quantum jump (and be conscious according to TGD inspired theory of consciousness), the subsystem must be able to generate entanglement entropy very effectively: therefore strong NMP favors the generation of entanglement entropy and, rather paradoxically, implies both evolution and the second law of thermodynamics as different sides of the same coin.

2. The maximum for the real counterpart of the p-adic entropy is proportional to $ln(p)$ and this implies that cosmological evolution leading to the emergence of larger p-adic length scales in the topological condensate favors also the increase of the entanglement entropy.

   Hence, *if* one can indeed identify thermal entropy as an entanglement entropy, there are good hopes that second law of thermodynamics follows as a consequence.

This picture leads to a straightforward generalization of Haken's non-equilibrium thermodynamics description of the self-organizing systems [20] with configuration zero modes appearing in the role of the order parameters and the negative of the Kähler function playing the role of the potential function. The classical dynamics given by Langevin and Focker-Planck equations is replaced with the nondeterministic dynamics defined by quantum jumps. Quantum jump can be regarded as a basic step of self-organization.

As a special case, quantum description of the thermodynamical phase transitions should emerge. Quantum entanglement of the almost degenerate configurations near Maxwell line would be the purely quantal element of the quantum theory of phase transitions. The absolute minimization of the thermodynamical free energy and Maxwell rule would basically follow from the assumption that phase transition is induced by a quantum jump selecting between various maxima of the Kähler function and from the maximization of the Kähler function plus strong form of Negentropy Maximization Principle. The super cooling and super heating effects could be interpreted as produced by classical dynamics defined by the absolute minimization of the Kähler action for which the delay rule holds true.

9.5 Imbeddings of the cylindrically symmetric flows

In order to find orders of magnitude for the critical radii, the embeddings of some simple cylindrically symmetric flows will be considered. It is more convenient to consider Z^0 field instead of the Kähler field: these fields are proportional to each other for electrovac space-times: $J = pZ^0/6$ ($p = sin^2(\theta_W)$).

9.5.1 The general form of the imbedding of the cylindrically symmetric rotational flow.

In the following the flows at condensate levels $n \geq n_Z$ will be considered so that Z^0 fields are expected to dominate over the electromagnetic fields. Since the neutrinos screening the nuclear Z^0 charge are not expected to participate in the flow, only the Z^0 charge coming from level $n-1$ contributes to the spatial components of the Z^0 gauge current density at the level n and the time like component of the current density is therefore much smaller than the spatial components. This motivates the study of the field configurations for which Z^0 electric field is negligibly small as compared to Z^0 magnetic field.

1. The ration of em and Z^0 fields for vacuum extremals is given by $\gamma/Z^0 = -p/2$, $p = sin^2(\theta_W)$. Vanishing of the electromagnetic field is achieved for $p = 0$. It is indeed possible that Weinberg angle vanishes for vacuum extremals. The CP_2 projection of the imbedding is two-dimensional,

which implies the orthogonality of the magnetic and electric fields belonging to the same condensate level. On basis of the results of appendix Z^0 and em fields for vacuum extremals are given by

$$\begin{aligned} Z^0 &= (k+u)du \wedge d\Phi \ , \\ \gamma &= -\frac{p}{2} Z^0 \ . \end{aligned} \tag{9.5.1}$$

Here $u = cos(\Theta)$ and Φ corresponds to spherical coordinates.

2. Z^0 charge density of matter is assumed to serve as a source of Z^0 fields and in the idealization that matter consists of identical nuclei (A, Z) one can write the charge density as

$$\rho_Z = -K_Z N_n \ , \ K_Z = \frac{g_Z^2}{4\sqrt{\epsilon_Z}} \frac{N}{A} \ . \tag{9.5.2}$$

Here N_n is the density of nucleons and $N/\sqrt{\epsilon_Z}$ is the weak isospin per nucleus using neutrino isospin as a unit. ϵ_Z depends on the p-adic length scale involved and p-adic fractality suggests the scaling

$$\frac{N}{\sqrt{\epsilon_Z}} \propto N_0 \times (\frac{L(k_0)}{L(k)})^3 = N_0 \times 2^{-3(k-k_0)/2}$$

as a function of $p \simeq 2^k$. Prime values of k are favored and $k = 113, 151, 157, 163, 167$ corresponding to Mersenne primes are especially interesting.

The general situation corresponds to a flow for which the matter rotates around the z-axis with velocity $\beta(\rho)$ and creates Z^0 magnetic field in the z-direction. The Z^0 magnetic field associated with the flow at n:th condensate level is given by

$$B^Z = K_Z N_n \int \beta(\rho) d\rho \ . \tag{9.5.3}$$

The spatial dependence of the Z^0 electric field is same as that of B^Z and this means that Z^0 charge density serving as the source of E^Z cannot be constant: a possible resolution of the problem is that the screening neutrinos at level n arrange themselves so that Z^0 charge density is not constant although the nucleon density is.

Using coordinates $(r, u = cos(\Theta), \Psi, \Phi)$ for CP_2, the cylindrically symmetric electromagnetically neutral imbedding of this flow is obtained in the form

$$\begin{aligned} u &= u(\rho) \ , \\ \Psi &= \omega_2 m^0 + n_2 \phi \ , \quad \Phi = \omega_1 m^0 + n_1 \phi \ , \end{aligned} \tag{9.5.4}$$

where the relationship between the variables r and Θ is fixed by the vacuum extremal property (see Appendix of the book). The value of the parameter k is given by $k = \omega_2/\omega_1 = n_2/n_1$.

From the general expression for the Z^0 field in the vacuum extremal space-time one obtains the following differential equation for u:

$$\begin{aligned} B^Z &= (k+u) n_1 \frac{\partial_\rho u}{\rho} \ , \\ &= K_Z N_n \int \beta(\rho) d\rho \ , \end{aligned} \tag{9.5.5}$$

which gives the relationship between u and ρ in the following form

$$\int (k+u)du = \frac{K_Z N_n}{n_1}\int d\rho\rho \int d\rho\beta(\rho) \ . \tag{9.5.6}$$

Assuming that $u=-1$ corresponds to the z-axis and the boundary of topological field quantum to $u=1$, one obtains an expression for the critical radius:

$$\begin{aligned}\int_0^{\rho_{cr}} d\rho\rho \int \beta(\rho)d\rho &= -\frac{n_1}{K_Z N_n}\times 2k \ , \\ K_Z &= \frac{g_Z^2}{4\sqrt{\epsilon_Z}}\frac{N}{A}\end{aligned} \tag{9.5.7}$$

An attractive possibility is that the structures associated with the ordinary hydrodynamic flow might be understood as consequences of CP_2 geometry. It will be found that the order of magnitude estimates give quantitative support for this guess.

One obtains also a quantization of Z^0 magnetic flux as

$$\int B_Z da = 2\pi n_1 \int (k+u)du = 4\pi k n_1 \ , \tag{9.5.8}$$

What is nice is that the quantization condition eliminates the dependence of the critical radius on the poorly known vacuum quantum numbers totally. The least one can hope is that the condition fixes orders of magnitude correctly.

p-Adic length scale hypothesis suggests a simple scaling for the flow velocities guaranteing that ρ_{cr} scales as $L(k)$. $K_Z \propto L(k)^{-3}$ scaling, which follows from the assumption that the number of dark Z^0 charges per p-adic volume does not depend on p, implies the scaling

$$\int \beta_k(\rho)d\rho \propto L(k)^{-3}$$

achieved for

$$\beta_k(\rho) \propto (\frac{\rho}{L(k)})^k L(k) \ .$$

The decay of a structure characterized by the p-adic length scale $L(k)$ to smaller structures with smaller values of k could provide a general mechanism for generating fractal structures [17]. The model of turbulence favors the scaling $2^k = 2^5$ for the vortices in the hierarchy. This scaling could also correspond to the Mersenne prime $M_5 = 2^5 - 1 = 31$.

CP_2 topology is bound to become important for large scale flows. The central ill understood problem in the astrophysics is the understanding of the turbulence and the dissipation of the angular momentum [21]. From the foregoing it is clear that TGD approach might provide understanding concerning several astrophysical problems [21]. An interesting test for the ideas is the possible existence of the nested fractal structures related by discrete scale transformations.

9.5.2 Orders of magnitude for some vacuum parameters

The space-time associated with the flow is characterized by several parameters. Besides the parameters ω_i and n_i there are integer valued parameter m and the parameter u_0. In the following estimates for the general orders of magnitude for some of these parameters will be derived.

An estimate for the parameter ϵ_Z

The requirement that gravitational interaction is stronger than Z^0 force in long length scales implies $\epsilon_Z(n \rightarrow \infty) \geq 10^{36}$. At the condensate level $n = n_Z$ at which elementary particles feed their Z^0 charges the estimate

$$\epsilon_Z \sim 10^{20} \ ,$$

holds true by the argument related to the dissipation in super fluid flow, to be developed later. For the Z^0 magnetic field at level n the $\epsilon_Z(n-1)$, rather than $\epsilon_Z(n)$, appears in the expression of B_Z (assuming that dark neutrinos do not participate in the flow) so that at level $n = n_Z$ strong B_Z fields are possible ($\epsilon_Z = 1$).

An estimate for the quantum number n_1

An essentially similar estimate have been already carried out in the previous chapter. The requirement that angular momentum density is of correct order of magnitude, gives an estimate for the value of the parameter n_1. The expression of the conserved gravitational angular momentum current in the z-direction is given by

$$J^\alpha = T^{\alpha\beta}_{gr}\partial_\beta m^k m_{kl} j^l \ , \tag{9.5.9}$$

where j^k denotes the vector field associated with the infinitesimal rotation and $T^{\alpha\beta}_{gr}$ denotes gravitational energy momentum tensor defined by Einstein's equations. For the angular momentum density one obtains in the cylindrical M^4 coordinates for X^4 the expression

$$J^t = T^{t\phi}_{gr}\rho^2 \ . \tag{9.5.10}$$

The leading order contribution to the angular momentum density comes from the non-vanishing of the metric component

$$\begin{aligned} g_{t\phi} &= s^{eff}_{\Phi\Phi}\omega_1 n_1 = -\frac{R^2}{4}X \times \left[(1-X)(k+u)^2 + 1 - u^2\right]\omega_1 n_1 \ , \\ X &= D|k+u| \ , \ D = \frac{r_0^2}{1+r_0^2} \times \frac{1}{k+u_0} \ , \ r_0 = r(u_0) \ , \end{aligned} \tag{9.5.11}$$

and one obtains the order of magnitude estimate

$$J^t \simeq -T^{tt}_{gr} g_{t\phi}\rho^2 \simeq \rho_m \frac{R^2}{4}\omega_1 n_1 \ . \tag{9.5.12}$$

In order to obtain a correct order of magnitude for the angular momentum density associated with the rotational flow one must have

$$\frac{R^2}{4}\omega_1 n_1 \simeq \rho\beta(\rho) \ , \tag{9.5.13}$$

which implies

$$n_1 \simeq \frac{L}{R}\beta \ , \tag{9.5.14}$$

where L and β are the typical scale and velocity associated with the flow. It is clear that n_1 is an enormous number: essentially the size of the rotational flow measured using CP_2 length as a unit.

Estimate for ω_2, n_2 and m

The values of the parameters ω_2 and n_2 and m remain free and the attractive possibility is that the value of the parameter n_2 is small, perhaps of the order of one. If this the case then the value of the parameter ω_2 is also small

$$\frac{\omega_2}{\omega_1} = \frac{n_2}{n_1} \simeq \frac{R}{L}\frac{n_2}{\beta} \ . \tag{9.5.15}$$

The first guess is that at microscopic scales the order of magnitude for ω_2 corresponds to the p-adic lengths scale of dark matter particles in question and ω_1 is of order CP_2 mass as the imbeddings of Schwartchild metric as a vacuum extremal suggest [D3]. $\omega_2 \sim m_e$ gives $n_2 \sim 10^{-19}(L/R)\beta$. For $L = 0.1$ meters and $\beta \simeq 10^{-8}$ one would have $n_2 \sim 10^6$.

9.5.3 Critical radii for some special flows

In order to get concrete picture of the situation it is useful to calculate the critical radius for some special flows.

Vortex flow

The velocity field is irrotational except on the z-axis and velocity and Z^0 magnetic fields are given by

$$\begin{aligned} \beta &= \frac{K}{\rho} \ , \\ B^Z &= K_Z N_n K ln(\frac{\rho}{\rho_0}) \ . \end{aligned} \tag{9.5.16}$$

Assuming that $r = 0$ on the z-axis, one obtains for the critical radius the equation

$$\rho_{cr}^2 (ln(\frac{\rho_{cr}}{\rho_0}) - \frac{1}{2}) = -\frac{2n_1 k}{K_Z N_n K} \ . \tag{9.5.17}$$

To a logarithmic accuracy, this gives the order of magnitude estimate

$$\rho_{cr} = 2\sqrt{\frac{n_1 k}{K_Z N_n K}} \ . \tag{9.5.18}$$

The size of the critical radius decreases as the vorticity K increases.

Rigid body flow

Velocity field and Z^0 magnetic field are given by

$$\begin{aligned} \beta &= \Omega\rho \ , \\ B_Z &= K_Z N \Omega \frac{\rho^2}{2} \ . \end{aligned} \tag{9.5.19}$$

The value of the critical radius is given by the condition

$$\rho_{cr} = (\frac{16 k n_1}{K_Z N_n \Omega})^{1/4} \ , \tag{9.5.20}$$

for the quantized Z^0 magnetic flux.

9.6 Transition to the turbulence in channel flow

In sequel a general model for the transition to turbulent flow is proposed. In order to see whether the proposed scenario has anything to do with the reality it is useful to look whether one can understand the generation of a turbulence in some simple situation, which is chosen to be channel flow. The consideration is restricted to the length scales $L > \xi$ so that Z^0 magnetization should play key role in the generation of turbulence if the proposed general model is correct.

9.6.1 Transition to the turbulence

In the following a general model for the transition to turbulent flow below length scale identifiable as a weak length scale characterizing dark weak bosons L_w associated with the largest vortices. Similar model might apply also in the case of magnetic fields. In the following the phrase 'Kähler field' refers either to the ordinary electromagnetic field or Z^0 field or possibly to their linear combination depending on the context.

1. The probability of the configuration is proportional to the exponent of the Kähler function so that the most probable configurations correspond to a large value of the Kähler action. Kähler action can be increased by making either the magnitude of the Kähler electric part smaller or the magnitude of the Kähler magnetic part larger. The first mechanism is expected to be at work at non-relativistic velocities since the ratio of the Kähler magnetic and electric contributions to the Kähler action is expected to be of the order of β^2, where β is typical flow velocity. The transition to configuration with larger Kähler action is expected to take place provided it is energetically possible and is consistent with the minimization of the Kähler action.

2. Spontaneous Kähler magnetization provides the means to generate a positive action. The Kähler action of the Kähler magnetized space-time domain should be larger than that associated with the same domain without magnetization. It turns out that the Kähler electric action associated to a vortex region moving with the fluid has smaller magnitude than that associated with the same volume of the original flow: the reason is that Kähler electric field associated with the vortex is small near the core of the vortex. CP_2 geometry implies that the stable domains of the Kähler magnetization have some finite critical size. Kähler magnetized domains correspond to vortices and due to the viscosity, vortices grow until their achieve a critical size.

3. Vortex must get somehow rid of its angular momentum and kinetic energy and the topological quantum numbers n_1 and n_2 must become zero. One candidate for the region, where new vortices are produced is the region near the critical radius, where the velocity gradients are large so that the viscosity plays important role. The vortices created in this region cannot however lead to a decrease of n_1 and n_2. The process leading to a decrease of n_1 and n_2 is a generalization of the process known as phase slippage in super fluidity [16]. Daughter vortices are created at the core of the mother vortex and they propagate under the action of Magnus and friction forces to the boundary of the mother vortex and carry away the quantum numbers n_1 and n_2 of the mother vortex gradually.

   For the flow $\beta = K/\rho$, which is irrotational outside the symmetry axis, which actually corresponds to a cylindrical hole of finite radius r, this hypothesis makes sense since the variation of velocity is large in normal direction in the core and dissipation rate therefore largest near the boundary of the hole. The radius r defines a natural lower bound for the sizes of vortices involved.

4. The transition to turbulence involves the generation vortices of various sizes related by scale transformations. That this is the case is suggested by the following argument. It is an empirical fact that the size of the daughter vortices is smaller than the size of mother vortex (this assumption forms the basis of Kolmogorow and Heisenberg theories of turbulence [23]). The conservation laws of energy and angular momentum however imply that daughter vorticities cannot be larger than mother vorticity. The critical radii of the mother and daughter vortices are related by the scale transformation $\rho_{cr} \rightarrow \lambda\rho_{cr}$. λ is expected to be a negative power of 2 and it turns out that $\lambda < 2^{-5}$ is consistent with the Heisenberg's model for the generation of turbulence. In fact, a distribution $\lambda(k) = 2^{-k}$, $k \geq 5$, for vortex sizes might be allowed.

The hypothesis that vortex decay corresponds to a decay of higher levels in the dark matter hierarchy by de-coherence such that $\hbar$ is reduced by could a factor $\lambda = v_0/n \simeq 2^{-11}/n$, $n = 1, 2, ...$, is consistent with the proposal. The decay would correspond to a decay of Bose-Einstein condensates of corresponding weak bosons to those at the lower level of darkness and thus having Compton lengths reduced by λ.

5. The transition to turbulence can be understood as a a fractal like process. In the case of the channel flow, the walls serve as sources of the mother vortices with large critical radii. These vortices in turn decay to smaller vortices. At a given condensate level the process stops, when the size of the daughter vortices is so small that the hydrodynamics approximation fails so that the radius of the smallest vortices is of same order of magnitude as the length scale $L(n)$ giving the size of smallest structures at the condensate level in question. A necessary condition for the process to occur is that the total Kähler action generated is positive. The criterion for the process to occur is that the total Kähler action associated with the cascade is positive.

It should be emphasized that the decomposition of the space-time into above described regions is very general phenomenon characteristic for TGD. It happens for a general space-time with vanishing electromagnetic fields and also for more general space-time surfaces: the condition in question might state the vanishing of the Kähler field or electromagnetic field or the proportionality of the Kähler field and electromagnetic field. This suggests rather unexpected support for the basic assumptions of TGD: many of the fractal structures encountered in Nature might be direct manifestations of CP_2 geometry!

9.6.2 Definition of the model

The transition to turbulence is cascade process.

1. Mother vortices having initial radius ρ_0 are created at the walls of the channel, where the velocity gradients are large and viscosity plays important role. Let ξ is the length scale above which hydrodynamic approximation works. ξ should be of the order of atomic length scale $a = 10^{-10}$ m.

   In the rest frame of the vortex the velocity field is given by

$$\beta(\rho) = \frac{K}{\rho} . \quad (9.6.1)$$

   The sign of the vorticity is such that the formation of the vortices tends to make velocity zero at the walls of the channel.

2. Mother vortices move across the channel under the combined action of the Magnus force $F = K \times v$ and friction force and reach a critical size. Mother vortices dissipate their energy and angular momentum by the emission of daughter vortices by the phase slippage process. The critical radius of the daughter vortices is by a factor λ smaller than the critical radius of the mother vortex. The value of λ remains a parameter to be fitted.

3. The process repeats itself until the size of the daughter vortices is of the order of ξ and hydrodynamic approximation fails.

9.6.3 Estimates for the parameters

Consider now a more quantitative definition of the process.

1. The order of magnitude estimates for the parameters $k(0) \equiv k$ and $\rho_{cr}(0) \equiv \rho_1$ are obtained in the following manner.
   i) ρ_1 should be smaller than the width of the channel for obvious geometric reasons:

$$\rho_1 \ \leq \ d \ . \tag{9.6.2}$$

This same estimate follows from the requirement that the configuration with a vortex possesses larger Kähler action than the configuration without any vortex as will be found later.
ii) An upper bound for the vorticity K is obtained by requiring that the flow velocity at $\rho \simeq \xi$ is not larger than the thermal velocity (sound velocity could be taken as an alternative lower bound: orders of magnitude are same): $K/\xi \leq \beta_{th}$, which gives

$$K \ \leq \ K_{max} \simeq \xi\beta_{th} \ . \tag{9.6.3}$$

2. A natural requirement is that the rotation velocity of the vortices at the critical radius is of the same order of magnitude as the velocity of the main flow

$$\frac{K}{\rho_1} \ \simeq \ \beta \ . \tag{9.6.4}$$

This condition guarantees that the angular momentum of the vortex is of the same order of magnitude as the angular momentum for the main flow in the vortex region. Substituting this constraint and the upper bound for k to the condition $\rho_1 \leq d$ one obtains Reynolds number type criterion

$$\frac{\beta d}{\nu} \ \geq \ R_{cr} \equiv \frac{\beta_{th}\xi}{\nu} \ , \tag{9.6.5}$$

when the vorticity K is maximal ($K \simeq \xi$ in units $c = 1$).

3. A kinetic theory estimate for the order of magnitude estimate of the gas viscosity gives a correct order of magnitude in case of the small viscosity liquids, too and is given by

$$\nu \ \simeq \ \frac{\beta_{th}}{N\sigma} \ , \tag{9.6.6}$$

where N is the density of nucleons in the liquid. Typically one has $N \simeq 10^{30}/Am^3$ (A is atomic mass number) and $\sigma \sim a^2$, $a = 10^{-10}$ m is atomic cross section: $\sigma \simeq 10^{-20}\ m^2$ holds true for liquids at room temperature.

4. Using the order of magnitude estimate for the kinematic viscosity ν one obtains

$$R_{cr} \ = \ \frac{\beta_{th}\xi}{\nu} \simeq N\sigma\xi \simeq Na^3\xi \sim \frac{10^4}{A} \times \frac{\xi}{a} \ . \tag{9.6.7}$$

For $\xi \sim a$ the value of R_{cr} is of the correct order of magnitude since the fully developed turbulence sets in at Reynolds numbers of this order of magnitude. In case of water more careful estimate using the actual value of the kinematic viscosity and thermal velocity in room temperature gives $R_{cr} \simeq 1200 - 12000$.

According to this criterion turbulence can develop also for smaller Reynolds numbers by vortices with $K \leq d \leq \xi\beta_{th}/\beta$ (as it does) but not all vorticities allowed by the velocity condition are possible. For the critical Reynolds number means that all possible vorticities allowed by $\beta(\xi) \leq \beta_{th}$ are allowed and for larger Reynolds numbers the upper limit for the size of vortices: $\rho_{cr} \leq \xi\beta_{th}/\beta \leq d$ is strictly smaller than the width of the channel.

The critical Reynolds number follows from the geometric condition $\rho_{cr} \leq d$ in the case of a channel flow. It will be later found that the same condition follows also from the requirement that the generation of the vortex increases the Kähler action so that same kind of condition is expected also in case of, say, the flow between two rotating disks.

9.6.4 Kähler fields associated with the cascade process

In the following a simple model for the Kähler electric and magnetic fields associated with the main flow and vortices will be constructed. The following simplifying assumptions about the flow are made:
i) The flow takes place in a channel of height h, width d and length L.
ii) The flow velocity β is constant throughout the channel.
iii) The main flow has a constant density $\rho_m \equiv Nm_p$, possesses kinematic viscosity ν and thermal velocity β_{th}.

Consider first the Kähler electric and magnetic fields associated with the main flow and a vortex assumed to have its axis in the z-direction.

1. When the fluid is at rest, it creates Kähler electric field, which near the symmetry axis of the flow is cylindrically symmetric for long and wide channel is in the z-direction and given by

$$\begin{aligned} E^K_\rho &= K_Z N_n \frac{\rho}{2} \ , \\ K_Z &= \epsilon_1 10^{-19} \ . \end{aligned} \tag{9.6.8}$$

   Near the walls $x = d$ and $x = 0$ and far from the corners, the Kähler electric field is to a good approximation orthogonal to the wall and given by the expression

$$E^K_x = K_Z N_n (x - \frac{d}{2}) \ . \tag{9.6.9}$$

   Same applies on the walls $z = 0$ and $z = h$. The small effects caused by the density gradients on the Kähler electric field, are neglected.

2. The Kähler magnetic field near the axis of the symmetry has circles as its flow lines and the magnitude of the field is given by

$$B^K_\phi = K_Z N_n \beta \frac{\rho^2}{2} \ . \tag{9.6.10}$$

   Near the walls $x = d$ and $x = 0$ and sufficiently far from the corners the Kähler magnetic field is given by the expression

$$B^K_z = K_Z N_n \beta (x - \frac{d}{2}) \ . \tag{9.6.11}$$

3. The Kähler magnetic field created by the locally irrotational vortex vortex is given by the expression

$$B^K_z = K_Z N_n K ln(\frac{\rho}{\rho_0}) \ . \tag{9.6.12}$$

4. The Kähler electric field created by the vortex can be estimated by assuming the simplest possible imbedding with vanishing electromagnetic fields ($\Psi = \omega_2 m^0 + n_2\phi$ and $\Phi = \omega_1 m^0 + n_1\phi$). The relationship between Kähler electric field and Kähler magnetic field is given by

$$\begin{aligned} E_\rho^K &= \frac{\omega_1}{n_1} B_z^K \rho \\ &= \frac{\omega_1}{n_1} K_Z N_n K ln(\frac{\rho}{\rho_0}) \simeq K_Z N_n ln(\frac{\rho}{\rho_0})\rho \ , \end{aligned} \tag{9.6.13}$$

and apart from the logarithmic factor behaves like the field created by a constant charge density. The last estimate is obtained using the previous order of magnitude estimate for the size of the integer n_1: $n_1 \simeq K/\sqrt{G}$. From this relationship one obtains an estimate for S_B^2/S_E^2: $S_B^2/S_E^2 \simeq K^2/\rho_{cr}^2 \ll 1$.

9.6.5 Order of magnitude estimate for the change of the Kähler action and Reynolds criterion

In the following a rough order of magnitude estimate for the various contributions to Kähler action and numerical criteria for the transition to the turbulence are derived. The estimates are based on the following assumptions.

1. The Kähler fields associated with the moving vortices are obtained by Lorentz boosts leaving the Kähler action of the vortex invariant.

2. Kähler magnetic contributions to the Kähler action are neglected so that the increase of the Kähler action must result from the decrease of the magnitude of the Kähler electric part of the action. This is indeed expected to take place since the Kähler electric field of the vortex is small near the vortex core.

3. The Kähler action resulting from the interaction of the main flow and vortex is neglected. For the Kähler electric part of the action this assumption is well founded by the symmetry considerations. The Kähler electric field of the vortex is radially symmetric and in the region, where this field has a considerable magnitude, the Kähler field of the main flow is constant to a good approximation so that the integral $\int E_{vortex} \cdot E_{flow} d^4x$ vanishes to a good approximation. The corresponding magnetic interaction term can be neglected by its smallness.

As a consequence the change in the Kähler action is simply the change in the Kähler electric contribution to Kähler action, when the Kähler electric field of the main flow is replaced with the Kähler electric field of the vortex inside the space-time volume occupied by the vortex and the condition for the generation of turbulence reads as

$$\delta S_E^K = S_E^K(vortex) - S_E^K(flow) \geq 0 \ . \tag{9.6.14}$$

For the vortex of $n:th$ generation $S_E^K(n)$ has order of magnitude given by

$$\begin{aligned} S_E^K(n) &= \frac{1}{16\pi\alpha_K}\int E_n \cdot E_n d^4x \\ &\propto K_Z^2 N_n^2 (\rho_{cr}^4(n)) h\frac{\pi}{4}\tau(n) \ , \end{aligned} \tag{9.6.15}$$

where $\tau(n)$ is the average lifetime of the n:th generation vortex. The value of $S_E^K(flow)$ near the wall has order of magnitude given by the expression

$$\begin{aligned} S_E^K(flow) &= \frac{1}{16\pi\alpha_K}\int E_{flow} \cdot E_{flow} d^4x \\ &\propto K_Z^2 N_n^2 d^2 (\rho_{cr}^2(n)) h\frac{\pi}{4}\tau(n) \end{aligned} \tag{9.6.16}$$

to a logarithmic accuracy. From the condition $S^K(vortex) \geq S^K(flow)$ one obtains to the same logarithmic accuracy

$$\rho_{cr}(n) \quad \leq \quad d \ , \tag{9.6.17}$$

which is identical to the condition obtained by a purely geometric argument. The condition is satisfied for all vortices in the cascade if it is satisfied for the initiating vortex.

Some comments on the condition is in order.

1. The condition poses an upper bound for the vorticities of the mother vortices: $K \leq \beta d$ in addition to the bound $K\xi \leq \beta_{th}$ and implies for the vortices with the maximal vorticity the condition $\beta d/\nu \geq 2/\beta_s$ as found already earlier. This means that full turbulence becomes possible at critical Reynolds number. Partially developed turbulence is possible for smaller Reynolds numbers, too. The vortices with the largest vorticity increase Kähler action most effectively and this suggests that the ordinary dissipation for a non-turbulent flow corresponds to the formation of small mother vortices.

2. Also flows without turbulence are possible since the condition states only that the most probable flows are turbulent. This is indeed what has been observed in the case of real flows: by appropriate experimental arrangements one can hinder the development of the turbulence up to rather high Reynolds numbers.

3. The critical Reynolds number derived from the requirement of large Kähler function has a correct order of magnitude for laboratory scale flows: $R_{cr} \sim \frac{10^4}{A} \times \frac{\xi}{a}$ ($R_{cr} \sim 10^4/A$ at room temperature).

4. The result is insensitive to the details of the cascade model since the first vortex serves as the bottle neck of the cascade.

9.6.6 Phase slippage as a mechanism for the decay of vortices

Phase slippage in TGD context

Vortices must somehow dissipate their energy and angular momentum. Since angular momentum is proportional to the integer n_1 this means that some mechanism for reducing the value of n_1 must exist. This kind of mechanism is indeed known in the context of super fluidity and known as phase slippage [16]. In case of the channel flow phase slippage means that the order parameter χ, which is completely analogous to the angle variables Ψ and Φ, develops in the following manner.

The original linear behavior $\chi = kx$, where x is the coordinate in the direction of flow is gradually deformed to a behavior for which χ changes by a multiple of 2π at single point $x = x_0$ and behaves otherwise linearly (see Fig. 9.6.6). Since χ and $\chi + n2\pi$ correspond to the same physical situation the result means that one replace the graph of χ with graph without the jump. This process implies dissipation: the value of the momentum like quantum number k has decreased by a discrete amount. Physically the phase slippage corresponds to the propagation of a vortex across the channel although this is not quite obvious: the quantized vorticity of the vortex is n/M so that vorticity is conserved in the process.

In the present context the phase slippage process has a nice geometric interpretation. A pair of $r = \infty$ and $r = 0$ surfaces is generated in the process. Ψ (Φ) can change discontinuously on the these surfaces and Ψ (Φ) indeed changes by a multiple of 4π (2π) and a phase slippage is generated. In present case it is quite obvious that this process corresponds to a propagation of a vortex across the channel.

The process can be generalized to provide a dissipation mechanism for the vortices. Daughter vortex is generated on the core of the decaying vortex and moves under the action of Magnus and friction forces in radial direction and finally leaves mother vortex. The quantum numbers n_1 and n_2 associated with the process are conserved.

$$n_k(mother, i) \quad = \quad n_k(mother, f) + n_k(daughter) \ , \quad k = 1, 2 \ . \tag{9.6.18}$$

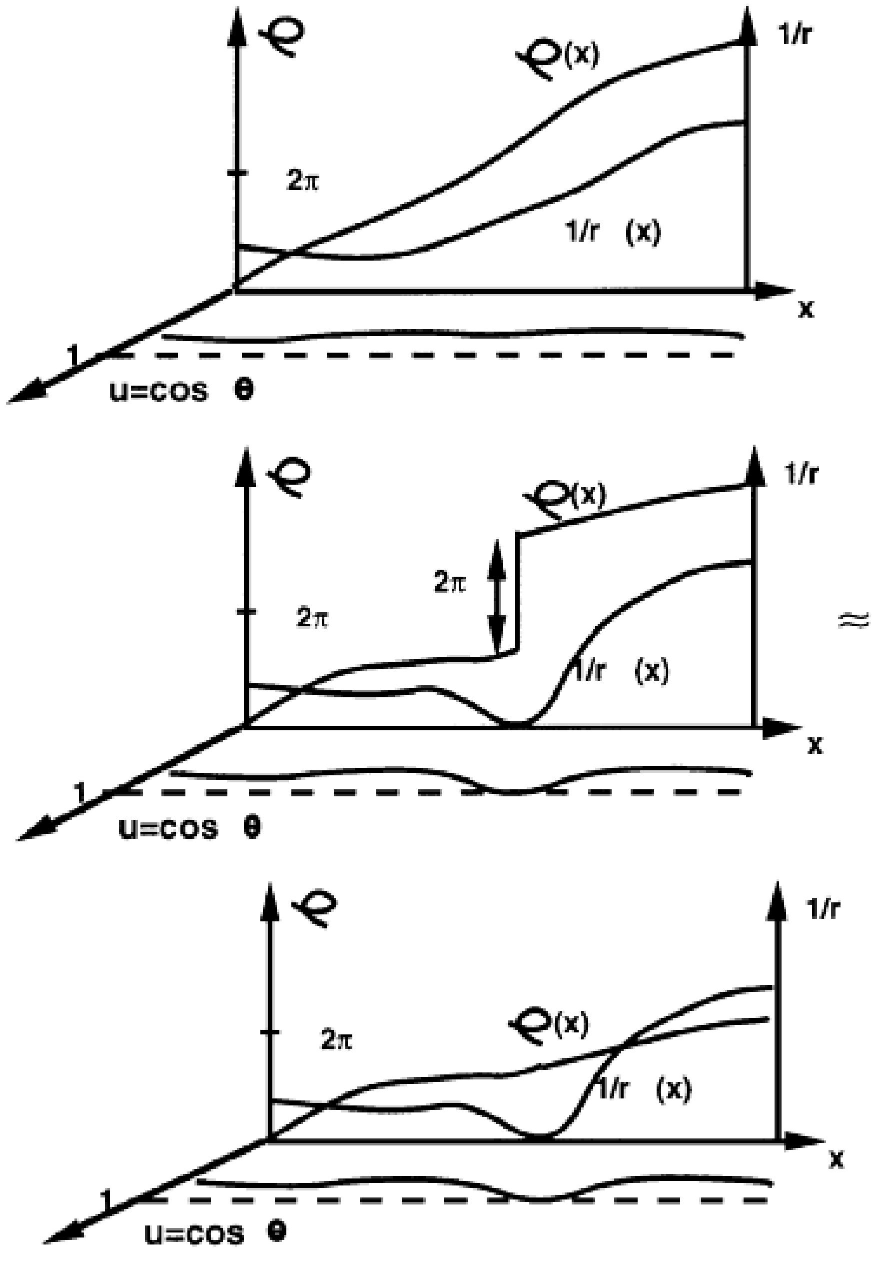

Figure 9.2: Phase slippage process and CP_2 geometry

If one assumes that K and n_1 are proportional to each other as they should be by the semiclassical argument, the critical radius of the mother vortex doesn't change in the process. If this process repeats itself sufficiently many times n_2 and n_1 become zero gradually resulting in a complete dissipation for the energy and angular momentum of the original vortex.

A model for the emission of the daughter vortices

A natural manner to model the emission of daughter vortices is as a stochastic process. Vortices are characterized by the quantum label $\Lambda = (n_1, n_2, \omega_1, \omega_2, m)$ and phase slippage corresponds to the emission process

$$\Lambda_1 \quad \rightarrow \quad \Lambda_2 + \Lambda_3 \ , \tag{9.6.19}$$

characterized by the decay rates

$$\Gamma(\Lambda_1 \rightarrow \Lambda_2 + \Lambda_3) \ . \tag{9.6.20}$$

Also the reverse process is possible but there are good reasons to assume that the fusion of the two vortices is a rather rare process.

It is straightforward to write general kinetic equations for the distribution of vortices as a function of Λ and in particular, as a function of the critical radius: this in turn leads to the distribution of the kinetic energy of the vortex as function of the the size of the vortex predicted also in the Heisenberg model for turbulence [23, 22]. In order to get grasp of the situation it is however useful to make some simplifying assumptions about the decay of the vortices.

1. Vortex growth is a rapid process as compared to the motion of vortex between the core and the boundary of the mother vortex. This implies that the integer m associated with the daughter vortex must be smaller than the integer associated with the mother vortex. For simplicity it is assumed

$$m(daughter) \quad = \quad m(mother) - 1 \ . \tag{9.6.21}$$

2. The ratio $n_1/n_2 = \omega_1/\omega_2$ remains constant in the decay process if possible: this implies that the change in the functional relationship between CP_2 coordinates u and r is minimized. Since the ratio n_1/k is constant by a semiclassical argument implying that angular momentum is proportional to n_1, the conservation law

$$\frac{n_i}{k} \quad = \quad constant \ , \tag{9.6.22}$$

holding true for all vortices of the cascade is suggestive.

3. The conservation law implies that the critical radius, vorticity and and n_i of the daughter vortex are given by

$$\begin{aligned} \rho_{crit}(daughter) &= \lambda\rho_{crit}(mother) \ , \\ k(daughter) &= \lambda k(mother) \ , \\ n_i(daughter) &\simeq \lambda n_i(mother) \ , \\ \lambda &= 2^{-x} \ . \end{aligned} \tag{9.6.23}$$

The value of x is expected to be integer and will be fixed by the comparison with experiment.

The assumption

$$k(daughter) = \lambda k(mother) \ ,$$

makes sense if one gives up the the assumption that magnetic flux is quantized irrespective of the value of n_1 as is clear by looking at the expression Eq. (9.5.18) for the critical radius for the vortex flow. One can however allow the increase of n (n_1 is multiple of n rather than arbitrary integer):

$$n(daughter) = \frac{n(mother)}{\lambda^2} \ ,$$

as is clear from the formula for the critical radius to achieve the quantization of magnetic flux. If magnetic flux quantization is assumed with the parameter $n = 1$ (n_1 integer) one must have

$$k(daughter) = \frac{k(mother)}{\lambda} \ ,$$

in order to get the critical radius correctly. The increase of k might be forced by the angular momentum conservation: if daughter vortices are created on the boundary of the mother vortex (as implied by the geometric picture) in the layer of a thickness $\rho_{crit}(daughter)$, the requirement that the angular momentum of the daughter vortices is of same order of magnitude as that of mother vortex, implies the desired formula. One must however remember that this argument need not make sense since flow equilibrium rather than decay of single vortex is in question. Also the increase of the average rotation velocity in small length scales looks un-physical feature. In any case, there are two possible scenarios:

$$\begin{array}{l} \text{a) Quantized magnetic flux and } n_i/k = constant: \ , \\ k(daughter) = \lambda k(mother) \ , \\ n(daughter) = \frac{n(mother)}{\lambda^2} \ , \\ \\ \text{Quantized magnetic flux and } n = 1: \\ k(daughter) = \frac{k(mother)}{\lambda} \ , \end{array} \tag{9.6.24}$$

and the scenario 1) looks more attractive.

For the mother vortex the corresponding quantities are after the decay given by

$$\begin{aligned} \rho_{crit}(mother, f) &= \rho_{crit}(mother, i) \ , \\ k(mother, f) &= k(mother, i)(1 - \lambda) \ , \\ n_i(mother, f) &\simeq n_i(mother, i)(1 - \lambda) \ . \end{aligned} \tag{9.6.25}$$

The process stops, when the condition $n_2(mother, f) = n_2(1 - \lambda)^{N_f} \leq \lambda$ (n_2 refers to the mother vortex created at the wall) is satisfied, which gives the the estimate

$$N_f(n_2) \simeq \frac{(ln(n_2) + ln(\lambda))}{|ln(1 - \lambda))|} \ , \tag{9.6.26}$$

for the total number of the daughter generations with $m(daughter) = m(mother) - 1$ born in the dissipation of the mother vortex by the emission of the daughter vortices.

The distribution of the vortices as a function of the critical radius

Consider now the evaluation of the distribution for the number $N(\rho)$ of the vortices as function of the critical radius ρ.

1. The number of the daughters in the k:th generation having is given by

$$
\begin{aligned}
N_d(k) &\simeq \prod_{i=0}^{i=k} N_f(i) \ , \\
N_f(i) &= \frac{(ln(n_2)+(i+1)ln(\lambda))}{|ln(1-\lambda))|} \ .
\end{aligned}
\tag{9.6.27}
$$

2. The size distribution is obtained by expressing the number k of generations in terms of the critical radius

$$
k = -\frac{ln(\rho_m/\rho))}{ln(\lambda)} \ . \tag{9.6.28}
$$

Here ρ_m denotes the initial value of the vortex radius created at the wall of the channel. Assuming that the size distribution $N(\rho_m)$ for the mother vortices emitted at the wall is known, one obtains the following expression for the size distribution of vortices

$$
\begin{aligned}
N(\rho) &= \int N(\rho|\rho_m)N(\rho_m)d\rho_m \ , \\
N(\rho|\rho_m) &= \prod_{i=0}^{k} N_f(i) \ , \\
N_f(i) &= \frac{(ln(n_2)+(i+1)ln(\lambda)}{|ln(1-\lambda)|} \ .
\end{aligned}
\tag{9.6.29}
$$

An approximate expression of $N(\rho/\rho_m)$ holding true for small values of ρ is given by

$$
\begin{aligned}
N(\rho|\rho_m) &\simeq D(\frac{\rho_m}{\rho})^{\alpha+1/ln(\lambda)} \ , \\
D &= B^{-\frac{B}{ln(\lambda)}}A^{\frac{A}{ln(\lambda)}} \ , \\
A &= ln(n_2)+ln(\lambda) \ , \\
B &= A+ln(\frac{\rho}{\rho_m}) \ , \\
\alpha &= -\frac{ln(-\frac{1}{ln(1-\lambda)})}{ln(\lambda)}) \simeq 1 \ .
\end{aligned}
\tag{9.6.30}
$$

D is a slowly varying logarithmic factor so that $N(\rho_m|\rho)$ behaves as the power $\rho^{1+\frac{1}{ln(\lambda)}}$ for all values of ρ_m. This implies that for small radii the general form of the size distribution is universal

$$
N(\rho) \simeq C(\frac{\rho_m}{\rho})^{\alpha+\frac{1}{ln(\lambda)}} \ , \tag{9.6.31}
$$

where C is some constant, which is determined once the rate of the energy dissipation is known.

The distribution of the kinetic energy of vortex per mass density ρ_m as a function of the vortex radius ρ can be evaluated using the formula

$$\frac{T(\rho)}{\rho_m} = \pi \int_0^{\rho} \beta^2(\rho)\rho d\rho \ . \tag{9.6.32}$$

1. For $\beta = K/\rho$ one obtains at the limit of the small radii

$$T(\rho) = C\pi K^2 ln(\frac{\rho}{\rho_0})(\frac{\rho}{\rho_0})^{\alpha+\frac{1}{ln(\lambda)}} \ . \tag{9.6.33}$$

The leading order behavior of the Fourier transform of the energy function defined as $\hat{T}(p) \equiv \int exp(ip\rho)T(\rho)d\rho$ is for small values of the wave vector given by

$$\begin{aligned} \hat{T}(p) &\simeq p^{\Delta} \ , \\ \Delta &= -1-\alpha-\frac{1}{ln(\lambda)}) \ . \end{aligned} \tag{9.6.34}$$

2. For $\beta = \Omega\rho$ one obtains

$$\begin{aligned} T(\rho) &= C\pi\Omega^2(\frac{\rho}{\rho_0})^{4+\alpha+\frac{1}{ln(\lambda)}} \ , \\ \Delta &= -4-\alpha-\frac{1}{ln(\lambda)} \ . \end{aligned} \tag{9.6.35}$$

In the Heisenberg model for the turbulence [23, 22] a similar form is obtained and the exponent is in that case equal to $\Delta = -5/3$ and experimentally verified in some cases. It should also be noticed that according to [22] the assumptions implying $\Delta = -5/3$ in the Heisenberg model are not strictly true for the small values of the vortex radii. On basis of this result it seems that the values of $\Delta(TGD) = -4-\alpha+\frac{1}{ln(\lambda)}$ are un-physical in the case of the rigid body flow.

Only the flow $\beta = K/\rho$ predicting constant Z^0 magnetic field apart from logarithmic corrections predicts physically acceptable values of Δ. For $\lambda = 2^5$ one would have $\Delta(TGD) = -1-\alpha-\frac{1}{ln(\lambda)} \simeq -1.709$ to be compared with $-5/3 = -1.667$ of the Heisenberg model. The deviation from the prediction of Heisenber model is 2.5 per cent. The prediction does not depend strongly on the value of of the $\lambda = 2^{-x}$ and at the limit $x = \infty$ one has $\Delta = -2$. Hence a statistical distribution for the p-adic scalings involved with the decay does not affect dramatically the prediction.

The general vision about dark matter hierarchy characterized by the values of Planck constant given by $\hbar(n) = \lambda^{-n}\hbar(1)$, $\lambda = v_0/n \simeq 2^{-11}/n$, n integer, encourages to consider the possibility that the scaling is associated with a transition $\hbar(n) \rightarrow \hbar(n-1)$ to a lower level in the dark matter hierarchy accompanied by the reduction of Compton lengths and Compton times by factor λ. The decay to smaller vortices would correspond to a reduction of quantum coherence via a decay of dark weak bosons to lower level dark weak bosons. For $n = 1$ one has $\Delta = -1.869$. For $n = 3$ one would have $\Delta = -1.885$.

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Chapter 10

Macroscopic Quantum Phenomena and CP_2 Geometry

10.1 Introduction

Super conductivity, super fluidity and quantum Hall effect are examples of macroscopic quantum phenomena and it is instructive to apply the TGD inspired topological ideas about the formation of the macroscopic quantum systems to these phenomena. This chapter is is written for about 15 years ago and I hope that the reader does not forget that much has occurred in TGD since then.

For instance, Z^0 magnetic fields are suggested to be important for understanding super fluidity without precise characterization of there origin. About 15 years after writing the first version of this chapter, it became clear that the source of thelong ranged Z^0 fields, as well as other weak fields and color gauge fields predicted by the classical theory could be dark matter at various space-time sheets. Also a precise number theoretic characterization of dark matter, or actually infinite hierarchy of dark matters, emerged. Already earlier it had become clear that the theory predicts a fractal hierarchy of scaled down copies of electro-weak and color physics. I have not added any discussion of the origin of Z^0 classical gauge fields here. This kind of discussion can be found [**?**] and in [F6, F8, F9] .

In the first section the general ideas of the TGD inspired description of supra phases are described. The aim is to make clear the close similarity between super conductivity and super fluidity by treating these phenomena in parallel. What makes possible the unified description is the hypothesis that the role of the ordinary magnetic field in the super conductivity is taken by the Z^0 magnetic field in the super fluid phase.

In the second, more technical section, certain simple imbeddings of Kähler electric and magnetic fields created by matter and relevant to the applications of the theory, are studied.

In the third section a TGD inspired phenomenological description of Quantum Hall effect is proposed. A more refined view about Quantum Hall effect developed about 15 years later can be found in [E9]. In the last section the TGD inspired description of less exotic condensed matter phenomena (conductors, di-electrics and magnetism) using TGD based concepts will be discussed briefly.

10.2 General theory

RGE invariance predicts that that 3-space should have fractal like structure consisting of topological field quanta of all possible sizes glued on each other by the topological sum operation. The join along boundaries bond provides a tool for constructing larger quantum systems from the smaller ones. Since dissipation corresponds to a loss of the quantum coherence, join along boundaries bond should provide a key to a topological description of the dissipation. The generation of the long range classical Z^0 fields is a phenomenon characteristic for TGD, and is expected to be important in the small vacuum quantum number limit of TGD at the condensate levels $n \geq n_Z$ $L(n) \geq \xi \sim 10^{-6}\ m$. For supra phases the correlation lengths are such that classical Z^0 force should not have any role in their description.

The mathematical similarities between super conductors and super liquids however suggest that Z^0 magnetic field might play same role in the description of dissipation of super fluids as ordinary magnetic

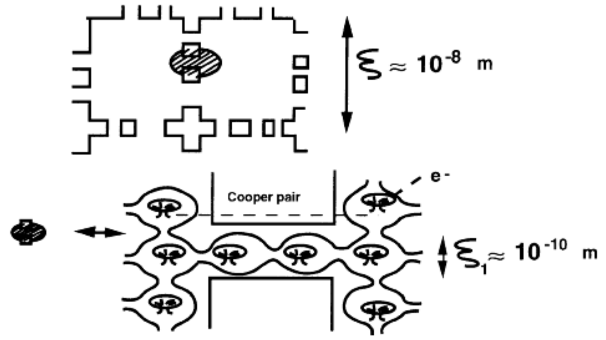

Figure 10.1: Schematic representation for super conductor

field in the description of the super conductors. The many sheeted structure of the topological condensate and length scale hierarchy remains rather implicit in the following considerations and the most relevant condensation levels are 'atomic condensation level' at which electrons and nuclei are condensed and the level n_Z at which nuclei feed their Z^0 charges.

10.2.1 Identification of the topological field quanta

Both super conductors and Super fluids are characterized by the coherence length ξ. This length tells the size of the largest possible coherent quantum subsystem in the ordinary phase and becomes infinite, when the transition to the supra phase takes place. Below the critical point the value of ξ is finite, but there is macroscopic quantum coherence since the order parameter develops vacuum expectation value. Since topological field quanta correspond in TGD framework to coherent quantum systems a natural assumption is that the relevant topological field quanta have size of the order of ξ. ξ is typically of the order of $\xi \simeq 10^{-8} - 10^{-7}$ meters for super conductors, for super fluid He^4 ξ is of the order of atomic length scale and for He^3 ξ is of the order of 10^{-8} meters. This suggests that also ordinary matter behaves like supra phase in the length scales shorter than ξ. Of course, the corresponding time scale is rather short for the typical velocities of the supra flows.

In accordance with RGE hypothesis, it is assumed that topological field quanta of size ξ have suffered topological condensation in the background 3-space and topological field quanta in turn contain matter as topologically condensed 3-surfaces having size of atomic length scale (see Fig. 10.2.1 and 10.2.2 for a schematic description of what the supra phases look like). For super conductors the topological field quanta of atomic size have also joined along their boundaries to form a lattice.

The size of the topological field quantum is determined by the vacuum quantum numbers associated with it. Since the size of the topological field quantum is rather small, the values of the vacuum quantum ω_1, ω_2 must be small. A first principle explanation for the finite size of the topological field quantum is the maximation of Kähler function. The contribution of the Kähler electric field to the Kähler action is smaller in magnitude if topological field quantization takes place: the reason is that Kähler electric field necessarily vanishes at some point(s) inside the topological field quantum.

In the simplest model for a topological field quantum matter serves as a source of Kähler field, which in present case is purely electromagnetic field and possible due to the incomplete screening of the nuclear electromagnetic charge by electrons. The critical radius associated with the imbedding of the Kähler electric field gives the size of the topological field quantum, which should be of the order of ξ. The simplest model for the field quantum is as a spherical region. The join along boundaries condensate of the topological field quanta serves as a model for the ordinary phase.

The sizes of the field quanta are exponentially sensitive to the value of the fractal quantum number m, which is small in present case. The order of magnitude for ω_1 is not much larger than proton mass: the estimates give $\omega_1 = (10^{2.5} - 10^3)m_p$ (m_p is proton mass). In the astrophysical length scales and possibly also in the background 3-space surrounding topological field quanta in question the value of ω_1 is of the order of $m_0 \sim 1/R \sim 10^{-4} m_{Pl}$, where R is CP_2 radius.

Inside each topological field quantum one must perform a choice of the quantization axis and in the ordinary phase these choices are not correlated in accordance with the idea that quantum coherence is lost. In supra phase the presence of the join along boundaries bonds implies that same choice of the quantization axis must be performed in the whole phase and the global choice of the quantization axis is analogous to that taking place in the quantum measurement.

10.2.2 Formation of the supra phase

Supra phase corresponds to lattice like structure of the topological field quanta of size ξ joined together by the join along boundaries bonds. In the lowest order approximation one can regard this lattice as a network formed by straight cylinders glued together by bonds. (see Fig. 10.2.1 and 10.2.2). In supraphase the quantum numbers n_1 associated with the composite field quanta must vanish identically since otherwise the coordinate Φ is discontinuous somewhere on the bond joining the neighbouring field quanta and the field quantum in question separates from the supra phase. Exception is formed by the direction of the quantization axis, where bonds survive.

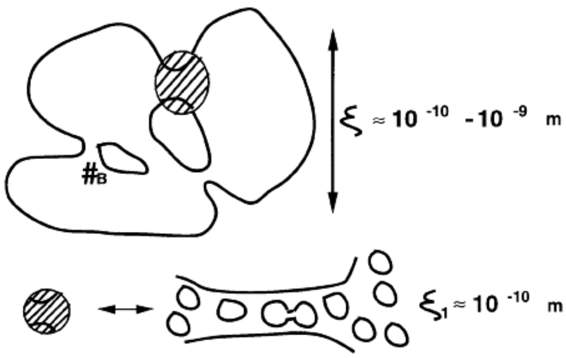

Figure 10.2: Schematic representation for Super Fluid

Two-fluid picture topologically

Supra flow is made possible by the bonds between the neighbouring topological field quanta and there is no essential difference between super conductors and super fluids in this respect. In case of the super conductors the topological field quanta form a rigid lattice but in case of super fluids topological field quanta are able to move. This freedom implies the two-fluid picture of the super fluidity (see Fig. 10.2.2) as the following argument shows.

1. Normal liquid corresponds to the topological field quanta (of size ξ), which flow in the background 3-space. Since the bonds are absent in the ordinary phase, the matter condensed on the topological field quanta follows the flow of the topological field quanta so that topological field quanta can be regarded as effective fluid particles and their mass density is that of the liquid: $\rho_n = \rho$.

2. In supra phase the presence of the bonds make possible the flow of the topologically condensed matter and if the bonds are stable the condensed matter flows completely freely: $\rho_s = \rho$. This means that topological field quanta itself lose totally their inertia so that $\rho_n = 0$. Although the flow of the topological field quanta is possible it does not correspond to the flow of an inertial mass. This is certainly the situation at sufficiently low temperatures.

3. For temperatures slightly below T_c the situation is known to be intermediate between these two situations and two-fluid hydrodynamics [23] is a good phenomenological description of the

situation. One can consider two alternative explanations for this state of affairs. The first explanation is that the fluid is a mixture of the normal and super fluid components not only in critical temperature but also little below it so that one can speak about two fluids with average densities satisfying the condition $\rho_n+\rho_s = \rho$. The second alternative is that for the temperatures close to T_c the bonds are not completely stable and condensed matter doesn't flow completely freely so that topological field quanta do not lose their inertia totally.

4. One can understand also the frictionless supra flow in this picture. For example, in the frictionless supra flow in a channel, the topological field quanta are at rest with respect to the walls of the channel and only the matter condensed on the field quanta flows.

It should be emphasized that in TGD framework it is not possible to apply two-fluid picture to the description of the electrons in Super conductors since the particles of the "normal fluid" correspond to topological field quanta rather than electrons or atoms.

Ground states for the supra phases

In the ground state of the super conductor, the order parameter is covariantly constant with respect to the covariant derivative defined by the electromagnetic gauge potential. Covariant constancy indeed makes sense since, in the absence of the magnetic fields, the gauge potential is pure gauge in the spatial degrees of freedom. In the standard physics context the first homotopy group of the 3-space is trivial and gauge potential can always be gauge transformed away so that the order parameter is just constant in the ground state. In TGD context, the first homotopy of 3-surface is nontrivial and very complicated for a join along boundaries condensate formed from the topological field quanta glued by the join along boundaries bonds. This implies that there is rich structure of different covariantly constant ground states, which look macroscopically identical since the splitting of single join along boundaries bond is not expected to affect the macroscopic properties of the system.

The induced gauge potential is in the case of the super conductors just the electromagnetic gauge potential. Assuming that Z^0 gauge fields are absent, one obtains the proportionality of the electromagnetic and Kähler gauge potentials:

$$A_{em} = 3A_K = 3P^k dQ_k \ . \tag{10.2.1}$$

Here P_k and Q_k are canonical coordinates for CP_2. An especially natural choice for the canonical coordinates is the one for which Q_k, $k = 1, 2$ correspond to the phase angles Ψ and Φ associated with the complex CP_2 coordinates for which the action of $U(2)$ rotations is linear.

In case of the supra fluids Z^0 gauge potential if electromagnetic neutrality holds true and again the gauge potential is proportional to Kähler potential

$$\begin{aligned} A_Z &= \frac{6}{p}A_K = \frac{6}{p}P^k dQ_k \ , \\ p &\equiv sin^2(\theta_W) \ . \end{aligned} \tag{10.2.2}$$

If the ground state has vanishing gauge field the induced Kähler field must vanish and one has vacuum extremal of the Kähler action satisfying

$$P_k = \partial_k f(Q_i) \ , \tag{10.2.3}$$

where f is arbitrary function of the coordinates Q_i. In case that Q_i correspond to the angle coordinates Ψ and Φ of CP_2 one can write $f(Q_i)$ as a sum of a zero mode part and Fourier expansion

$$f = m\Psi + n\Phi + \sum_{kl} c_{kl} exp(ik\Psi + il\Phi) \ . \tag{10.2.4}$$

The covariant constancy condition for an order parameter possessing em (Z^0) charge Q_{em} (Q_Z) reads as

$$\begin{aligned}
(\partial_\mu + ia\partial_\mu f)\psi &= 0 \ , \\
a_{em} &= 3Q_{em} \ , \\
a_Z &= \frac{6Q_Z}{p} \ .
\end{aligned} \tag{10.2.5}$$

The solution of the condition is

$$\begin{aligned}
\psi &= exp(iS)\psi_0 \ , \\
S_{em} &= -3Q_{em}f \ , \\
S_Z &= -\frac{6Q_Z}{p}f \ .
\end{aligned} \tag{10.2.6}$$

in the two cases respectively.

The phase increments around the closed homotopically nontrivial loops clearly characterize the ground state of the supra phase. In the electromagnetic case the change of the phase of ψ around a closed loop equals to

$$\Delta S_{em} = 3Q_{em}(m\Delta\Psi + n\Delta\Psi) \ , \tag{10.2.7}$$

and is clearly a multiple of 2π (also for quarks!) since m and n appearing in the expansion of f are in general integers. For supra fluids one has

$$\Delta S_Z = \frac{6Q_Z}{p}(m\Delta\Psi + n\Delta\Phi) \ , \tag{10.2.8}$$

The values of Q_Z for proton and neutron are $Q_Z(neutron) = -1/4$ and $Q_Z(proton) = 1/4 - p$ so that one has for an order parameter describing the supra flow of nuclei (A, Z)

$$\Delta S_Z = 6(\frac{((2Z-A)}{4p} - Z))(m\Delta\Psi + n\Delta\Phi) \ , \tag{10.2.9}$$

The increment is *not* integer multiple of 2π without additional conditions on the value of the Weinberg angle. If p is rational number of form $p = r/s$, s must divide m and n. For instance, for $sin^2(\theta_W) = 1/4$ the vectorial couplings of the electron and proton to Z^0 field vanish and the average Z^0 charge of neutron is $Q_Z(n) = -1/4 = p$ so that one has in general $Q_Z(nucleus) = -(A-Z)/4$ and the increment of S_Z is automatically multiple of 2π for all choices of m and n:

$$\Delta S_Z = -6(A-Z)(m\Delta\Psi + n\Delta\Phi) \ . \tag{10.2.10}$$

Also for $p = 3/8$ the condition is identically satisfied.

For more complicated supra phases (Super liquid He^3) the order parameter possesses several components but also now a similar situation results. It is tempting to assume that for more general states the phase factor of ψ is power of S. If this is the case then supra phases are exceptional in the sense that CP_2 angle coordinates appear as physical observables rather than only the gauge fields (proportional to the gradients of CP_2 coordinates) as in the ordinary ordinary phase. What is clear is that the information about the homotopy of the state is coded into the phase of the order parameter. This state of affairs is especially interesting as far the applications to the BE condensate of the charged # throats possibly having an important role in bio-systems, are considered.

Binding energies and critical temperatures

What makes the supra flow possible are the bonds. Cooper pair also stabilize the bonds in case of the super conductors and ^3He super fluid. This becomes clear from the fact that the electrons of the Cooper pair have an average distance, which is considerably larger than ξ (about 10^{-6} meters in super conductors [23]) so that the splitting of the bonds destroys Cooper pairs. Energy is however needed to destroy Cooper pairs and this implies stability. If the energy associated with the bonds were negligible with the binding energy associated with the Cooper pairs the phase transition leading to super conducting phase would be a first order transition involving non-vanishing latent heat. This is however not the case [23]. This means that the binding energy of the Cooper pairs doesn't leave super conductor and probably goes to the energy associated with the bonds. Therefore the stabilization mechanism relies on the difficulty of transferring the bond energy to the Cooper pairs.

A rough estimate for the binding energy for the Cooper pair provides a test for the proposed ideas. In the ordinary phase conduction electrons tend to be confined inside the topological field quanta so that by Uncertainty Principle they possess kinetic energy of the order of

$$T \simeq \frac{1}{2m_e\xi^2} . \tag{10.2.11}$$

In the super conducting phase conduction electrons are not localized inside single field quantum so that the average kinetic energy is smaller and the order of magnitude estimate

$$\Delta E \simeq \frac{1}{4m_e\xi^2} , \tag{10.2.12}$$

for the binding energy of the Cooper pair is obtained. For $\xi \simeq 10^{-7}$ meters one obtains $\Delta E \simeq 10^{-4}eV$, which coresponds to the temperature of $T_c \simeq 0.25\ K$. The order of magnitude is correct.

For a high temperature super conductors with $T_c \simeq 100\ K$, the estimate gives $\xi \simeq 10^{-9}$ meters. High temperature super conductors have layered structure. In case of $YBa_2CU_2O_7$ the coherence length is $\xi_c = 1.5 - 3$ Angströms in the direction orthogonal to the layers and $\xi_{ab} = 14 \pm 2$ Angströms in the direction of the layers [19]. The supra current is known to be confined inside the layers so that ξ_{ab} should determine the critical temperature: the orders of magnitude are consistent with the formula correlating Δ and ξ in the example considered and also more generally, since the transversal coherence lengths are known to be by an order of magnitude smaller than for the ordinary super conductors.

For the binding energy of the super fluid particles one obtains a completely analogous estimate (m_e is replaced with the mass of He^3 or He^4 nucleus) and correct order of magnitude estimates are obtained for both He^3 and He^4 having widely different values of ξ (ξ is about 10^{-8} meters and few Angströms for ^4He and ^3He respectively). From the binding energies one can estimate the critical temperatures ($T_c \simeq \Delta E$) and correct order of magnitude estimates are obtained.

The presence of super fluid phase in neutron stars has been suggested [23]: Cooper pairs correspond to paired neutrons. The size of the field quantum is of the order of $\xi = 10^{-15} - 10^{-14}$ meters (this estimate is derived in the second section). For the critical temperature one obtains: $T_c \simeq 1/4m_n\xi^2 = 10^{11} - 10^{13}$ K.

In BCS theory ΔE is expressed in the following form [23]

$$\begin{aligned} \Delta &= 2\omega_D exp(-\frac{2}{N(0)V}) , \\ \omega_D &= \frac{c_s 6^{1/3}\pi}{N^{1/3}} . \end{aligned} \tag{10.2.13}$$

Here ω_D is Debye frequency, $N(0)$ is the density of states on the surface of the Fermi sphere and $V(0)$ characterizes the strength of the attractive force between the electrons of the Cooper pair. N is the number density of atoms and c_s is the velocity sound. The proportionality to ω_D implies isotope effect: $\Delta \propto 1/A^{\alpha}$, where α is typically of the order of $\alpha \simeq 1/2$, which has been verified experimentally

[23]. Assuming that both formulas are correct one gets a relationship between the vacuum quantum numbers ω_1 and ω_2 since ξ corresponds to the radius of the topological field quantum and is expressible in terms of the vacuum quantum numbers.

10.2.3 Generalized quantization conditions

In the standard formulation of the quantum description of Super conductivity one starts from Schrödinger amplitude ψ_s for supra phase. The expression for the matrix element of the electric current is given by

$$\begin{aligned} \bar{j}_e &= -i\frac{e}{2m}(\bar{\psi}_s\bar{D}\psi_s - c.c.) \ , \\ \bar{D} &= \nabla + iqe\bar{A} \ . \end{aligned} \tag{10.2.14}$$

Here q denotes the charge of the superconducting charge carrier in units of e. $q=-2$ for the super conductors encountered in laboratory. One can write ψ_s in the form $\psi_s = \sqrt{n_S}exp(iS)$.

Since n_s is in a good approximation constant in supra phase the expressions for the electric current and velocity operator can be written as

$$\begin{aligned} \bar{j}_e &= -\frac{e}{m}n_s(\nabla + qe\bar{A}) \ , \\ \bar{v}_s &= \frac{1}{m}(\nabla S + qe\bar{A}) \ . \end{aligned} \tag{10.2.15}$$

Since S is single valued, one obtains by integrating over a closed curve a formula relating the magnetic flux and velocity circulation for the carriers of the super current to each other.

$$\oint \bar{v}\cdot d\bar{l} - \frac{qe}{m}\oint \bar{A}\cdot d\bar{l} = \frac{n2\pi}{m} \ . \tag{10.2.16}$$

If the velocity field vanishes in the curve in question, one obtains the standard quantization of the magnetic flux.

By taking a curl of the formula for $\bar{v}_s$ and using Maxwell's equations one gets the standard formula

$$\begin{aligned} \nabla^2\bar{B} &= \frac{\bar{B}}{\lambda^2} \ , \\ \lambda^2 &= \frac{2m}{n_sq^2e^2} \ . \end{aligned} \tag{10.2.17}$$

Here λ is the peneration length for the magnetic field in the super conductor.

TGD predicts that vacuum Z^0 field can become long ranged at small vacuum quantum number limit of TGD and super fluidity might correspond to this kind of situation. If this is indeed the case then the previous formulas for the super conductors generalize in an obvious manner to the case of Super fluids

$$\oint \bar{v}\cdot d\bar{l} - \frac{Q_Zg_Z}{M}\oint \bar{A}_Z\cdot d\bar{l} = \frac{n2\pi}{M} \ . \tag{10.2.18}$$

Here M is the mass of the super fluid particle (He^4 or the Cooper pair formed by two He^3 atoms), g_Z is the gauge coupling of the Z^0 gauge interaction ($g_Z^2 = e^2/sin\theta_W cos\theta_W$) and Q_Z is Z^0 charge of the super fluid particle. Q_Z is defined as the expectation value over the spin degrees of freedom

$$\begin{aligned} Q_Z &= \langle I_L^3 - pQ_{em}\rangle \ , \\ p &= sin^2(\theta_W) \ . \end{aligned} \tag{10.2.19}$$

The values of Q_Z for quarks and electron at rest are

$$Q_Z(u) = \frac{1}{4} - \frac{2p}{3} \ , \quad Q_Z(d) = -\frac{1}{4} + \frac{p}{3} \ , \quad Q_Z(e) = -\frac{1}{4} + p \ . \tag{10.2.20}$$

From these one obtains the values of Q_Z for proton and neutron: $Q_Z(p) = 1/4 - p$ and $Q_Z(n) = -1/4$ respectively. The values of Q_Z for He^4 and He^3 are

$$Q_Z(^4He) = -\frac{1}{2} \ , \quad Q_Z(^3He) = -\frac{1}{4} \ . \tag{10.2.21}$$

If the magnetic flux associated with Z^0 magnetic field vanishes one obtains the standard formula for the quantization of the velocity circulation of the super fluid. The expression for the penetration depth of the Z^0 magnetic field reads as

$$\lambda^2 = \frac{2M}{N_s Q_Z^2 g_Z^2} \ . \tag{10.2.22}$$

The order of magnitude of λ is of the order of $10^{-5} - 10^{-6}$ meters in accordance with the basic assumption $\xi \sim 10^{-6}$ meters for the scale at which classical Z^0 force becomes important. In this formula N_s is the entire super fluid density (essentially Z^0 charge density) and the formula makes sense at the condensation level at which the nuclei feed their Z^0 charges. At the higher condensate levels n, one must replace the density with the actual density of Z^0 charge $N_s \rightarrow N_s/\sqrt{\epsilon_Z(n)}$ (due to the neutrino screening$\epsilon_Z(n)$ is rather large number).

It will found that this generalization implies considerable differences between TGD based and standard descriptions of the super fluidity. For example, the counter part of the magnetic flux quantum is predicted and is a good candidate for the elementary excitation leading to the dissipative super fluid flow at critical velocity considerably smaller than that associated with the known elementary excitations.

10.2.4 Dissipation in super fluids: critical velocities

Dissipation, or equivalently the loss of the quantum coherence results, when the lifetimes of the bonds connecting neighbouring field quanta are short and the joining and the splitting of the bonds provides the needed dissipation mechanism. One mechanism leading to a loss of the quantum coherence is thermal noise: the critical temperature has been already evaluated. In case of super conductors (super fluids) also external magnetic (Z^0 magnetic) fields lead to a loss of the quantum coherence: the values of the critical magnetic fields can be evaluated for the super conductors of type II and super fluids from the quantization condition. At a high enough flow velocity, the generation of the elementary excitations of the supra phase leads to dissipation. The estimates for the orders of magnitude for the critical velocities for the setup of the dissipation will be derived and are correct in both cases.

Critical velocity for super fluids

The so called Principle of Super Fluidity provides an explanation for the critical velocity of the Super fluid [23]. The application of the energy and momentum conservation to the emission of elementary excitation of energy ϵ and momentum p by flow implies the condition $v \geq \epsilon/p$ and therefore the critical velocity is given by the formula

$$v_L = Min\{\frac{\epsilon}{p}\} \ . \tag{10.2.23}$$

In case of the super conductors the formula gives $v_L = \Delta(T)/k_F$ (Δ is the energy gap associated with the Cooper pair and k_F is Fermi momentum): the order of magnitude is correct. In case of Super fluids the critical velocities deduced from the roton and phonon spectrum (239 m/s and 58 m/s respectively) are several orders of magnitude larger than the velocities $v_{cr} \simeq 6 \cdot 10^{-3}$ meters), where the dissipation is known to set up. Velocity vortex predicts a critical velocity, which is too large by an order of magnitude. The hitherto unsolved problem is to identify the excitations giving rise to the dissipation in the supra flow.

The TGD based candidate for the excitation is Z^0 magnetic flux quantum. Z^0 magnetic flux quantum can appear at the condensate level with $L(n) \geq 10^{-6}$ meters to which nuclei feed their Z^0 charges so that the super fluid flow (typically rotating vessel) must have size scale much larger than this length scale. Both hydrodynamic and magnetic excitations are vortex like structures and in order to estimate orders of magnitude they can be idealized as straight vortices with a cylindrical symmetry, possessing Z^0 magnetic field in the direction of the vortex and rotational velocity field (to be studied in detail in the next section).

A general order of magnitude estimate for the critical velocity is obtained by assuming that at velocities higher than the critical velocity the kinetic energy of the supra phase goes to the energy of the excitation in question. The criticality criterion states that $dE_K(R)/dl$, the kinetic energy of the supra flow per unit length of the vortex of radius R and $dE_{ex}(R)/dl$, the energy of the excitation per unit length of the vortex, are identical:

$$\frac{dE_K(R)}{dl} = \frac{dE_{ex}(R)}{dl} .$$

This implies for the critical velocity the expression

$$v_{cr} = \sqrt{\frac{2}{NM\pi R^2}}\sqrt{\frac{dE_{ex}(R)}{dl}} . \tag{10.2.24}$$

Let us consider now in more detail the magnetic and hydrodynamic vortices.

a) Z^0 magnetic flux quantum

For the Z^0 magnetic flux quantum it is natural to assume that the core of the vortex corresponds to $n_1 \neq 0$ excitation since the requirement that no magnetic field is present implies $n_2/n_1 = \omega_2/\omega_1$ so that both n_2 and n_1 must be non-vanishing. A reasonable idealization for the vortex core is as a cylinder of radius ξ. Inside the vortex core the order parameter of the supra phase is constant so that the condition

$$\oint \bar{v} \cdot d\bar{l} - \frac{Q_Z g_Z}{M_4} \oint \bar{A}_Z \cdot d\bar{l} = 0 , \tag{10.2.25}$$

holding true for the ground states described by covariantly constant order parameter, is appropriate. The general quantization condition allows $n \neq 0$ but this implies singular velocity in the core of the vortex so that it will be dropped from consideration.

Since $B_Z = B_Z^0$ is constant, one can solve $\bar{v}$

$$v = \frac{g_Z Q_Z B_Z^0}{2M_4}\rho . \tag{10.2.26}$$

The core rotates like a rigid body and the rotation frequency is just the rotation frequency of Z^0 charged particle in Z^0 magnetic field. $\nabla^2 B_Z = 0 \neq B_Z/\lambda^2$ so that the matter inside the vortex core is not in supra phase.

Outside the vortex core the conditions

$$\begin{aligned}\oint \bar{v} \cdot d\bar{l} - \frac{Q_Z g_Z}{M_4} \int B_Z da &= \frac{n2\pi}{M_4} , \\ \nabla^2 B_Z &= \frac{B_Z}{\lambda^2} .\end{aligned} \tag{10.2.27}$$

are satisfied.

Both Z^0 magnetic and velocity fields decay exponentially. At large distances one obtains flux quantization and the constant value of B_Z inside the vortex core is fixed by the flux quantization condition:

$$B_Z^0 = [-2\int_{\xi}^{\infty} B_Z \rho d\rho + \frac{2n}{g_Z Q_Z}]\frac{1}{\xi^2} \ . \tag{10.2.28}$$

For order of magnitude purposes one can use the approximation

$$B_Z^0 \simeq \frac{2n}{q_Z Q_Z \lambda^2} \ . \tag{10.2.29}$$

Since the magnitude of B_Z^0 is quantized in integer multiples, all values of n are possible.

There are two contributions to the energy density of the flux quantum. The energy E_B of the Z^0 magnetic field and the kinetic energy T_{rot} of the rotating super fluid particles. The latter contribution is negligible ($T_{rot}/E_B \simeq (\xi/\lambda)^2$) so that it is enough to consider the magnetic energy density. Since B_Z is largest in the core of the vortex the most conservative form for the criterion is obtained by requiring that the kinetic energy density $T_K = N_s M_4 v^2/2$ of the super fluid flow equals to the Z^0 magnetic energy density $E_B = B_Z^2/2$ inside the core. This condition gives the following expression for the critical velocity

$$v_{cr}(magn) = \frac{B_Z^0}{\sqrt{NM_4}} \simeq g_z Q_Z \sqrt{\frac{N_s}{M_4^3}} \ . \tag{10.2.30}$$

Substituting the typical value of N_s: $N_s \simeq 10^{28.5}/m^3$ one finds $v_{cr} \simeq 10^{-3}$ m/s. The value of the critical velocity is indeed known to be few millimeters in second [23, 20]!

b) Hydrodynamic vortices

The velocity field of the vortex behaves as k/ρ, where $k = n2\pi/M$ is the quantized vorticity. The kinetic energy of the vortex is of the order of $M_4 k^2 ln(\lambda/\xi)/2$ so that that one obtains for the critical velocity the expression

$$v_{cr}(hydro) \simeq \sqrt{2} ln(\lambda/\xi) v_{cr}(magn) \ . \tag{10.2.31}$$

Substituting the numerical values of the parameters, one finds that the numerical factor is of the order of ten so that hydrodynamic critical velocity is too large by an order of magnitude[23, 20].

Critical velocities for the super conductors

To derive the critical velocities for the super conductors of type II one can apply considerations formally identical with the previous ones. The structure of the magnetized vortices is similar to that of Z^0 magnetized vortices and at the critical velocity the kinetic energy density of the super conducting phase must be identical to the magnetic energy density of $n_1 = 1$ excitation:

$$\frac{n_s m_e \beta_c^2}{2} = \frac{B_c^2}{2} \ . \tag{10.2.32}$$

Using the expression for the number density of the super conducting electrons $n_s = \frac{m_e}{e^2\lambda^2}$ one gets

$$\beta_c = \frac{B_c \lambda e}{m_e} \ . \tag{10.2.33}$$

Using the estimate for B_c one obtains $\beta_c \simeq \frac{\sqrt{4\pi}}{m_e\lambda}$ for the super conductors of type II. The order of magnitude obtained, typically 10^2 m/s, is correct [23]. For super conducting elements of type I β_c is considerably smaller since both the critical field and λ are smaller: the order of magnitude is few meters per second and considerably smaller than the critical velocity v_L obtained from the Landau criterion.

10.2.5 Meissner effect

Meissner effect is one of the basic effects of super conductivity and it is of interest to find the TGD based description of the effect and how Meissner effect generalizes to the super fluid phase.

Meissner effect in superconductors

Meissner effect differs for the super conductors of type I and II. For super conductors of type I, the external field penetrates the whole super conductor if it has strength larger than the critical strength B_c. For super conductors of type II the external magnetic field begins to penetrate after having reached certain critical value B_{c_1} and total penetration takes place at considerably larger value of B_{c_2}. The penetration takes place as flux quanta

$$\int B \cdot da = \frac{m\pi}{e} , \tag{10.2.34}$$

where m is integer. This condition follows from the general quantization conditions provided the velocity of the super conducting charge carriers vanishes for large distances from the core of the magnetic flux quantum.

The TGD inspired model for the Meissner effect is based on the following observations.

1. The study of the simple models for the topological field quanta to be carried out later shows that in the supra phase topological field quanta have vanishing magnetic vacuum quantum numbers (n_1, n_2) and that there is a nontrivial magnetic field associated with $(n_1, n_2) \neq (0, 0)$ excitations of the topological field quanta. Magnetic field is in the direction of the quantization axis and is approximately constant for a cylindrically symmetric field quantum. The flux of this magnetic field is also quantized by purely topological reasons.

   For $(n_1 = 0, n_2 \neq 0)$ magnetic field is also non-vanishing and this field doesn't cut the bonds between the field quanta so that one could in principle construct a magnetic field in super conductor using these excitations. If, however, the condition

   $$k \equiv \frac{\omega_2}{\omega_1} \ll 1 , \tag{10.2.35}$$

   holds true, then the flux associated with $(n_1 \neq 0, n_2 = 0)$ is much smaller than for $n_1 = 0$ excitations and it is energetically more favorable to excite $n_1 \neq 0$ excitations so that super conductivity is lost. The study of the simple models for field quanta shows that the assumption that ω_1 has same value for all supra phases, implies this condition.

2. The flux of the critical magnetic field is typically of the order of 10^{-2} Tesla and the flux of B_{c_2} over the field quantum of radius $\xi \simeq 10^{-7}$ m is considerably smaller than the quantized value of the magnetic flux for the super conducting elements (mostly of type I).

3. Since λ is much smaller than ξ for super conductors of type I, the magnetic flux associated with the magnetic vortex is smaller than the quantized magnetic flux, which together with the quantization condition implies that the velocity associated with the vortex cannot approach zero in large distances so that the kinetic energy of the vortex is large and this kind of excitation is not energetically favorable in case of the super conductors of type I. Rather, the magnetic field penetrates as $n_1 \neq 0$ excitation into each topological field quantum separately and as a result the bonds between field quanta are destroyed in the directions transversal to the magnetic field and supra phase is destroyed. For the super conductors of type II λ is large as compared to the radius of the vortex core and magnetic field can penetrate in the form of the flux quanta.

These observations suggest the following description of the Meissner effect.

a) Meissner effect for the super conductor of type I

Magnetic field penetrates into super conductors of type I as topologically nontrivial ($n_1 = 1 \neq 0$) excitations of the individual field quanta (see Fig. 10.2.5). The critical magnetic field is just that associated with $n_1 = 1$ excitation and the penetration of the magnetic field tends to destroy the bonds between the neighbouring field quanta since Φ becomes necessarily discontinuous on the bond. The bonds in the direction of $\bar{B}$ form an exception and might well survive. A structure consisting of topologically condensed cylinder like structures (see Fig. 10.2.5) results. That super conductivity disappears totally is suggested by the observation that $\Lambda = 0$ inside these structures and by the fact electrons rotate in the magnetic field.

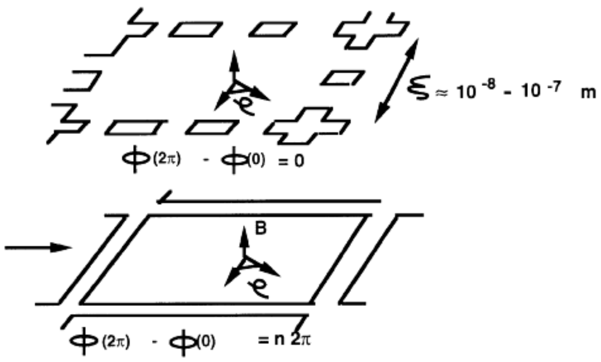

Figure 10.3: The penetration of magnetic field into a super conductor of type I

The quantization of the magnetic flux takes place in case of Super conductors of type I, too, but the unit is now defined by B_c and smaller than the standard unit. The requirement that the magnetic field associated with the $n_1 = 1$ field quantum equals to B_c gives condition on the vacuum parameters of type I super conductor.

It would be nice if one could estimate the value of the critical magnetic field or equivalently, the value of the magnetic field associated with the $n_1 = 1$ excitation. The prediction is possible provided one can estimate the values of the vacuum quantum numbers associated with the imbedding of Kähler electric field of matter: in the next section this kind of estimate is carried out.

b) Meissner effect for the super conductor of type II

Magnetic field penetrates into super conductors of type II as approximately cylindrical field quanta. The core of the cylinder corresponds to a topological field quantum of radius of order ξ, which has suffered topologically nontrivial ($n_1 \neq 0$) excitation. Since the flux associated with $n = 1$ quantum is considerably maller than that required by the quantization of magnetic flux, an exponentially damped magnetic field is created in the surrounding field quanta. This field corresponds to a topologically trivial deformation ($n_1 = 0$!) in the dependence of Φ on the M^4 coordinates and therefore the bonds connecting nearby neighbours are not destroyed and this region corresponds to a supra phase. The quantized magnetic flux is essentially given by the region surrounding the core.

The value of the critical magnetic field B_{c_1} can be estimated by noticing that the external magnetic field decomposes into field quanta with the property that the total flux of field quanta is same as that associated with the external field. This gives

$$B = n_v \frac{\pi}{e} , \qquad (10.2.36)$$

where n_v is the number of flux quanta per unit area. As an estimate for n_v one can take $n_v \simeq 1/\pi\lambda^2$, so that one obtains the estimate

$$B_{c_1} \simeq \frac{1}{e\lambda^2} . \tag{10.2.37}$$

The order of magnitude is about 10^{-1} Tesla for $\lambda \simeq 10^{-7}$ m: for Nb, which is the only superconducting element of type II the order of magnitude for critical magnetic field is indeed this [23]. The value of the magnetic field associated with $n = 1$ excitation cannot be very much larger than this field. It is natural to identify B_{c_2} as the magnetic field associated with $n_1 = 1$ excitation and so that the previous estimate combined with the estimate for B_1 gives $B_{c_2} \simeq 2B_{c_1}$.

Notice that the proposed model explains why ferromagnetic materials cannot be super conducting provided one can assume that the condition $k \ll 1$ holds true generally (ω_1 depends only weakly on material).

Meissner effect for super fluids

TGD predicts that Meissner effect is possible for super fluids, too and that super fluids are completely analogous to super conductors of type II. The magnetic vortices in the super fluid correspond to the quanta of the Z^0 magnetic flux.

The critical value of B_Z cannot be obtained directly from the experiment. The critical value of B_Z can be estimated by generalizing the formula of B_c for super conductors of type II and the formula for the penetration length λ

$$\begin{aligned} B_c^Z &\simeq \frac{1}{Q_Z g_Z \lambda^2} , \\ \lambda^2 &= \frac{2M}{Q_Z^2 g_Z^2 N_s} , \end{aligned} \tag{10.2.38}$$

where M is the mass of the super fluid particle and g_Z is Z^0 coupling constant and N_s the number density of the super fluid particles.

Superfluid should prohibit the penetration of Z^0 magnetic field created by some external source by creating surface flow. The obvious question is whether one can imagine any experimental tests for the prediction. To get grasp of the situation one can consider the following simple experimental arrangement.

A cylinder containing super fluid is surrounded by a rotating cylinder (see Fig. 10.2.5). The rotation of the outer cylinder creates Kähler magnetic and therefore also Z^0 magnetic field. Meissner effect implies that a surface flow is generated on the boundary of the super fluid vessel possessing direction opposite to that of rotation. A related effect would be the penetration of the Z^0 magnetic field in the form of vortices creating visible hydrodynamic vortices in the liquid. Unfortunately, the Z^0 field in question is extremely weak (for ordinary vacuum quantum numbers) so that the surface flow needed to cancel the Z^0 magnetic field is very small and might imply that the effect is not observable. Also the penetration of the field in the form of vortices is very unprobable since penetration takes place only above some critical field strength, which is quite large.

Consider next a simple quantitive model for the situation. The constant axial Kähler magnetic field created by the rotating outer cylinder is given by the expression

$$\begin{aligned} B^K_{out} &= \epsilon_1(out) N_{out} \Omega_{out} S_{out} , \\ S_{out} &= \pi(R_1^2 - R_0^2) , \end{aligned} \tag{10.2.39}$$

where S_{out} denotes the cross-sectional area of the outer cylinder with the inner radius R_0 and outer radius R_1 and rotating with the angular velocity Ω_{out}.

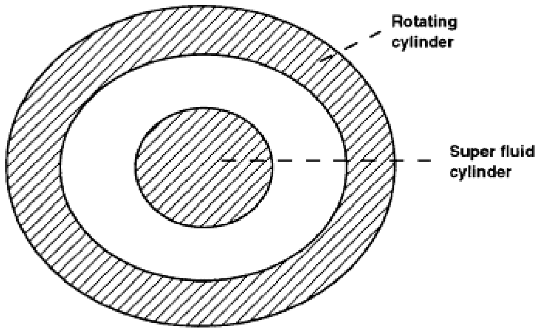

Figure 10.4: Experimental arrangement demonstrating Meissner effect for Super fluids

The constant axial magnetic field created by a surface current of thickness λ rotating around the superfluid cylinder of radius R is given by

$$\begin{aligned} B^K_{in} &= \epsilon_1(in) N_s \Omega_{in} Sin \ , \\ S_{in} &= \pi(R^2 - (R-\lambda)^2) \ , \end{aligned} \tag{10.2.40}$$

where N_s denotes the density of the super fluid particles and Ω_{in} is the rotation velocity of the super fluid flow.

These fields must cancel each other inside the super fluid so that a condition for the ratio of rotation frequencies results

$$\begin{aligned} \frac{\Omega_{in}}{\Omega_{out}} &= \frac{\epsilon_1(out)}{\epsilon_1(in)} \frac{N_{out}}{N_s} \frac{S_{out}}{S_{in}} \\ &\simeq \frac{\epsilon_1(out)}{\epsilon_1(in)} \frac{N_{out}}{N_s} \frac{R_1^2}{2R\lambda} \ , \end{aligned} \tag{10.2.41}$$

where the assumption $R_1 \gg R_0$ is made. An order of magnitude estimate for Ω_{in} is obtained using magnitudes $R_1 = 1\ m$, $R = 10^{-3}\ m$, $\lambda \simeq 10^{-5}\ m$ and $\Omega_{out} \simeq 10^3/s$. The Z^0 current fed from the "previous" condensate level serves as source of Z^0 magnetic field at level n since neutrinos do not participate in the flow. The estimate for the the ratio of parameters $\epsilon_1(n_Z)$ is obtained as follows: at nuclear condensate level one has $\epsilon_1 \sim 10^{19} g_Z$ (no screening) and at the condensate level n_Z one has $\sqrt{\epsilon_Z(n_Z)} \sim 10^{10} - 10^{11}$ from the estimate to be carried out in next subsection, which gives $\epsilon_1(out) \in 10^8 g_Z - 10^9 g_Z$. This gives

$$\Omega_{in} \sim 10^{-10} \frac{N_0}{N_s} \Omega_{out} \geq \frac{1}{200\ minutes} \ , \tag{10.2.42}$$

for $\epsilon_Z = 10^{11}$. Whether the existence or nonexistence of this kind of effect could be determined experimentally remains an open question.

Rotating super fluid

In the two fluid theory the condition that super fluid flow is irrotational ($\nabla \times \bar{v} = 0$) seems to exclude the rigid body rotation of the super fluid. On the average super fluid phase is however known to rotate like rigid body [23, 20] and the problem is to explain this result.

a) Hydrodynamic vortices

The generally accepted resolution of the difficulty [23] is that super fluid flow decomposes into hydrodynamic vortices, with the property that the flow is irro- tational inside the vortices except in the core of the vortex where super fluid density vanishes: this is achieved if the velocity is given by $v = k/\rho$. The requirement that super fluid wave function is single valued, implies the quantization of the circulation for the vortex

$$\oint \bar{v}\cdot d\bar{r} = \frac{n2\pi}{M} \ ,$$

implying the condition $k = n/M$. Vortices in turn form a regular array, which rotates like a rigid body. The average vorticity per surface area is given by $n_v k$, where k must be same as the vorticity of the rigid body rotation: this gives for the density of vortices the expression

$$n_v(hydro) = \frac{2\Omega}{2\pi k} = \frac{\Omega M_4}{\pi} \ . \qquad (10.2.43)$$

The vortex core, where super fluid density vanishes according to the conventional theory, should have radius $\rho_0 \simeq 10^{-10}\ m$. Although the vortices as such are not visible there is indirect experimental evidence for the existence of the vortex like structures, in particular for the existence of vortex cores [23, 20] possessing inner core radius of order $10^{-10}\ m$.

The generation of the vortices should begin at some critical angular velocity Ω (the circulation of the rigid body flow being of the order of the quantum of circulation at this value of Ω: this kind of effect has indeed been observed: the critical velocity is however smaller than the predicted one [23].

One can wonder what happens at the rotation velocities smaller than the critical one. Does super fluid flow like a rigid body or does it rotate at all? There is some experimental evidence supporting the view that super fluid does not rotate for sufficiently low rotation velocities so that the behavior is analogous to Meissner effect with Ω playing the role of the magnetic field.

b) Z^0 magnetic vortices

Consider now an alternative TGD inspired description of the situation. The problem is clearly created by the velocity circulation condition, which implies that supra flow is irrotational almost everywhere. In TGD approach the quantization condition however contains also the contribution of the Z^0 magnetic flux besides the velocity circulation so that there is no reason to require that velocity field has vanishing curl anymore! Assuming that super fluid flows as rigid body one can adjust B_Z so that the quantization condition is satisfied.

$$B_Z = \frac{2\Omega M_4}{g_Z Q_Z} \ . \qquad (10.2.44)$$

The resulting field is rather weak as compared to the critical B_Z. Ω must be of the order of $10^7/s$ (ten orders of magnitude larger than the critical rotation velocity for the formation of vortices!) to guarantee that B_Z is equal to the critical B_Z. This suggests that B_Z vortices cannot appear at rotation velocities studied and that the generation of the velocity vortices is the correct solution of the problem.

There are also other counter arguments. First, since the required field is much smaller than the critical field it seems impossible to imbed this magnetic field into super phase (one should excite some topological field quanta to $n_1 \neq 0$ state). Secondly, the generation of the subcritical magnetic field is excluded by the Meissner effect. Thirdly, $\nabla^2 B_Z = 0 \neq B_Z/\lambda^2$ so that super phase would be destroyed if constant B_Z is generated. On the other hand, the solution has the nice feature that the rigid body rotation of the super fluid could be regarded as a direct experimental evidence for the existence of macroscopic Z^0 field.

One manner to escape these problems is to argue that B_Z is constant in average sense only and that the actual field is consists of a network of Z^0 magnetic flux quanta in rigid body motion. The requirement that the total flux over the cross section of the container is same as the flux of constant field gives for the density of magnetic flux quanta per unit area the expression

$$n_v(magn) = \frac{\Omega M_4}{\pi} . \quad (10.2.45)$$

The density is identical with that obtained for hydrodynamical vortices! This observation suggests the solution to the discrepancy and a more detailed mechanism for the descruction of superfluidity. Super fluidity is destroyed, when Z^0 magnetic field (created by rotating Z^0 charge density) at condensation level $n_1 > n_Z$ ($L(n_Z) \sim 10^{-6}$ m) penetrates to the level n_Z in form of flux quanta with strength B_c^Z. The conservation of magnetic flux explains why the average field strength at the level n_Z is identical with the penetrating field strength at the level n_1. Since Z^0 charge current of the previous level serves as source of Z^0 magnetic at level n one obtains as a byproduct an estimate for the value of $\epsilon_Z(n_Z)$ from the formula 10.2.38 for the critical Z^0 magnetic field strength giving $\sqrt{\epsilon_Z(n_Z)} \sim 10^{10}$ and $\epsilon_1 \sim 10^9 g_Z$ so that neutrino screening of Z^0 charge at level n_Z is rather effective.

Which of the mechanisms is correct or are both mechanisms at work? In order to answer this question one should verify experimentally whether the vortices observed in a rotating super fluid are really velocity vortices or Z^0 magnetic vortices or both. Since the critical velocity for the Z^0 magnetic vortices is smaller than for the hydrodynamical vortices, one might argue that at critical angular velocity Z^0 magnetic vortices appear and hydrodynamic vortices appear for larger angular velocities. Some indirect support for the TGD based scenario indeed exists. The study of the rotating ^3He has demonstrated that the angular velocity Ω and ordinary magnetic field B play very similar physical role in the texture of the rotating ^3He and that the texture of ^3He is rather sensitive to both these parameters. In TGD picture one can replace Ω and B by B_Z and B and a rich structure of the quantized excitations is predicted.

10.2.6 Phase slippage

The so called phase slippage [16] provides a mechanism for the dissipation in the case o superfluids. Also this phenomenon has natural interpretation in terms of the flux quantization. The conventional description of the phase slippage is in terms of angle like order parameter χ. For linear flow the order parameter behaves linearly as a function of the coordinate x in the direction of the flow

$$\chi(x) = kx , \quad (10.2.46)$$

where k can be interpreted as the momentum of the super fluid particle.

In the phase slippage the graph of $\chi(x)$ as a function of x is deformed so that χ jumps by an integer multiple of 2π at some point x_0 and stays linear for $x \leq x_0$ and for $x \geq x_0$. The value of k must however decrease for $x \geq x_0$ and this means that the momentum of the super fluid particle decreases and dissipation occurs. Since the discontinuity is multiple of 2π the graph can be replaced with a new one without any discontinuity and smoothed out so that the graph of χ is linear with new value of the momentum k. The change in the momentum k is quantized:

$$\Delta k = n\frac{2\pi}{L} , \quad (10.2.47)$$

where L is the length of the channel. The process corresponds physically to the propagation of the vortex generated at the wall of the channel across the channel under the action of Magnus and friction forces and the integer n associated with the vortex ($\chi = n\phi$) equals to the integer associated with the Δk.

The process has obvious geometric interpretation in TGD approach. The angles Ψ and Φ are the counterparts of the angle like order parameter χ and phase slippage corresponds to the propagation of a vortex ($r = 0$ at the axis of the vortex and $r = \infty$ at the surface of the vortex) through the channel. In general the vortex is characterized by two integers n_1 and n_2. It has been already shown that the ordinary hydrodynamical dissipation and generation of turbulence might be understood in terms of the phase slippage process: the only difference with respect to the super fluidity is that the integers n_i and frequencies ω_i are much larger now: ordinary hydrodynamical system is obtained from the super fluid in the limit of the large quantum numbers.

10.3 Models for the topological field quanta

In the sequel simple models for the electromagnetic and Z^0 gauge fields created by condensed matter are studied. The aim is to get some grasp on the physically reasonable values of the vacuum parameters appearing in the imbedding by using as experimental input the values of coherence length ξ and critical magnetic fields. Two kinds of imbeddings are studied.

1. Spherically symmetric, electrovac imbedding of Z^0 condensate levels $n \geq n_Z$) or ordinary electric field (condensate levels $n < n_Z$) created by matter serves as a simple model for the topological field quanta in the ordinary condensed phase.

2. Cylindrically symmetric field quantum serves as an idealization for the linear structures obtained by glueing spherically symmetric topological field quanta together using joing along boundaries operation and is interesting as a model for the core of various vortex like structures. Several imbeddings of this kind are constructed.
   i) An imbedding of cylindrically symmetric em/Z_0 electric field for matter at rest is constructed assuming that matter density serves as the source of em/Z_0 electric field.
   ii) By applying a boost in the direction of cylinder axis an imbedding of the em/Z_0 magnetic field associated with say super fluid flow is obtained.
   iii) Allowing non-vanishing quantum numbers n_i an imbedding of a constant Z^0/m magnetic magnetic field in the direction of the cylinder axis is obtained. The requirement that the magnetic flux of this field is quantized in the standard manner, poses and additional condition on the vacuum parameters. One can construct ordinary magnetic fields in the length scales $n \geq n_Z$ as deformations of Z^0 electric field configuration. As a consequence of the construction procedure, the critical radius of all these imbeddings depends on the properties of the matter only.

The dependence of the critical radii on the vacuum quantum numbers is studied and estimates for the vacuum numbers of topological field quanta are deduced Ordinary phase with $\omega_1 \sim m_0 \sim 10^{-4}m_{Pl}$ is shown to correspond to the large quantum number limit in the sense that the critical radii are macroscopic and therefore also magnetic flux m as well as the quantum numbers ω_i and n_i are very large. The imbedding of the magnetic field is obtained nonperturbatively in the sense that the change Δn_i needed to generate the magnetic field satisfies the condition $\Delta n_i/n_i \gg 1$.

Supra phases correspond to the small quantum number limit and to Z^0 neutral space-times: using ξ and B_c as inputs, it is found that the parameter ω_1 is of the order of $10^{2.5} - 10^3$ proton masses. The assumption that ω_1 is same for all super conductors implies $\omega_2/\omega_1 \ll 1$, which condition in turn is necessary condition for Meissner effect to take place. The value of the fractal quantum number m is assumed to be zero for ^4He and -2 for the other supra phases. the non-vanishing value of m affects radically the value of ϵ_1 so that estimates have considerable uncertainties.

10.3.1 The Kähler field created by a constant mass density

In the following the em/Z^0 electric field created by an Z^0/em neutral, constant mass distribution assuming that mass distribution serves as a source of pure em/Z^0 field proportional to Kähler field, are studied. Although the mass distribution itself is homogeneous, Kähler electric field necessarily breaks translational symmetry. Concerning the applications in mind, the breaking of the translational symmetry to the spherical or cylindrical symmetry is the most natural one and will therefore be considered in the sequel. Also the imbedding of a spherically (cylindrically) symmetric Kähler electric field can break spherical (cylindrical symmetry) since several gauge potentials are possible by gauge invariance and different gauges are related by the canonical transformations of CP_2 and correspond to different four-surfaces: it is assumed however that imbedding is spherically (cylindrically) symmetric, too. What makes the cylindrically symmetric field configuration so interesting is that one can construct several physically interesting field configurations from it by modifying the values of the vacuum quantum numbers so that electrovac conditions cease to hold true.

To begin with, recall the conditions guaranteeing the vanishing of either Z^0 or electromagnetic gauge fields

$$\begin{aligned} r &= tan(X) \ , \quad \Psi = k\Phi \ , \\ X &= \frac{ln(|(u+k)/C|)\epsilon}{2} \ . \end{aligned} \qquad (10.3.1)$$

One must chose the branch of arcus tangent in the expression of X in terms of r and this implies the condition $m\pi \leq X \leq (2m+1)\pi/2$, where m is an integer fixing the branch of the arcustangent and will be referred to as euantum number. The following remarks are useful for what follows:

1. The vanishing of the Z^0 field is achieved for

$$\epsilon = \epsilon(em) = \frac{1}{2} \ ,$$

and the vanishing of the electromagnetic field is achieved for

$$\epsilon = \epsilon(Z) = \frac{(3+p)}{(3+2p)} \ ,$$

($p = sin^2(\theta_W) \simeq 0.234$).

2. The CP_2 projection of the imbedding is two-dimensional, which implies the orthogonality of the magnetic and electric fields belonging to same condensate level. Z^0/em field is proportional to induced Kähler form for the imbeddings in question

$$\begin{aligned} \gamma &= k_{em}J = a_{em}sin^2X du\wedge d\Phi \ , \\ k_{em} &= 3 \ , \quad a_{em} = -\frac{3}{4} \ , \\ Z^0 &= k_Z J = a_Z sin^2X du\wedge d\Phi \ , \\ k_Z &= \frac{6}{p} \ , \quad a_Z = -\frac{3}{3+p} \ . \end{aligned} \qquad (10.3.2)$$

One consequence of $F_{em} = 3J$ is that the # throats feeding magnetic flux to/from a purely electromagnetic condensate level behave on given space-time sheet as magnetic mopoles with magnetic charge quantized in multiples of the magnetic charge associated with the ordinary Dirac monopole: what is peculiar is that the magnetic charge is divisible by 3. As quantum effects are considered the # throats behave as extremely tiny magnetic dipoles.

3. Electromagnetic/Z^0 charge density of matter is assumed to serve as source of em/Z^0 fields and in the idealization that matter consists of identical nuclei (A, Z) one can write the charge density as

$$\begin{aligned} \rho_{em} &= \frac{e^2}{\sqrt{\epsilon_{em}}}\frac{Z}{A}N = K_{em}N \ , \\ \rho_Z &= -\frac{g_Z^2}{4\sqrt{\epsilon_Z}}\frac{A-Z}{A}N = K_Z N \ , \end{aligned} \qquad (10.3.3)$$

where N is the density of the nucleons. It has been assumed that only neutrons contribute to the nuclear Z^0 charge.

The formulas associated with the spherically and cylindrically symmetric imbeddings differ from each other by numerical factors only and the cylindrically symmetric case will be considered first. Assuming cylindrical symmetry em/Z^0 electric field is radial and its magnitude is given by

$$\begin{aligned} |E_\rho^{em}| &= \delta K_{em}\frac{N\rho}{2} \ , \\ |E_\rho^{Z}| &= \delta K_{Z}\frac{N\rho}{2} \ , \\ \delta &= 1 \ , \end{aligned} \tag{10.3.4}$$

The numerical factor δ is introduced in order to generalize the results to spherically symmetric case easily.

Cylindrically symmetric imbedding of the em/Z^0 electric field is obtained through the ansatz

$$\begin{aligned} \Phi &= \omega_1 t \ , \quad \Psi = \omega_2 t \ , \quad u = u(\rho) \ , \\ k &= \frac{\omega_2}{\omega_1} \ . \end{aligned} \tag{10.3.5}$$

One can define $\omega_1 = m_p\sqrt{(\epsilon_i)}x$, where x is numerical factor not very far from unity in astrophysical scales. The dependence of u on ρ is fixed from the imbeddability condition for the appropriate electric field

$$\begin{aligned} \frac{a_i}{k_i}sin^2X\partial_\rho u\omega_1 &= \delta K_i N\frac{\rho}{2} \ , \\ i &= em, Z^0 \ . \end{aligned} \tag{10.3.6}$$

From this expression one can integrate u as a function of ρ

$$\int_{u_0}^{u} sin^2(X(u))du = \delta\frac{K_ik_i}{a_i\omega_1}N\rho^2 \ . \tag{10.3.7}$$

This equation determines the value of the critical radius of the imbedding as a function of u_0, the value of u at $r=\infty$ surface provided $u=0$ at $r=0$ surface. Performing the integral, one obtains the condition

$$\begin{aligned} \rho_{cr} &= \sqrt{\frac{2a_i\omega_1}{\delta K_ik_iN}}\sqrt{2(u_0+k)}exp(-m\pi/\epsilon(i))X(\epsilon(i)) \ , \\ X(\epsilon) &= \sqrt{\frac{(2+\epsilon^2)exp(\pi/\epsilon)+\epsilon^2)}{(1+\epsilon^2)}} \ , \\ i &= em, Z^0 \ . \end{aligned} \tag{10.3.8}$$

Here u_0 is the value of $u=cos(\Theta)$ at the axis of the vortex ($k=\omega_2/\omega_1$) and various parameters with index i are defined in the previous formulas.

The general orders of magnitude become clear, when one writes the formula in a numerical form by using the density $N_0 = 10^{30}/m^3$ is a reference density of atomic nuclei.

1. In electromagnetic case one obtains

$$\begin{aligned} \rho_{cr} &\simeq X\cdot 3.7\cdot 10^{-6} \ \text{meters} \ , \\ X &= \sqrt{(u_0+k)}\sqrt{\epsilon_{em}x}\sqrt{\frac{A}{Z}\frac{N_0}{N}}\frac{1}{\sqrt{\delta}}10^{-2.7288m} \ , \\ \omega_1 &= \sqrt{\epsilon_{em}}xm(proton) \ . \end{aligned} \tag{10.3.9}$$

The critical radius for spherically symmetric imbedding is obtained by replacing $\delta = 1$ with $\delta = 2/3$.

2. In Z^0 case one obtains

$$\begin{aligned} \rho_{cr} &\simeq X \cdot 7.75 \cdot 10^{-7} \text{ meters} \ , \\ X &= \sqrt{(u_0+k)}\sqrt{\epsilon_Z x}\sqrt{\frac{A}{(A-Z)}\frac{N_0}{N}\frac{1}{\sqrt{\delta}}10^{-1.46m}} \ , \\ \omega_1 &= \sqrt{\epsilon_{em}} x m(proton) \ . \end{aligned} \quad (10.3.10)$$

for $p = sin^2(\theta_W) = 1/4$.

The previous formulas contain still unknown parameters $(u_0 + k, x)$ but order of magnitude estimates are possible for the critical radius since the value of $u_0 \leq 1$ is not expected to be anomalously small.

For the em neutral space-time there are two especially interesting special cases.

1. For $\sqrt{\epsilon_Z} \sim 10^{18}$ (so that Z^0 force is of the same order of magnitude as gravitational force) and for $m = 0$ critical radius is about 10^{11} m, which is roughly the size of the solar system.

2. For $\sqrt{\epsilon_Z} \sim 10^{10}$ (level n_Z) and for $m = 0$ one has $\rho_{cr} \sim 10^3$ m in typical condensed matter densities.
   For Z^0 neutral space-time expected to be important in subcellular length scales $m = 0$,$x = 1$ and $\epsilon_{em} = 1$ (no charge screening by electrons) the critical radius is about 10^{-6} meters. If one assumes $\omega_1 = \epsilon_{em} m_e x$ (replacing $m(proton)$ by m_e) with $x \sim 1$ one obtains critical radius of order 10^{-8}–10^{-7} meters, which is of same order of magnitude as characteristic length parameters for super conductors. Same is achieved by assuming $m = -1$ instead of $m = 0$.

Critical radius depends exponentially on the value of the integer m and the imbeddings with different values of m are related by a discrete scale transformation $\rho_{cr} \rightarrow exp(-m\pi/\epsilon)\rho_{cr}$: the "fundamental" change of scale is given $exp(\pi/\epsilon) \simeq 28.9$ in the electromagnetically neutral case (note the dependence on $sin^2(\theta_W)$) and by 535.5 in the Z^0 neutral case. Of course, it is not at all obvious whether the scaled up surfaces are structurally stable.

Using the BCS expression and TGD based estimate for the binding energy of the Cooper pairs, one obtains the formula

$$\rho_{cr} \simeq \frac{1}{\sqrt{m_e}\Delta} exp(\frac{1}{N(0)V}) \ , \quad (10.3.11)$$

which gives relationship between vacuum parameters and parameters of BCS model [23].

10.3.2 The imbedding of a constant magnetic field

The imbedding of constant em/Z^0 magnetic field is obtained from the corresponding electric field associated with the constant mass density assuming that Ψ and Φ depend also on the angle ϕ

$$\begin{aligned} \Phi &= \omega_1 t + n_1\phi \ , \quad \Psi = \omega_2 t + n_2 \phi \ , \quad u = u(\rho) \ , \\ k &= \frac{\omega_2}{\omega_1} = \frac{n_2}{n_1} \ . \end{aligned} \quad (10.3.12)$$

The condition $n_2/n_1 = k$ guarantees electromagnetic neutrality. Magnetic fields are in the direction of the z-axis and their magnitudes are given by the expression

$$\begin{aligned} |B_i| &= |\frac{n_1}{\omega_1}\frac{E_i}{\rho}| = \frac{n_1 N}{\omega_1}\delta\frac{K_i}{2} \ , \\ i &= em, Z^0 \ . \end{aligned} \quad (10.3.13)$$

and are indeed constant.

The magnetic flux associated with the topological field quantum is in the electromagnetic case given by

$$\Phi \;=\; \int B_{em}da = -n_1\frac{3}{4}(u_0+k)exp(-4m\pi)\frac{(9exp(2\pi)+1)}{5}\pi \; . \tag{10.3.14}$$

The quantitization of the magnetic flux gives a condition for the parameters u_0 and k. The requirement that the flux is quantized in multiples of the elementary flux quantum irrespective of the value of n_1 implies the condition

$$\begin{aligned} \frac{3}{4}(u_0+k)exp(-4m\pi)\frac{(9exp(2\pi)+1)}{5} &= \frac{1}{n} \; , \\ n &= 1 \; . \end{aligned} \tag{10.3.15}$$

The more general condition $n>1$ corresponds to the assumption that n_1 is multiple of of n.

Applying this condition to the expression for the critical radius, one has

$$\begin{aligned} \rho_{cr} &= \sqrt{\frac{A}{Z}}\sqrt{\epsilon_{em}x}\sqrt{\frac{2}{e^2}\frac{m(proton)}{N}}\frac{1}{\sqrt{n}} \\ &\sim \sqrt{\frac{A}{Z}}\sqrt{\epsilon_{em}x}\frac{1}{\sqrt{n}}\cdot 1.6\cdot 10^{-7} \;\; \text{meters} \;\; , \\ B^{em} &= \frac{2n_1}{\rho_{cr}^2} = 2n_1n\frac{Z}{A}\frac{e^2}{2\epsilon_{em}x}\frac{N}{m(proton)} \; . \end{aligned} \tag{10.3.16}$$

The requirement that the radius of the flux quantum is of order $10^{-8}-10^{-7}$ meters (magnetic penetration length for the super conductor) gives in $n=1$ case the estimate $\sqrt{\epsilon_{em}x}\sim 1$ at the condensation level in question. Since $\epsilon_{em}\geq 1$ holds true this means that $x<1$ must hold true. An alternative possibility is that $n>1$ holds true instead of $n=1$. The third possibility is that the imbeddability condition gives only an upper bound for the critical radius and that stability conditions give additional constraints. An additional restriction for the values of the free parameters comes from the requirement that the critical magnetic field ought to be of the order of $B_{cr}\simeq 10^{-2}\; Tesla$ for the super conductors of type I and larger for the super conductors of type II. The critical magnetic field obviously corresponds to the smallest possible magnetic field allowed by the flux quantization and this estimate does not give anything new at order of magnitude level.

The quantization of the Z^0 magnetic flux gives

$$\begin{aligned} a_Z(u_0+k)exp(-2m\pi/\epsilon(Z))C(\epsilon(Z)) &= \frac{1}{n} \; , \\ n &= 1 \; , \end{aligned} \tag{10.3.17}$$

and reduces the expression for the critical radius and magnetic field to the form

$$\begin{aligned} \rho_{cr} &= \sqrt{\frac{A}{(A-Z)}}\sqrt{\epsilon_Z x}\sqrt{\frac{8}{g_Z^2}\frac{m(proton)}{N}} \; , \\ B^Z &= \frac{2n_1}{\rho_{cr}^2} \\ &= n_1n\frac{(A-Z)}{A}\frac{g_Z^2}{4\epsilon_Z x}\frac{N}{m(proton)} \; , \end{aligned} \tag{10.3.18}$$

completely analogous to the expressions deduced in the electromagnetic case.

In $n > n_Z$ case Z^0 magnetic fields are expected to dominate over the Z^0 electric fields: the reason is that the screening neutrinos probably do not contribute to the Z^0 gauge current density acting as the source of Z^0 magnetic field but contribute to Z^0 charge density causing a very effective screening. This means that the the source of Z^0 magnetic field at level n corresponds to the Z^0 charge density (and ϵ_Z) associated with level $n-1$. In particular, at level n_Z there is no screening for Z^0 magnetic field. For $n > n_Z$ one can generate approximately constant ordinary magnetic fields by giving up the condition $n_2/n_1 = \omega_2/\omega_1$. The expression for the magnetic field strength is given by

$$\begin{aligned} |B^{em}| &= \frac{(3+p)(3+2p)}{6} B^Z \\ &= 2n_1 \frac{(3+p)(3+2p)}{6} \frac{(A-Z)}{A} \frac{g_Z^2}{8\epsilon_Z x} \frac{N}{m(proton)} \ , \\ p &= sin^2(\theta_W) \ , \end{aligned} \tag{10.3.19}$$

where the quantization condition for Z^0 flux is used (the least one can hope is that one might fix the orders of magnitudes correctly for free parameters). At the level $n = n_Z$ one can generate fields of order one Tesla (Tesla corresponds roughly to $N/m(proton)$) at small quantum number limit ($\epsilon_Z(n_Z - 1) = 1$). At the next level the field of one Tesla requires $n_1 \sim 10^{20}$ for $\epsilon_Z x \sim 10^{20}$ so that large quantum number limit is in question.

10.3.3 Magnetic fields associated with constant velocity flows

One can construct a simple candidate for the Kähler magnetic field associated with a fluid flow with a constant velocity by boosting the cylindrically symmetric Kähler electric field in the direction of the cylinder axis:

$$\begin{aligned} \Phi &= \omega_1 t + k_1 z \ , \quad \Psi = \omega_2 t + k_2 z \ , \quad u = u(\rho) \ , \\ k_i &= \omega_i \beta \ . \end{aligned} \tag{10.3.20}$$

The field lines are circles around the z-axis and the strength of the Kähler magnetic and Z^0 magnetic fields are given by

$$\begin{aligned} |B_K| &= |\frac{k_1}{\omega_1} E_K| \ , \\ B_Z &= \frac{3}{sin^2(\theta_W)} B^K \ . \end{aligned} \tag{10.3.21}$$

Super fluid flow is a natural application for this mechanism for generating magnetic field. In this case the cylindrical symmetry of the Kähler electric field is indeed very natural. Note that the although the flux tubes are in the direction of the flow the critical radius doesn't depend on the flow velocity.

In order to obtain non-vanishing magnetic field (associated, say, with super conducting current) one must give up the condition that the field is obtained by a boost. For example, one can assume that $k_1 \neq \omega_1 \beta$. An interesting possibility is that the magnetic field associated with the super conducting current is obtained in this manner. It should be noticed that one can obtain also helical magnetic fields by performing boost to a configuration with non-vanishing magnetic field.

10.4 Quantum Hall effect from topological field quantization

The concept of the topological field quantum and the ideas about the formation of macroscopic quantum systems and about the topological description of the dissipation provide a classical TGD based description of Quantum Hall effect very similar to that found for supra phases.

10.4.1 The effect

Consider first briefly the effect. The effect is observed two-dimensional systems consisting of a conducting slab in a strong magnetic field perpendicular to the slab. When potential difference V is applied in the y-direction of the slab (see Fig. 10.4.1), the Lorentz force induces a transversal current. The current is proportional to the electric field associated with the potential:

$$j_x = \sigma_{xy} E_y \ , \tag{10.4.1}$$

where σ_{xy} is the transversal conductivity.

Two kinds of effects have been observed at low temperatures ($T \simeq 1\ K$) and using strong magnetic fields $B \simeq 10\ T$.

1. In integer quantum Hall effect σ_{xy} is quantized in units of the fine structure constant

$$\sigma_{xy} = n \times 2\alpha \ , \tag{10.4.2}$$

where n is integer.

2. In the fractional quantum Hall effect σ_{xy} is quantized in fractional units

$$\sigma_{xy} = \frac{n}{m} \times 2\alpha \ , \tag{10.4.3}$$

where the integer m is fixed. Several values of m have been found to be possible.

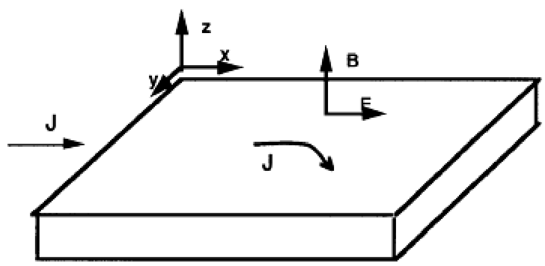

Figure 10.5: Quantum Hall effect

10.4.2 The model

One can understand Quantum Hall effect in TGD framework using the following arguments.

Conduction electrons as a mesoscopic quantum system

Assume that in the Quantum Hall phase conduction electrons form a mesocopic quantum system, which means that topological field quanta with size of the order of $\xi \simeq 10^{-8} - 10^{-7}$ meters are glued together by join along boundaries bond to form a lattice like structure. The bonds must be stable since otherwise their splitting and rejoining causes an additional dissipation contributing to the transversal conductivity and Quantum Hall effect is lost. The estimate for the critical temperature $T_c \simeq 1/2m_e\xi^2$ used for the supra phases applies also now and correctly gives $T_c \simeq 1\ K$.

How to avoid the splitting of the joing along boundaries bonds in a strong magnetic field

Since a strong magnetic field (of the order of few Tesla) is present, individual topological field quanta are excited to $(n_1, n_2) \neq 0$ states. There are *two* possible manners to avoid the breaking of the bonds between the neighbouring topological field quanta:

1. The condition $n_1 = 0$ is satisfied for all topological field quanta. $n_1 = 0$ field quanta are favored if the condition

$$k \equiv \omega_2/\omega_1 \gg 1 \ , \tag{10.4.4}$$

   is satisfied so that $n_2 = 0$ quanta have much larger magnetic flux than $n_1 = 0$ field quanta. If $k \gg 1$ condition is satisfied, the magnetic field inside the flux quantum can change in discrete, but sufficiently small, steps, when external magnetic field is varied. For the values of the vacuum quantum numbers encountered for the supra phases, the value of n_2 ought to be rather large, of the order of $10 - 100$ in Quantum Hall phase. A possible problem of this scenario is that the flux associated with the $n_1 = 1$ quantum is of same order as the flux of the external magnetic field: why this excitation is not generated?

   The $k \ll 1$ condition encountered in the case of supra phases leads to difficulties. The magnetic field associated with $n_1 = 0$ excitations is large and of the order of the external magnetic field if same values for vacuum quantum numbers are assumed as for the supra phases so that external could excite these excitations. The problem is that the magnetic field associated with $n_1 \neq 0$ excitations is much smaller and its is difficult to understand why the variation of the external magnetic field does not not excite them (with the consequence that Quantum Hall phase disappears).

2. The condition $u = cos(\Theta) = \pm 1$ is satisfied on the $r = \infty$ boundaries of the field quanta. In this case both n_1 and n_2 can vary freely. For the magnetic fields used and for the values of parameters found for supra phases n_1 should be of the order of $n_1 = 1$ and n_2 can have much larger values. This makes possible the variation of the magnetic flux inside the field quantum in discrete steps, the step being however reasonably small. Thus it seems that this alternative is the physical one.

Quantization conditions

Assume that the quantization conditions

$$\int \bar{B}_{em} \cdot d\bar{a} - m \oint \bar{v} \cdot d\bar{l} = \frac{m \times 2\pi}{qe} \ , \tag{10.4.5}$$

encountered in the case of the supra phases are satisfied in Quantum Hall phase, too. Since the magnetic flux inside the topological field quanta is quantized in multiples of certain basic unit associated with n_1, which is much smaller than the standard flux quantum, the velocity field must adjust itself inside each flux quantum so that the quantization condition is satisfied. This is achieved if the velocity field is a super position of two terms

$$\bar{v} = \bar{v}_0 + \bar{v}_{rot} \ , \tag{10.4.6}$$

where $\bar{v}_0$ is essentially constant velocity field associated to the Hall current and $\bar{v}_{rot}$ is a local velocity field inside the topological field quantum, whose function is to cancel the failure of the magnetic field to satisfy the standard flux quantization condition

$$m_e \oint \bar{v}_{rot} \cdot d\bar{l} = -\frac{m2\pi}{qe} + \int \bar{B}_{em} \cdot d\bar{a} \equiv - \int \Delta \bar{B} \cdot d\bar{a} \ . \tag{10.4.7}$$

Here $\bar{v}_{rot}$ corresponds to a rigid body rotation in the constant magnetic field $\Delta\bar{B}$, which is the difference between the actual field and the field for which magnetic flux is quantized in standard units. Obviously, the external magnetic field must be so strong that the flux through a topological field quantum is of the order of the field quantum: otherwise unrealistically large local velocities are needed to guarantee quantization condition (or m would be equal to zero).

Carriers of the Hall current as an incompressible 2-dimensional liquid

Assume that the carriers of the Hall current behave like an incompressible, two-dimensional liquid (this assumption is made in the competing models, too [18]). Assume also that the Euler equations are satisfied and write them into the following form

$$n_e m_e \frac{\partial \bar{v}}{\partial t} = -\nabla p - n_e m_e \nabla(\frac{v^2}{2}) + n_e m_e \bar{v} \times (\nabla \times \bar{v}) + n_e q e(\bar{E} + \bar{v} \times \bar{B}) \ . \tag{10.4.8}$$

Here n_e is the number of Hall current carriers per unit area orthogonal to the direction of magnetic field and m_e is the mass of the current carrier (electron).

Stationary state

The stationary situation for which the velocity can be decomposed in the manner already described is characterized by the conditions

$$\begin{aligned} \bar{v} &= \bar{v}_0 + \bar{v}_{rot} \ , \\ \frac{\partial \bar{v}}{\partial t} &= 0 \ , \\ \nabla[p + n_e m_e(\frac{v^2}{2} - \frac{v_{rot}^2}{2})] + X &= 0 \ , \\ X &\equiv n_e q e \bar{v}_{rot} \times \bar{B} \ . \end{aligned} \tag{10.4.9}$$

The remaining equation leads to the formula for transversal conductivity

$$n_e m_e \bar{v}_0 \times (\nabla \times \bar{v}_{rot}) + qen_e\bar{E} + qen_e\bar{v}_0 \times \bar{B} = 0 \ . \tag{10.4.10}$$

Before deriving the expression for the transversal conductivity it is useful to verify that the solution ansatz works. One can subsitute to the quantity $X \equiv \bar{v}_{rot} \times \bar{B}$ the expression of $\bar{v}_{rot}$ obtained from quantization condition (rigid body rotation) and one finds that this term is also expressible as a gradient: $X = a\nabla(B^2\rho^2)$, where a is some numerical constant. This implies that second condition reduces to a condition of form

$$p + n_e m_e(\frac{v^2}{2} - \frac{v_{rot}^2}{2}) + n_e q e a B^2 \rho^2 = p_0 = \text{constant} \ . \tag{10.4.11}$$

This condition is a local condition referring to the properties of the flow inside the topological field quanta and is not essential for Quantum Hall effect.

Hall current

In order to obtain expression for the Hall current one can integrate the third condition involving Lorentz force over a transversal (orthogonal to B) surface area associated with one or more topological field quanta. One obtains the following expression for the Hall current $\bar{j}_H = qen_e\bar{v}_0$

$$\begin{aligned} j_H &= \sigma_{xy}E \ , \\ \sigma_{xy} &= -e\frac{\int n_e da}{(\int \bar{B}\cdot d\bar{a} - m_e \oint \bar{v}\cdot d\bar{l})} \ . \end{aligned} \tag{10.4.12}$$

Same expression can be obtained also directly form the Euler equations under much milder assumptions by integrating the x- component of the equations over the surface area. All the terms in Euler equation and not appearing in the formula for the Hall current (∇v^2, ∇v_{rot}^2, ∇p, $\bar{v}_{rot}\times\bar{B}$) give vanishing contribution to the integral over the field quantum provided they correspond to the variations of the physical quantities, whose average vanishes in length scales larger than the size of the topological field quantum.

One can write this formula in a form exhibiting fractional Quantum Hall effect by noticing that the integral $\oint n_e da$ is just n_{free}, the number of the carriers of Hall current inside the topological field quantum (or the several of them) and is quantized! The general quantization condition in turn implies that the denominator is integer multiple of $2\pi/qe$. What one obtains is the following formula for the transversal conducticity

$$\sigma_{xy} = -\frac{n_{free}e^2}{m2\pi} \ . \tag{10.4.13}$$

One obtains integer quantum Hall effect for $m = 1$ and fractional quantum Hall effect for $m \geq 1$.

Comments

Some comments concerning the proposed scenario are in order.

1. For a macroscopic quantum system consisting of a very large number of the topological field quanta n_{free} and m are so large that the value of the conductivity is practically continuous without any further assumptions. If one however assumes that the values of m and the number of the free charge carriers are same for all topological field quanta then it is possible to realize the situation, where n_{free}/m can be written as a ratio of small integers.

2. All integer values for m (in accordance with the experimental facts!) are possible (not only odd integers as in case of the anyon super conductivity in its simplest version [22]). m corresponds to the angular momentum of an electron rotating around the flux tube in accordance with the Laughlin's proposal for the state functions of charge carriers [22]. Since $m = 1$ angular momentum is expected to be most probable in low temperatures and for low magnetic fields, fractional quantum Hall effect is expected to be more rare phenomenon than integer Hall effect.

3. When magnetic field is kept as constant and potential V is varied the number of the free charge carriers inside the flux quantum changes in discrete steps at some critical values of the potential so that plateaus of σ_{xy} result. When magnetic field is varied compensating, velocity fields inside the field quanta are generated in order to preserve the quantization condition. When magnetic field is suitable, a change in the vacuum quantum number n_2 and possibly n_1 takes place and the rotational velocity field $\bar{v}_{rot}$ goes to zero. This doesn't lead to a change of the transversal conductivity in general. When total magnetic flux becomes sufficiently near to its quantized value also the integer m characterizing the flux quantum can change so that the fractional number characterizing quantum Hall effect changes. This kind of a transition can be regarded as a phase transition taking place in the whole specimen.

4. The proposed explanation differs from the more standard explanations in some respects.
   i) The concept of fractional filling fractions follows from the quantization conditions and from the concept of the topological field quantum.

ii) No reference is made to fractional statistics or to fractional electric charges.
iii) The situation $m = 0$ is particularly interesting physically. In this case the transversal Hall conductivity is formally infinite. The only reasonable solution of the Euler equation in this case seems to be that for which the velocity in the transversal direction vanishes so that Hall effect and magnetic field is effectively absent (!) and classically (probably not quantum mechanically) there is a continuous acceleration in the direction of the electric field. Clearly the slab behaves as a super conductor apart from the presence of $\bar{v}_{rot}$ term in velocity.
iv) The standard models for the fractional Quantum Hall effect predict also super conductivity together with the breaking of CP invariance. In present case the presence of the classical Z^0 electric vacuum fields suggests small parity breaking. This effect takes however place in ordinary supra phases, too and possibly in all condensed matter systems.

10.5 TGD and condensed matter

In previous sections we have applied TGD to a rather exotic condensed matter phenomena. Quite contrary to the original expectations it has turned out that TGD might have applications to less exotic condensed matter phenomena, too. In fact, it seems that TGD might be applied to reformulate the description of conductors, di-electrics, and magnetism using topological concepts.

10.5.1 Electronic conductivity and topological field quantization

The standard Drude model for conductors [21] starts from the equilibrium condition $dv/dt = v/\tau - eE/m_e = 0$ to derive the expression for the conductivity of a metal as $\sigma = Ne^2\tau/m_e$. τ is interpreted as the average time between two collisions and is obtained from the estimate $\tau \simeq a/v_{th}$, where a is the distance between atoms and v_{th} is thermal velocity. The estimate is by a factor $10^2 - 10^3$ too small at low temperatures and approaches the observed conductivity at high temperatures only. A correct order of magnitude estimate is obtained if a is replaced with the size $\xi \simeq 10^{-8} - 10^{-7}$ meters of topological field quantum in accordance with the idea that ordinary metal behaves as a super conductor at length scales smaller than ξ. The decrease of the conductivity at higher temperatures can be understood, too: the joing along boundaries bonds between atoms become more and more unstable as the temperature is increased.

10.5.2 Dielectrics and topological field quantization

Why do electrons then move freely in length scales smaller than ξ? This can be understood by introducing a TGD based description of a dielectric to be discussed in more detail later. The point is that there are two condensation levels present. This means that the electric flux D (electric displacement) associated with a test charge divides into two parts. First part P (polarization) flows at the first level of the condensate (in particular along the bonds joining topological field quanta of atomic size). Second part E (electric field flows at the background space-time, which corresponds to a larger space-time sheet. Since total electric flux is conserved, the fractions of electric flux sum up to one: $1/\varepsilon_1 + 1/\varepsilon_2 = 1$ ($D = E + P$), where the fractions are defined in terms of the dielectric constants ε_1 and ε_2 associated with the two levels of condensation. For an ideal conductor all electric flux runs to the larger space-time sheet and there are no electric fields at the first level of the condensate: electrons move freely! For and ideal di-electric all electric flux flows at the first level of condensation and strong electric fields are associated with the join along boundaries bonds.

10.5.3 Magnetism and topological field quantization

Same kind of argumentation should work in case of magnetism, too. The magnetic flux H created by a test current can be decomposed to two parts. The first part M (magnetization) flows through the first level of the condensate and second part B (magnetic field) flows through the larger space-time sheet. Again one can associate susceptibilities μ_1 and μ_2 ($\mu_1 + \mu_2 = 1$) to both levels of the condensate to describe the properties of a simple magnetic substance.

The mechanism underlying spontaneous magnetization is not very well understood [20, 17, 21] and an interesting question is whether the magnetic domains in the spontaneous magnetization could be understood using TGD based concepts. The quantization of the field strength for a flux quantum implies that macroscopic magnetization results if the magnetic fields of $n_1 \geq 0$ excitations associated with these flux quanta are oriented in parallel. From the known values of the magnetic fields in ferromagnets and from the sizes of the magnetized domains it is possible to estimate the values of ω_1 and and the fractal quantum number m. The typical values of the magnetic fields are of the order of 10^{-2} Tesla and stable domains of magnetization are known to have size of the order of 10^{-8} meters. The fact that the orders of magnitude are same as for super conductors suggests that the sizes of the topological field quanta do not depend strongly on the properties of the condensed matter system.

In the phenomenological theory of the ferromagnetism the so called Weiss molecular field appears [21]. If this field is present then the magnetic moments of individual electrons are oriented parallel and magnetization is essentially the density of the magnetic moments per volume: $M \propto N_e \mu_e$. The problem is that this field is very large, having magnitude of the order of 10^3 Tesla, which is about 10^5 times large than the actual magnetic field!

Standard explanation is that this field is only an effective field giving a short hand description of essentially quantum level phenomena (so called exchange interaction between electrons, which favors parallel spins for the electrons of the neighboring atoms). A possible TGD based classical explanation is that there is indeed magnetic field of this strength present. This field is present at the "zeroth" level of condensation that is inside the field quanta having atomic size (which are glued together by the join along boundaries bonds). Again the field strength is quantized and flux quantum is related by the scaling factor $(\xi_1/\xi_0)^2 \simeq 10^4 - 10^6$ to the magnetic field quantum at the first condensation level. The order of magnitude is indeed correct!

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Appendix A

Appendix

A-1 Basic properties of CP_2

A-1.1 CP_2 as a manifold

CP_2, the complex projective space of two complex dimensions, is obtained by identifying the points of complex 3-space C^3 under the projective equivalence

$$(z^1, z^2, z^3) \equiv \lambda(z^1, z^2, z^3) \ . \tag{A-1.1}$$

Here λ is any non-zero complex number. Note that CP_2 can also regarded as the coset space $SU(3)/U(2)$. The pair z^i/z^j for fixed j and $z^i \neq 0$ defines a complex coordinate chart for CP_2. As j runs from 1 to 3 one obtains an atlas of three charts covering CP_2, the charts being holomorphically related to each other (e.g. CP_2 is a complex manifold). The points $z^3 \neq 0$ form a subset of CP_2 homoeomorphic to R^4 and the points with $z^3 = 0$ a set homeomorphic to S^2. Therefore CP_2 is obtained by "adding the 2-sphere at infinity to R^4".

Besides the standard complex coordinates $\xi^i = z^i/z^3$, $i = 1, 2$ the coordinates of Eguchi and Freund [2] will be used and their relation to the complex coordinates is given by

$$\begin{aligned} \xi^1 &= z + it \ , \\ \xi^2 &= x + iy \ . \end{aligned} \tag{A-1.2}$$

These are related to the "spherical coordinates" via the equations

$$\begin{aligned} \xi^1 &= rexp(i\frac{(\Psi+\Phi)}{2})cos(\frac{\Theta}{2}) \ , \\ \xi^2 &= rexp(i\frac{(\Psi-\Phi)}{2})sin(\frac{\Theta}{2}) \ . \end{aligned} \tag{A-1.3}$$

The ranges of the variables r, Θ, Φ, Ψ are $[0, \infty], [0, \pi], [0, 4\pi], [0, 2\pi]$ respectively.

Considered as a real four-manifold CP_2 is compact and simply connected, with Euler number 3, Pontryagin number 3 and second Betti number $b = 1$.

A-1.2 Metric and Kähler structures of CP_2

In order to obtain a natural metric for CP_2, observe that CP_2 can be thought of as a set of the orbits of the isometries $z^i \rightarrow exp(i\alpha)z^i$ on the sphere S^5: $\sum z^i \bar{z}^i = R^2$. The metric of CP_2 is obtained by projecting the metric of S^5 orthogonally to the orbits of the isometries. Therefore the distance between the points of CP_2 is that between the representative orbits on S^5. The line element has the following form in the complex coordinates

$$ds^2 = g_{a\bar{b}} d\xi^a d\bar{\xi}^b \ , \qquad \text{(A-1.4)}$$

where the Hermitian, in fact Kähler, metric $g_{a\bar{b}}$ is defined by

$$g_{a\bar{b}} = R^2 \partial_a \partial_{\bar{b}} K \ , \qquad \text{(A-1.5)}$$

where the function K, Kähler function, is defined as

$$\begin{aligned} K &= log(F) \ , \\ F &= 1 + r^2 \ . \end{aligned} \qquad \text{(A-1.6)}$$

The representation of the metric is given by

$$\frac{ds^2}{R^2} = \frac{(dr^2 + r^2\sigma_3^2)}{F^2} + \frac{r^2(\sigma_1^2 + \sigma_2^2)}{F} \ , \qquad \text{(A-1.7)}$$

where the quantities σ_i are defined as

$$\begin{aligned} r^2\sigma_1 &= Im(\xi^1 d\xi^2 - \xi^2 d\xi^1) \ , \\ r^2\sigma_2 &= -Re(\xi^1 d\xi^2 - \xi^2 d\xi^1) \ , \\ r^2\sigma_3 &= -Im(\xi^1 d\bar{\xi}^1 + \xi^2 d\bar{\xi}^2) \ . \end{aligned} \qquad \text{(A-1.8)}$$

The vierbein forms, which satisfy the defining relation

$$s_{kl} = R^2 \sum_A e_k^A e_l^A \ , \qquad \text{(A-1.9)}$$

are given by

$$\begin{aligned} e^0 &= \tfrac{dr}{F} \ , \quad & e^1 &= \tfrac{r\sigma_1}{\sqrt{F}} \ , \\ e^2 &= \tfrac{r\sigma_2}{\sqrt{F}} \ , \quad & e^3 &= \tfrac{r\sigma_3}{F} \ . \end{aligned} \qquad \text{(A-1.10)}$$

The explicit representations of vierbein vectors are given by

$$\begin{aligned} e^0 &= \tfrac{dr}{F} \ , & e^1 &= \tfrac{r(sin\Theta cos\Psi d\Phi + sin\Psi d\Theta)}{2\sqrt{F}} \ , \\ e^2 &= \tfrac{r(sin\Theta sin\Psi d\Phi - cos\Psi d\Theta)}{2\sqrt{F}} \ , & e^3 &= \tfrac{r(d\Psi + cos\Theta d\Phi)}{2F} \ . \end{aligned} \qquad \text{(A-1.11)}$$

The explicit representation of the line element is given by the expression

$$ds^2/R^2 = dr^2/F^2 + (r^2/4F^2)(d\Psi + cos\Theta d\Phi)^2 + (r^2/4F)(d\Theta^2 + sin^2\Theta d\Phi^2) \ . \qquad \text{(A-1.12)}$$

The vierbein connection satisfying the defining relation

$$de^A = -V_B^A \wedge e^B \ , \qquad \text{(A-1.13)}$$

is given by

$$\begin{array}{lllllll} V_{01} & = & -\frac{e^1}{r} \ , & V_{23} & = & \frac{e^1}{r} \ , \\ V_{02} & = & -\frac{e^2}{r} \ , & V_{31} & = & \frac{e^2}{r} \ , \\ V_{03} & = & (r-\frac{1}{r})e^3 \ , & V_{12} & = & (2r+\frac{1}{r})e^3 \ . \end{array} \tag{A-1.14}$$

The representation of the covariantly constant curvature tensor is given by

$$\begin{array}{lllllll} R_{01} & = & e^0\wedge e^1 - e^2\wedge e^3 \ , & R_{23} & = & e^0\wedge e^1 - e^2\wedge e^3 \ , \\ R_{02} & = & e^0\wedge e^2 - e^3\wedge e^1 \ , & R_{31} & = & -e^0\wedge e^2 + e^3\wedge e^1 \ , \\ R_{03} & = & 4e^0\wedge e^3 + 2e^1\wedge e^2 \ , & R_{12} & = & 2e^0\wedge e^3 + 4e^1\wedge e^2 \ . \end{array} \tag{A-1.15}$$

Metric defines a real, covariantly constant, and therefore closed 2-form J

$$J \;=\; -ig_{a\bar{b}}d\xi^a d\bar{\xi}^b \ , \tag{A-1.16}$$

the so called Kähler form. Kähler form J defines in CP_2 a symplectic structure because it satisfies the condition

$$J^k_{\ r}J^{rl} \;=\; -s^{kl} \ . \tag{A-1.17}$$

The form J is integer valued and by its covariant constancy satisfies free Maxwell equations. Hence it can be regarded as a curvature form of a $U(1)$ gauge potential B carrying a magnetic charge of unit $1/2g$ (g denotes the gauge coupling). Locally one has therefore

$$J \;=\; dB \ , \tag{A-1.18}$$

where B is the so called Kähler potential, which is not defined globally since J describes magnetic monopole.

It should be noticed that the magnetic flux of J through a 2-surface in CP_2 is proportional to its homology equivalence class, which is integer valued. The explicit representations of J and B are given by

$$\begin{array}{lll} B & = & 2re^3 \ , \\ J & = & 2(e^0\wedge e^3 + e^1\wedge e^2) = \dfrac{r}{F^2}dr\wedge(d\Psi + cos\Theta d\Phi) + \dfrac{r^2}{2F}sin\Theta d\Theta d\Phi \ . \end{array} \tag{A-1.19}$$

The vielbein curvature form and Kähler form are covariantly constant and have in the complex coordinates only components of type (1,1).

Useful coordinates for CP_2 are the so called canonical coordinates in which Kähler potential and Kähler form have very simple expressions

$$\begin{array}{lll} B & = & \sum\limits_{k=1,2} P_k dQ_k \ , \\ J & = & \sum\limits_{k=1,2} dP_k\wedge dQ_k \ . \end{array} \tag{A-1.20}$$

The relationship of the canonical coordinates to the "spherical" coordinates is given by the equations

$$\begin{array}{lll} P_1 & = & -\dfrac{1}{1+r^2} \ , \\ P_2 & = & \dfrac{r^2 cos\Theta}{2(1+r^2)} \ , \\ Q_1 & = & \Psi \ , \\ Q_2 & = & \Phi \ . \end{array} \tag{A-1.21}$$

A-1.3 Spinors in CP_2

CP_2 doesn't allow spinor structure in the conventional sense [5]. However, the coupling of the spinors to a half odd multiple of the Kähler potential leads to a respectable spinor structure. Because the delicacies associated with the spinor structure of CP_2 play a fundamental role in TGD, the arguments of Hawking are repeated here.

To see how the space can fail to have an ordinary spinor structure consider the parallel transport of the vierbein in a simply connected space M. The parallel propagation around a closed curve with a base point x leads to a rotated vierbein at x: $e^A = R^A_B e^B$ and one can associate to each closed path an element of $SO(4)$.

Consider now a one-parameter family of closed curves $\gamma(v) : v \in (0,1)$ with the same base point x and $\gamma(0)$ and $\gamma(1)$ trivial paths. Clearly these paths define a sphere S^2 in M and the element $R^A_B(v)$ defines a closed path in $SO(4)$. When the sphere S^2 is contractible to a point e.g., homologically trivial, the path in $SO(4)$ is also contractible to a point and therefore represents a trivial element of the homotopy group $\Pi_1(SO(4)) = Z_2$.

For a homologically nontrivial 2-surface S^2 the associated path in $SO(4)$ can be homotopically nontrivial and therefore corresponds to a nonclosed path in the covering group Spin(4) (leading from the matrix 1 to -1 in the matrix representation). Assume this is the case.

Assume now that the space allows spinor structure. Then one can parallelly propagate also spinors and by the above construction associate a closed path of Spin(4) to the surface S^2. Now, however this path corresponds to a lift of the corresponding $SO(4)$ path and cannot be closed. Thus one ends up with a contradiction.

From the preceding argument it is clear that one could compensate the nonallowed -1- factor associated with the parallel transport of the spinor around the sphere S^2 by coupling it to a gauge potential in such a way that in the parallel transport the gauge potential introduces a compensating -1-factor. For a $U(1)$ gauge potential this factor is given by the exponential $exp(i2\Phi)$, where Φ is the the magnetic flux through the surface. This factor has the value -1 provided the $U(1)$ potential carries half odd multiple of Dirac charge $1/2g$. In case of CP_2 the required gauge potential is half odd multiple of the Kähler potential B defined previously. In the case of $M^4 \times CP_2$ one can in addition couple the spinor components with different chiralities independently to an odd multiple of $B/2$.

A-1.4 Geodesic submanifolds of CP_2

Geodesic submanifolds are defined as submanifolds having common geodesic lines with the imbedding space. As a consequence the second fundamental form of the geodesic manifold vanishes, which means that the tangent vectors h^k_α (understood as vectors of H) are covariantly constant quantities with respect to the covariant derivative taking into account that the tangent vectors are vectors both with respect to H and X^4.

In [3] a general characterization of the geodesic submanifolds for an arbitrary symmetric space G/H is given. Geodesic submanifolds are in 1-1-correspondence with the so called Lie triple systems of the Lie-algebra g of the group G. The Lie triple system t is defined as a subspace of g characterized by the closedness property with respect to double commutation

$$[X,[Y,Z]] \in t \quad \text{for} \quad X,Y,Z \in t \ . \tag{A-1.22}$$

$SU(3)$ allows, besides geodesic lines, two nonequivalent (not isometry related) geodesic spheres. This is understood by observing that $SU(3)$ allows two nonequivalent $SU(2)$ algebras corresponding to subgroups $SO(3)$ (orthogonal 3×3 matrices) and the usual isospin group $SU(2)$. By taking any subset of two generators from these algebras, one obtains a Lie triple system and by exponentiating this system, one obtains a 2-dimensional geodesic submanifold of CP_2.

Standard representatives for the geodesic spheres of CP_2 are given by the equations

$$S^2_I \ : \ \xi^1 = \bar{\xi}^2 \ \text{ or equivalently } \ (\Theta = \pi/2, \Psi = 0) \ ,$$

$$S^2_{II} \ : \ \xi^1 = \xi^2 \ \text{ or equivalently } \ (\Theta = \pi/2, \Phi = 0) \ .$$

The non-equivalence of these sub-manifolds is clear from the fact that isometries act as holomorphic transformations in CP_2. The vanishing of the second fundamental form is also easy to verify. The first geodesic manifold is homologically trivial: in fact, the induced Kähler form vanishes identically for S^2_I. S^2_{II} is homologically nontrivial and the flux of the Kähler form gives its homology equivalence class.

A-2 Identification of the electro-weak couplings

The delicacies of the spinor structure of CP_2 make it a unique candidate for space S. First, the coupling of the spinors to the $U(1)$ gauge potential defined by the Kähler structure provides the missing $U(1)$ factor in the gauge group. Secondly, it is possible to couple different H-chiralities independently to a half odd multiple of the Kähler potential. Thus the hopes of obtaining a correct spectrum for the electromagnetic charge are considerable. In the following it will be demonstrated that the couplings of the induced spinor connection are indeed those of the GWS model [4] and in particular that the right handed neutrinos decouple completely from the electro-weak interactions.

To begin with, recall that the space H allows to define three different chiralities for spinors. Spinors with fixed H-chirality $e = \pm 1$, CP_2-chirality l, r and M^4-chirality L, R are defined by the condition

$$\begin{aligned} \Gamma\Psi &= e\Psi \ , \\ e &= \pm 1 \ , \end{aligned} \tag{A-2.1}$$

where Γ denotes the matrix $\Gamma_9 = \gamma_5 \times \gamma_5$, $1 \times \gamma_5$ and $\gamma_5 \times 1$ respectively. Clearly, for a fixed H-chirality CP_2- and M^4-chiralities are correlated.

The spinors with H-chirality $e = \pm 1$ can be identified as quark and lepton like spinors respectively. The separate conservation of baryon and lepton numbers can be understood as a consequence of generalized chiral invariance if this identification is accepted. For the spinors with a definite H-chirality one can identify the vielbein group of CP_2 as the electro-weak group: $SO(4) = SU(2)_L \times SU(2)_R$.

The covariant derivatives are defined by the spinorial connection

$$A = V + \frac{B}{2}(n_+ 1_+ + n_- 1_-) \ . \tag{A-2.2}$$

Here V and B denote the projections of the vielbein and Kähler gauge potentials respectively and $1_{+(-)}$ projects to the spinor H-chirality $+(-)$. The integers $n_\pm$ are odd from the requirement of a respectable spinor structure.

The explicit representation of the vielbein connection V and of B are given by the equations

$$\begin{aligned} V_{01} &= -\frac{e^1}{r} \ , & V_{23} &= \frac{e^1}{r} \ , \\ V_{02} &= -\frac{e^2}{r} \ , & V_{31} &= \frac{e^2}{r} \ , \\ V_{03} &= (r - \frac{1}{r})e^3 \ , & V_{12} &= (2r + \frac{1}{r})e^3 \ , \end{aligned} \tag{A-2.3}$$

and

$$B = 2re^3 \ , \tag{A-2.4}$$

respectively. The explicit representation of the vielbein is not needed here.

Let us first show that the charged part of the spinor connection couples purely left handedly. Identifying Σ^0_3 and Σ^1_2 as the diagonal (neutral) Lie-algebra generators of $SO(4)$, one finds that the charged part of the spinor connection is given by

$$A_{ch} = 2V_{23}I^1_L + 2V_{13}I^2_L \ , \tag{A-2.5}$$

where one have defined

$$\begin{aligned} I_L^1 &= \frac{(\Sigma_{01} - \Sigma_{23})}{2} \ , \\ I_L^2 &= \frac{(\Sigma_{02} - \Sigma_{13})}{2} \ . \end{aligned} \tag{A-2.6}$$

A_{ch} is clearly left handed so that one can perform the identification

$$W^{\pm} = \frac{2(e^1 \pm ie^2)}{r} \ , \tag{A-2.7}$$

where $W^{\pm}$ denotes the charged intermediate vector boson.

Consider next the identification of the neutral gauge bosons γ and Z^0 as appropriate linear combinations of the two functionally independent quantities

$$\begin{aligned} X &= re^3 \ , \\ Y &= \frac{e^3}{r} \ , \end{aligned} \tag{A-2.8}$$

appearing in the neutral part of the spinor connection. We show first that the mere requirement that photon couples vectorially implies the basic coupling structure of the GWS model leaving only the value of Weinberg angle undetermined.

To begin with let us define

$$\begin{aligned} \bar{\gamma} &= aX + bY \ , \\ \bar{Z}^0 &= cX + dY \ , \end{aligned} \tag{A-2.9}$$

where the normalization condition

$$ad - bc = 1 \ ,$$

is satisfied. The physical fields γ and Z^0 are related to $\bar{\gamma}$ and $\bar{Z}^0$ by simple normalization factors.

Expressing the neutral part of the spinor connection in term of these fields one obtains

$$\begin{aligned} A_{nc} &= [(c+d)2\Sigma_{03} + (2d-c)2\Sigma_{12} + d(n_+1_+ + n_-1_-)]\bar{\gamma} \\ &+ [(a-b)2\Sigma_{03} + (a-2b)2\Sigma_{12} - b(n_+1_+ + n_-1_-)]\bar{Z}^0 \ . \end{aligned} \tag{A-2.10}$$

Identifying Σ_{12} and $\Sigma_{03} = 1 \times \gamma_5 \Sigma_{12}$ as vectorial and axial Lie-algebra generators, respectively, the requirement that γ couples vectorially leads to the condition

$$c = -d \ . \tag{A-2.11}$$

Using this result plus previous equations, one obtains for the neutral part of the connection the expression

$$A_{nc} = \gamma Q_{em} + Z^0(I_L^3 - sin^2\theta_W Q_{em}) \ . \tag{A-2.12}$$

Here the electromagnetic charge Q_{em} and the weak isospin are defined by

$$\begin{aligned} Q_{em} &= \Sigma^{12} + \frac{(n_+1_+ + n_-1_-)}{6} \ , \\ I_L^3 &= \frac{(\Sigma^{12} - \Sigma^{03})}{2} \ . \end{aligned} \tag{A-2.13}$$

The fields γ and Z^0 are defined via the relations

$$\begin{aligned} \gamma &= 6d\bar{\gamma} = \frac{6}{(a+b)}(aX+bY) \ , \\ Z^0 &= 4(a+b)\bar{Z}^0 = 4(X-Y) \ . \end{aligned} \quad \text{(A-2.14)}$$

The value of the Weinberg angle is given by

$$sin^2\theta_W = \frac{3b}{2(a+b)} \ , \quad \text{(A-2.15)}$$

and is not fixed completely. Observe that right handed neutrinos decouple completely from the electro-weak interactions.

The determination of the value of Weinberg angle is a dynamical problem. The angle is completely fixed once the YM action is fixed by requiring that action contains no cross term of type γZ^0. Pure symmetry non-broken electro-weak YM action leads to a definite value for the Weinberg angle. One can however add a symmetry breaking term proportional to Kähler action and this changes the value of the Weinberg angle.

To evaluate the value of the Weinberg angle one can express the neutral part F_{nc} of the induced gauge field as

$$F_{nc} = 2R_{03}\Sigma^{03} + 2R_{12}\Sigma^{12} + J(n_+1_+ + n_-1_-) \ , \quad \text{(A-2.16)}$$

where one has

$$\begin{aligned} R_{03} &= 2(2e^0\wedge e^3 + e^1\wedge e^2) \ , \\ R_{12} &= 2(e^0\wedge e^3 + 2e^1\wedge e^2) \ , \\ J &= 2(e^0\wedge e^3 + e^1\wedge e^2) \ , \end{aligned} \quad \text{(A-2.17)}$$

in terms of the fields γ and Z^0 (photon and Z- boson)

$$F_{nc} = \gamma Q_{em} + Z^0(I_L^3 - sin^2\theta_W Q_{em}) \ . \quad \text{(A-2.18)}$$

Evaluating the expressions above one obtains for γ and Z^0 the expressions

$$\begin{aligned} \gamma &= 3J - sin^2\theta_W R_{03} \ , \\ Z^0 &= 2R_{03} \ . \end{aligned} \quad \text{(A-2.19)}$$

For the Kähler field one obtains

$$J = \frac{1}{3}(\gamma + sin^2\theta_W Z^0) \ . \quad \text{(A-2.20)}$$

Expressing the neutral part of the symmetry broken YM action

$$\begin{aligned} L_{ew} &= L_{sym} + fJ^{\alpha\beta}J_{\alpha\beta} \ , \\ L_{sym} &= \frac{1}{4g^2}Tr(F^{\alpha\beta}F_{\alpha\beta}) \ , \end{aligned} \quad \text{(A-2.21)}$$

where the trace is taken in spinor representation, in terms of γ and Z^0 one obtains for the coefficient X of the γZ^0 cross term (this coefficient must vanish) the expression

$$X = -\frac{K}{2g^2} + \frac{fp}{18} ,$$
$$K = Tr\left[Q_{em}(I_L^3 - sin^2\theta_W Q_{em})\right] , \tag{A-2.22}$$

In the general case the value of the coefficient K is given by

$$K = \sum_i \left[-\frac{(18+2n_i^2)sin^2\theta_W}{9}\right] , \tag{A-2.23}$$

where the sum is over the spinor chiralities, which appear as elementary fermions and n_i is the integer describing the coupling of the spinor field to the the Kähler potential. The cross term vanishes provided the value of the Weinberg angle is given by

$$sin^2\theta_W = \frac{9\sum_i 1}{(fg^2 + 2\sum_i(18+n_i^2))} . \tag{A-2.24}$$

In the scenario where both leptons and quarks are elementary fermions the value of the Weinberg angle is given by

$$sin^2\theta_W = \frac{9}{(\frac{fg^2}{2} + 28)} . \tag{A-2.25}$$

The bare value of the Weinberg angle is 9/28 in this scenario, which is quite close to the typical value 9/24 of GUTs [6].

A-2.1 Discrete symmetries

The treatment of discrete symmetries C, P, and T is based on the following requirements:
a) Symmetries must be realized as purely geometric transformations.
b) Transformation properties of the field variables should be essentially the same as in the conventional quantum field theories [1].

The action of the reflection P on spinors of is given by

$$\Psi \rightarrow P\Psi = \gamma^0 \otimes \gamma^0\Psi . \tag{A-2.26}$$

in the representation of the gamma matrices for which γ^0 is diagonal. It should be noticed that W and Z^0 bosons break parity symmetry as they should since their charge matrices do not commute with the matrix of P.

The guess that a complex conjugation in CP_2 is associated with T transformation of the physicist turns out to be correct. One can verify by a direct calculation that pure Dirac action is invariant under T realized according to

$$m^k \rightarrow T(M^k) ,$$
$$\xi^k \rightarrow \bar{\xi}^k ,$$
$$\Psi \rightarrow \gamma^1\gamma^3 \otimes 1\Psi . \tag{A-2.27}$$

The operation bearing closest resemblance to the ordinary charge conjugation corresponds geometrically to complex conjugation in CP_2:

$$\xi^k \rightarrow \bar{\xi}^k ,$$
$$\Psi \rightarrow \Psi^\dagger\gamma^2\gamma^0 \otimes 1 . \tag{A-2.28}$$

As one might have expected symmetries CP and T are exact symmetries of the pure Dirac action.

A-3 Space-time surfaces with vanishing em, Z^0, Kähler, or W fields

In the sequel it is shown that space-times for which either em, Z^0, or Kähler field vanishes decompose into regions characterized by six vacuum parameters: two of these quantum numbers (ω_1 and ω_2) are frequency type parameters, two (k_1 and k_2) are wave vector like quantum numbers, two of the quantum numbers (n_1 and n_2) are integers. The parameters ω_i and n_i will be referred as electric and magnetic quantum numbers. The existence of these quantum numbers is not a feature of these solutions alone but represents a much more general phenomenon differentiating in a clear cut manner between TGD and Maxwell's electrodynamics.

The simplest manner to avoid surface Kähler charges and discontinuities or infinities in the derivatives of CP_2 coordinates on the common boundary of two neighboring regions with different vacuum quantum numbers is topological field quantization, 3-space decomposes into disjoint topological field quanta, 3-surfaces having outer boundaries with possibly macroscopic size.

If one requires that space-time surface is an extremal of Kähler action and has a 2-dimensional CP_2 projection, only vacuum extremals and space-time surfaces for which CP_2 projection is a geodesic sphere, are allowed. Homologically non-trivial geodesic sphere correspond to vanishing W fields and homologically non-trivial sphere to non-vanishing W fields but vanishing γ and Z^0. For vacuum extremals all electro-weak gauge fields are in general non-vanishing although the net gauge field has U(1) holonomy.

A-3.1 Em neutral space-times

Em and Z^0 neutral spacetimes are especially interesting space-times as far as applications of TGD are considered. Consider first the electromagnetically neutral space-times. Using spherical coordinates (r,Θ,Ψ,Φ) for CP_2, the expression of Kähler form reads as

$$\begin{aligned} J &= \frac{r}{F^2}dr\wedge(d\Psi+cos(\Theta)d\Phi)+\frac{r^2}{2F}sin(\Theta)d\Theta\wedge d\Phi \ , \\ F &= 1+r^2 \ . \end{aligned} \tag{A-3.1}$$

The general expression of electromagnetic field reads as

$$\begin{aligned} F_{em} &= (3+2p)\frac{r}{F^2}dr\wedge(d\Psi+cos(\Theta)d\Phi)+(3+p)\frac{r^2}{2F}sin(\Theta)d\Theta\wedge d\Phi \ , \\ p &= sin^2(\Theta_W) \ , \end{aligned} \tag{A-3.2}$$

where Θ_W denotes Weinberg angle.

The vanishing of the electromagnetic fields is guaranteed, when the conditions

$$\begin{aligned} \Psi &= k\Phi \ , \\ (3+2p)\frac{1}{r^2F}(d(r^2)/d\Theta)(k+cos(\Theta)) &+ (3+p)sin(\Theta)=0 \ , \end{aligned} \tag{A-3.3}$$

hold true. The conditions imply that CP_2 projection of the electromagnetically neutral space-time is 2-dimensional. Solving the differential equation one obtains

$$\begin{aligned} r &= \sqrt{\frac{X}{1-X}} \ , \\ X &= D\left[|\frac{(k+u}{C}|\right]^{\epsilon} \ , \\ u &\equiv cos(\Theta) \ , \ C=k+cos(\Theta_0) \ , \ D=\frac{r_0^2}{1+r_0^2} \ , \ \epsilon=\frac{3+p}{3+2p} \ , \end{aligned} \tag{A-3.4}$$

where C and D are integration constants. $0 \leq X \leq 1$ is required by the reality of r. $r = 0$ would correspond to $X = 0$ giving $u = -k$ achieved only for $|k| \leq 1$ and $r = \infty$ to $X = 1$ giving $|u+k| = [(1+r_0^2)/r_0^2)]^{(3+2p)/(3+p)}$ achieved only for

$$sign(u+k) \times [\frac{1+r_0^2}{r_0^2}]^{\frac{3+2p}{3+p}} \leq k+1 \ ,$$

where $sign(x)$ denotes the sign of x.

Under rather general conditions the coordinates Ψ and Φ can be written in the form

$$\begin{aligned} \Psi &= \omega_2 m^0 + k_2 m^3 + n_2\phi + \text{Fourier expansion} \ , \\ \Phi &= \omega_1 m^0 + k_1 m^3 + n_1\phi + \text{Fourier expansion} \ . \end{aligned} \tag{A-3.5}$$

m^0,m^3 and ϕ denote the coordinate variables of the cylindrical M^4 coordinates) so that one has $k = \omega_2/\omega_1 = n_2/n_1 = k_2/k_1$. The regions of the space-time surface with given values of the vacuum parameters ω_i,k_i and n_i and m and C are bounded by the surfaces at which the electromagnetically neutral imbeddings become ill-defined, say by $r > 0$ or $r < \infty$ surfaces.

The space-time surface decomposes into regions characterized by different values of the vacuum parameters r_0 and Θ_0. At $r = \infty$ surfaces n_2,ω_2 and m can change since all values of Ψ correspond to the same point of CP_2: at $r = 0$ surfaces also n_1 and ω_1 can change since all values of Φ correspond to same point of CP_2, too. If $r = 0$ or $r = \infty$ is not in the allowed range space-time surface develops a boundary.

This implies what might be called topological quantization since in general it is not possible to find a smooth global imbedding for, say a constant magnetic field. Although global imbedding exists it decomposes into regions with different values of the vacuum parameters and the coordinate u in general possesses discontinuous derivative at $r = 0$ and $r = \infty$ surfaces. A possible manner to avoid edges of space-time is to allow field quantization so that 3-space (and field) decomposes into disjoint quanta, which can be regarded as structurally stable units a 3-space (and of the gauge field). This doesn't exclude partial join along boundaries for neighboring field quanta provided some additional conditions guaranteing the absence of edges are satisfied.

The vanishing of the electromagnetic fields implies that the condition

$$\Omega \equiv \frac{\omega_2}{n_2} - \frac{\omega_1}{n_1} = 0 \ , \tag{A-3.6}$$

is satisfied. In particular, the ratio ω_2/ω_1 is rational number for the electromagnetically neutral regions of space-time surface. The change of the parameter n_1 and n_2 (ω_1 and ω_2) in general generates magnetic field and therefore these integers will be referred to as magnetic (electric) quantum numbers.

The expression for the Kähler form and Z^0 field of the electromagnetically neutral space-time surface will be needed in sequel and is given by

$$\begin{aligned} J &= -\frac{p}{3+2p} X du \wedge d\Phi \ , \\ Z^0 &= -\frac{6}{p} J \ . \end{aligned} \tag{A-3.7}$$

The components of the electromagnetic field generated by varying vacuum parameters are proportional to the components of the Kähler field: in particular, the magnetic field is parallel to the Kähler magnetic field. The generation of a long range Z^0 vacuum field is a purely TGD based feature not encountered in the standard gauge theories.

The effective form of the CP_2 metric is given by

$$\begin{aligned} ds^2_{eff} &= (s_{rr}(\frac{dr}{d\Theta})^2 + s_{\Theta\Theta})d\Theta^2 + (s_{\Phi\Phi} + 2ks_{\Phi\Psi})d\Phi^2 = \frac{R^2}{4}[s^{eff}_{\Theta\Theta} d\Theta^2 + s^{eff}_{\Phi\Phi} d\Phi^2] \ , \\ s^{eff}_{\Theta\Theta} &= X \times \left[\frac{\epsilon^2(1-u^2)}{(k+u)^2} \times \frac{1}{1-X} + 1 - X\right] \ , \\ s^{eff}_{\Phi\Phi} &= X \times \left[(1-X)(k+u)^2 + 1 - u^2\right] \ , \end{aligned} \tag{A-3.8}$$

and is useful in the construction of electromagnetically neutral imbedding of, say Schwartchild metric. Note however that in general these imbeddings are not extremals of Kähler action.

A-3.2 Space-times with vanishing Z^0 or Kähler fields

The results just derived generalize to the Z^0 neutral case as such. The only modification is the replacement of the parameter ϵ with $\epsilon = 1/2$ as becomes clear by considering the condition stating that Z^0 field vanishes identically. Also the relationship $F_{em} = 3J = -\frac{3}{4}\frac{r^2}{F}du \wedge d\Phi$ is useful.

Also the generalization to the case of vacuum extremals is straightforward and corresponds to $\epsilon = 1, p = 0$ in the formula for em neutral space-times. In this case classical em and Z^0 fields are proportional to each other:

$$\begin{aligned} Z^0 &= 2e^0 \wedge e^3 = \frac{r}{F^2}(k+u)\frac{\partial r}{\partial u}du \wedge d\Phi = (k+u)du \wedge d\Phi \ , \\ r &= \sqrt{\frac{X}{1-X}} \ , \ X = D|k+u| \ , \\ \gamma &= -\frac{p}{2}Z^0 \ . \end{aligned} \quad \text{(A-3.9)}$$

For vanishing value of Weinberg angle ($p = 0$) em field vanishes and only Z^0 field remains as a long range gauge field. Vacuum extremals for which long range Z^0 field vanishes but em field is non-vanishing are not possible.

A-3.3 Induced gauge fields for space-times for which CP$_2$ projection is a geodesic sphere

For space-time sheets for which CP$_2$ projection is $r = \infty$ homologically non-trivial geodesic sphere of CP_2 one has

$$\gamma = (\frac{3}{4} - \frac{sin^2(\theta_W)}{2})Z^0 \simeq \frac{5Z^0}{8} \ .$$

The induced W fields vanish in this case and they vanish also for all geodesic sphere obtained by $SU(3)$ rotation.

For homologically trivial geodesic sphere a standard representative is obtained by using for the phase angles of standard complex CP_2 coordinates constant values. In this case induced em, Z^0, and Kähler fields vanish but induced W fields are non-vanishing. This holds also for surfaces obtained by color rotation. Hence one can say that for non-vacuum extremals with 2-D CP$_2$ projection color rotations and weak symmetries commute.

A-4 Second variation of the Kähler action

The Kähler action is apart from a multiplicative constant defined by the Lagrangian density

$$L = J^{\alpha\beta}J_{\alpha\beta}\sqrt{g} \ , \quad \text{(A-4.1)}$$

and depends on the imbedding space coordinates only through the induced metric and Kähler form. In order to calculate the second variation of the Kähler action one can use "covariantization" trick made possible by the covariant constancy of the imbedding space metric and Kähler form. Calculate second variation by treating components of the metric and Kähler form as a constant so that the action depends effectively only on the derivatives of the imbedding space coordinates and replace ordinary derivatives of the deformation with the covariant derivatives in the resulting expression for the second variation.

$$\begin{aligned} \partial_\alpha \delta h^k &\rightarrow D_\alpha \delta h^k \\ &= \partial_\alpha \delta h^k + \{ {}^{\ k}_{l\ m} \} \partial_\alpha h^m \delta h^l \ . \end{aligned} \quad \text{(A-4.2)}$$

The first variation of the Maxwell term is given by the expression

$$\delta_1 L = 2[T^{\alpha\beta}\delta_1 g_{\alpha\beta} + J^{\alpha\beta}\delta_1 J_{\alpha\beta}]\sqrt{g} \ , \quad \text{(A-4.3)}$$

where the canonical energy momentum tensor $T^{\alpha\beta}$ is given by

$$T^{\alpha\beta} = J^{\alpha\nu}J^{\beta}_{\ \nu} - (1/4)g^{\alpha\beta}J^{\mu\nu}J_{\mu\nu} \ . \quad \text{(A-4.4)}$$

and is traceless by Weyl invariance.

Second variation is obtained by differentiating first variation and decomposes into three terms

$$\delta_2 L = \delta_2^a L + \delta_2^b L + \delta_2^c L \ . \quad \text{(A-4.5)}$$

The first term is given by the expression

$$\begin{aligned} \delta_2^a L &= [T^{\alpha\beta}\delta_2 g_{\alpha\beta} + J^{\alpha\beta}\delta_2 J_{\alpha\beta} \\ &+ (T^{\alpha\beta}\delta_1 g_{\alpha\beta} + J^{\alpha\beta}\delta_1 J_{\alpha\beta})g^{\mu\nu}\delta_1 g_{\mu\nu}]\sqrt{g} \ . \end{aligned} \quad \text{(A-4.6)}$$

The second term is given by

$$\begin{aligned} \delta_2^b L &= [(\partial T^{\alpha\beta}/\partial g_{\mu\nu})\delta_1 g_{\alpha\beta}\delta_1 g_{\mu\nu} \\ &+ 2(\partial T^{\alpha\beta}/\partial J_{\mu\nu})\delta_1 g_{\alpha\beta}\delta_1 J_{\mu\nu}]\sqrt{g} \ . \end{aligned} \quad \text{(A-4.7)}$$

The partial derivatives of the energy momentum tensor appearing in the expression are given by

$$\begin{aligned} \partial T^{\alpha\beta}/\partial g_{\mu\nu} &= -g^{\alpha\mu}T^{\beta\nu} + K^{\alpha\nu}g^{\beta\mu} - \frac{1}{2}K^{\mu\nu}g^{\alpha\beta} + J^{\alpha\nu}J^{\beta\mu} \ , \\ K^{\alpha\beta} &= J^{\alpha\nu}J^{\beta}_{\ \nu} \ . \end{aligned} \quad \text{(A-4.8)}$$

$$\partial T^{\alpha\beta}/\partial J_{\mu\nu} = 2[g^{\alpha\mu}J^{\beta\nu} - g^{\alpha\beta}J^{\mu\nu}/4] \ . \quad \text{(A-4.9)}$$

The third term is given by the expression

$$\begin{aligned} \delta_2^c L &= [(\partial J^{\alpha\beta}/\partial J_{\mu\nu})\delta_1 J_{\alpha\beta}\delta_1 J_{\mu\nu}]\sqrt{g} \ , \\ \partial J^{\alpha\beta}/\partial J_{\mu\nu} &= g^{\alpha\mu}g^{\beta\nu} \ . \end{aligned} \quad \text{(A-4.10)}$$

Expressing the first term in terms of the coordinate variations one obtains

$$\delta_2^a L = 2[T^{\alpha\beta}h^{\perp}_{kl} + J^{\alpha\beta}J^{\perp}_{kl}]D_\alpha\delta_1 h^k D_\beta\delta_1 h^l\sqrt{g} \ , \quad \text{(A-4.11)}$$

where $h^{\perp}_{kl}$ and $J^{\perp}_{kl}$ are the projections of the imbedding space metric and Kähler form to the orthogonal complement of the tangent space of X^4

$$\begin{aligned} h^{\perp}_{kl} &= h_{kl} - g^{\mu\nu}h_{kr}h_{ls}\partial_\mu h^r\partial_\nu h^s \ , \\ J^{\perp}_{kl} &= h^{\perp}_{kr}h^{\perp}_{ls}J^{rs} \ , \end{aligned} \quad \text{(A-4.12)}$$

so that $\delta_2^a L$ vanishes for four-dimensional $Diff$ deformations parallel to X^4. This term vanishes also, when the induced Kähler form vanishes.

The contribution of the second term to the second variation is given by the expression

$$\begin{aligned}\delta_2^b L &= 4[(-g^{\alpha\mu}T^{\beta\nu} + K^{\alpha\nu}g^{\beta\mu} - \frac{1}{2}K^{\mu\nu}g^{\alpha\beta} + J^{\alpha\nu}J^{\beta\mu})h_{kr}h_{ls} \\ &+ 2(g^{\alpha\mu}J^{\beta\nu} - g^{\alpha\beta}J^{\mu\nu}/4)h_{ks}J_{lr}]\partial_\alpha h^k\partial_\beta h^l D_\mu\delta_1 h^r D_\nu\delta_1 h^s\sqrt{g} \ .\end{aligned} \tag{A-4.13}$$

Also this term is non-vanishing only provided the induced Kähler field is nontrivial.

The third term is given by the expression

$$\delta_2^c L = [g^{\alpha\mu}g^{\beta\nu}J_{kr}J_{ls}]\partial_\alpha h^k\partial_\beta h^l D_\mu\delta_1 h^r D_\nu\delta_1 h^s\sqrt{g} \ . \tag{A-4.14}$$

This term is the only term, which is nontrivial for the vacuum extremals with vanishing Kähler field and also in this case the variation is nontrivial for CP_2 coordinates only.

The second variation for the Kähler Lagrangian can be written in the following general form

$$\delta^2 L_{intX^4} = I_{kl}^{\alpha\beta}D_\alpha\delta h^k D_\beta\delta h^l \ , \tag{A-4.15}$$

where the general expressions for the tensor $I_{kl}^{\alpha\beta}$ reads as

$$I_{kl}^{\alpha\beta} = \partial_{\partial_\alpha h^k}\partial_{\partial_\beta h^l}L \ . \tag{A-4.16}$$

The explicit expression for the tensors $I_{kl}^{\alpha\beta}$ can be read from the expressions for $\delta L_2^i, i = a,b,c$ and $\delta_2 L_{CS}$ respectively.

The general form of the variational equations satisfied by the second variation in the interior of X^4 reads as

$$D_\alpha(I_{kl}^{\alpha\beta}D_\beta\delta h^l) = 0 \ . \tag{A-4.17}$$

On the boundary the variational equations read

$$I_{kl}^{n\beta}D_\beta\delta h^l = 0 \ . \tag{A-4.18}$$

These equations are satisfied on a dynamically generated boundary only. These equations are not satisfied on the intersection of the four-surface with the surfaces $a = \sqrt{(m^0)^2 - r_M^2} \rightarrow \infty$ and $a = 0$ (light cone boundary).

The expression for the second variation of the action reduces to a mere boundary term resulting from the intersections of the four-surface with $a \rightarrow \infty$ and $a = 0$ surfaces, when X^4 corresponds to a submanifold of light cone and reads

$$\delta^2 S = \int_{a=0}^{a=\infty} I_{kl}^{n\beta}\delta h^k D_\beta\delta h^l d^3x. \tag{A-4.19}$$

The general expressions for the tensor I suggests that only non-vanishing contribution to the second variation comes from the boundary of the light cone.

A-5 p-Adic numbers

p-Adic numbers (p is prime: 2,3,5,...) can be regarded as a completion of the rational numbers using a norm, which is different from the ordinary norm of real numbers [8]. p-Adic numbers are representable as power expansion of the prime number p of form:

$$x = \sum_{k\geq k_0} x(k)p^k, \; x(k) = 0, ..., p-1 \; . \tag{A-5.1}$$

The norm of a p-adic number is given by

$$|x| = p^{-k_0(x)} \; . \tag{A-5.2}$$

Here $k_0(x)$ is the lowest power in the expansion of the p-adic number. The norm differs drastically from the norm of the ordinary real numbers since it depends on the lowest pinary digit of the p-adic number only. Arbitrarily high powers in the expansion are possible since the norm of the p-adic number is finite also for numbers, which are infinite with respect to the ordinary norm. A convenient representation for p-adic numbers is in the form

$$x = p^{k_0}\varepsilon(x) \; , \tag{A-5.3}$$

where $\varepsilon(x) = k + ...$ with $0 < k < p$, is p-adic number with unit norm and analogous to the phase factor $exp(i\phi)$ of a complex number.

The distance function $d(x,y) = |x-y|_p$ defined by the p-adic norm possesses a very general property called ultra-metricity:

$$d(x,z) \leq max\{d(x,y), d(y,z)\} \; . \tag{A-5.4}$$

The properties of the distance function make it possible to decompose R_p into a union of disjoint sets using the criterion that x and y belong to same class if the distance between x and y satisfies the condition

$$d(x,y) \leq D \; . \tag{A-5.5}$$

This division of the metric space into classes has following properties:

a) Distances between the members of two different classes X and Y do not depend on the choice of points x and y inside classes. One can therefore speak about distance function between classes.

b) Distances of points x and y inside single class are smaller than distances between different classes.

c) Classes form a hierarchical tree.

Notice that the concept of the ultra-metricity emerged in physics from the models for spin glasses and is believed to have also applications in biology [10]. The emergence of p-adic topology as the topology of the effective space-time would make ultra-metricity property basic feature of physics.

A-6 Canonical correspondence between p-adic and real numbers

There exists a natural continuous map $Id : R_p \rightarrow R_+$ from p-adic numbers to non-negative real numbers given by the "pinary" expansion of the real number for $x \in R$ and $y \in R_p$ this correspondence reads

$$
\begin{aligned}
y &= \sum_{k>N} y_k p^k \rightarrow x = \sum_{k<N} y_k p^{-k} \quad , \\
y_k &\in \{0,1,..,p-1\} \quad .
\end{aligned}
\tag{A-6.1}
$$

This map is continuous as one easily finds out. There is however a little difficulty associated with the definition of the inverse map since the pinary expansion like also decimal expansion is not unique $(1 = 0.999...)$ for the real numbers x, which allow pinary expansion with finite number of pinary digits

$$
\begin{aligned}
x &= \sum_{k=N_0}^{N} x_k p^{-k} \quad , \\
x &= \sum_{k=N_0}^{N-1} x_k p^{-k} + (x_N - 1)p^{-N} + (p-1)p^{-N-1} \sum_{k=0,..} p^{-k} \quad .
\end{aligned}
\tag{A-6.2}
$$

The p-adic images associated with these expansions are different

$$
\begin{aligned}
y_1 &= \sum_{k=N_0}^{N} x_k p^k \quad , \\
y_2 &= \sum_{k=N_0}^{N-1} x_k p^k + (x_N - 1)p^N + (p-1)p^{N+1} \sum_{k=0,..} p^k \\
&= y_1 + (x_N - 1)p^N - p^{N+1} \quad ,
\end{aligned}
\tag{A-6.3}
$$

so that the inverse map is either two-valued for p-adic numbers having expansion with finite pinary digits or single valued and discontinuous and non-surjective if one makes pinary expansion unique by choosing the one with finite pinary digits. The finite pinary digit expansion is a natural choice since in the numerical work one always must use a pinary cutoff on the real axis.

What about the p-adic counterpart of the negative real numbers? It seems that in the applications this correspondence is not needed since canonical identification is used only in the direction $R_p \rightarrow R$ to map the predictions of p-adic probability calculus and statistics to real numbers (in particular, p-adic entanglement entropy must be mapped to its real counterpart). This means that also the inverse of the canonical identification is not needed in the applications. At tge space time level the p-adics and reals relate via common rationals. p-Adic effective topology is expected to be a good approximation only within some length scale range which means infrared and UV cutoffs.

The topology induced by the canonical identification t map in the set of positive real numbers differs from the ordinary topology. The difference is easily understood by interpreting the p-adic norm as a norm in the set of the real numbers. The norm is constant in each interval $[p^k, p^{k+1})$ (see Fig. A-6) and is equal to the usual real norm at the points $x = p^k$: the usual linear norm is replaced with a piecewise constant norm. This means that p-adic topology is coarser than the usual real topology and the higher the value of p is, the coarser the resulting topology is above a given length scale. This hierarchical ordering of the p-adic topologies will be a central feature as far as the proposed applications of the p-adic numbers are considered.

Ordinary continuity implies p-adic continuity since the norm induced from the p-adic topology is rougher than the ordinary norm. p-Adic continuity implies ordinary continuity from right as is clear already from the properties of the p-adic norm (the graph of the norm is indeed continuous from right). This feature is one clear signature of the p-adic topology.

The linear structure of the p-adic numbers induces a corresponding structure in the set of the non-negative real numbers and p-adic linearity in general differs from the ordinary concept of linearity. For example, p-adic sum is equal to real sum only provided the summands have no common pinary digits. Furthermore, the condition $x +_p y < max\{x, y\}$ holds in general for the p-adic sum of the

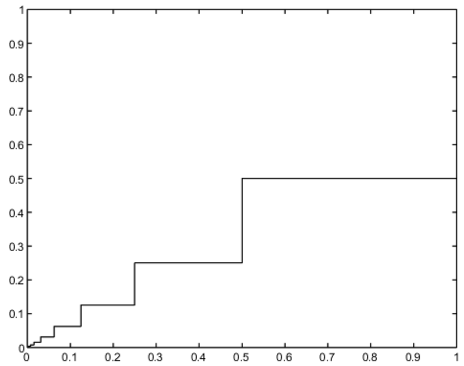

Figure A.1: The real norm induced by canonical identification from 2-adic norm.

real numbers. p-Adic multiplication is equivalent with the ordinary multiplication only provided that either of the members of the product is power of p. Moreover one has $x \times_p y < x \times y$ in general. The p-Adic negative -1_p associated with p-adic unit 1 is given by $(-1)_p = \sum_k (p-1)p^k$ and defines p-adic negative for each real number x. An interesting possibility is that p-adic linearity might replace the ordinary linearity in some strongly nonlinear systems so these systems would look simple in the p-adic topology.

Canonical identification is in a key role in the successful predictions of the elementary particle masses. Canonical identification makes also possible to understand the connection between p-adic and real probabilities. These suggests that canonical identification is involved with some deeper mathematical structure. The following inequalities hold true:

$$\begin{aligned} (x+y)_R &\leq x_R + y_R \ , \\ |x|_p|y|_R \leq (xy)_R &\leq x_R y_R \ , \end{aligned} \tag{A-6.4}$$

where $|x|_p$ denotes p-adic norm. These inequalities can be generalized to the case of $(R_p)^n$ (a linear vector space over the p-adic numbers).

$$\begin{aligned} (x+y)_R &\leq x_R + y_R \ , \\ |\lambda|_p|y|_R \leq (\lambda y)_R &\leq \lambda_R y_R \ , \end{aligned} \tag{A-6.5}$$

where the norm of the vector $x \in T_p^n$ is defined in some manner. The case of Euclidian space suggests the definition

$$(x_R)^2 = (\sum_n x_n^2)_R \ . \tag{A-6.6}$$

These inequalities resemble those satisfied by the vector norm. The only difference is the failure of linearity in the sense that the norm of a scaled vector is not obtained by scaling the norm of the original vector. Ordinary situation prevails only if the scaling corresponds to a power of p.

These observations suggests that the concept of a normed space or Banach space might have a generalization and physically the generalization might apply to the description of some nonlinear systems. The nonlinearity would be concentrated in the nonlinear behavior of the norm under scaling.

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