BICEP2 might have detected gravitational waves

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Abstract

BICEP2 team has announced a detection of gravitational waves via the effects of gravitational waves on the spectrum on polarization of cosmic microwave background (CMB). The findings - if true - have powerful implications for cosmological models. In this article the findings are discussed in the framework of TGD based cosmology in which the flatness of 3-space is interpreted in terms of quantum criticality rather than inflation. The key role is played by gradually thickening cosmic strings carrying magnetic monopole flux, dark energy as magnetic energy and dark matter as large h_{eff} phases at cosmic strings. Very thin cosmic strings dominate the cosmology before the emergence of space-time as we know it and quantum criticality is associated with the phase transition between these two phases. Later cosmic strings serve as seeds of various cosmological structures by decaying partially to ordinary matter somewhat like inflaton fields in inflationary cosmology. Cosmic strings also explain the presence of magnetic fields in cosmos difficult to understand in standard approch. The crucial point is that - in contrast to ordinary magnetic fields - monopole fluxes do not require for their creation any currents coherent in long scales.

1 Introduction

BICEP2 team [E2] has announced a detection of gravitational waves via the effects of gravitational waves on the spectrum on polarization of cosmic microwave background (CMB). What happens that gravitational waves (or possibly some other mechanism) transforms so called E modes which correspond the curl free part of polarization field expressible as gradient to B modes responsible for the divergenceless part of polarization field expressible as curl of vector field.

Interaction of photons with gravitons would induce this polarization changing transformation: this is discussed in earlier post by Lubos. The signal is unexpectedly strong constraints on possible models, in particular to the inflationary models which are currently in fashion. The map produced by BICEP describes the vorticity of the polarization field at the sky and one can clearly see it (`https://lh6.googleusercontent.com/-0PI9pZ7FImM/UycduxUJ3HI/AAAAAAAAG7w/uDlbGCe7ASM/bicep2-b_over_b_rect_BICEP2.png?imgmax=1600`).

There has been a lot of pre-hype about the finding as proof for inflation, which it is not. Even Scientific American falls in the sin of inflationary hyping: inflationary theory is only the dominating theory which might be able to explain the finding.

In the sequel the findings are discussed in the framework of TGD based cosmology in which the flatness of 3-space is interpreted in terms of quantum criticality rather than inflation. The key role is played by gradually thickening cosmic strings carrying magnetic monopole flux, dark energy as magnetic energy and dark matter as large h_{eff} phases at cosmic strings. Very thin cosmic strings dominate the cosmology before the emergence of space-time as we know it and quantum criticality is associated with the phase transition between these two phases. Later cosmic strings serve as seeds of various cosmological structures by decaying partially to ordinary matter somewhat like inflaton fields in inflationary cosmology. Cosmic strings also explain the presence of magnetic fields in cosmos difficult to understand in standard approch. The crucial point is that - in contrast to ordinary magnetic fields - monopole fluxes do not require for their creation any currents coherent in long scales.

2 Liam McAllister's summary about the findings of BICEP2 team

Liam McAllister from Cornell University has written an excellent posting about the discovery and its implications in Lubos's blog [E1]. McAllister discusses the finding from several points of view. Can one trust that the finding is real? How should one interpret the result? What are its implications? A brief summary is in order before going to details.

1. Consideration is restricted to inflationary scenarios but it is made clear that they are not the only option. It is emphasized that a huge amount of inflationary parameter space is excluded by the unexpectedly high strength of the effect. Also the general problems of inflationary models are made explicit - a great favor for those who are not inflationary enthusiasts and might have something else in mind.

2. Also other than gravitonic mechanisms transforming E modes to B modes can be imagined. For instance, the signal might not be primordial but caused by polarized foreground sources: BICEP claims that these contributions have been eliminated.

3. The most important conclusion is of course that a direct detection of gravitational waves - maybe even quantal ones - has been achieved. Earlier gravitational radiation has been detected only a slowing down of rotation rate of pulsars (Hulse-Taylor binary pulsar).

3 Comparison of inflationary models and TGD

Further conclusions depend on the cosmological model adopted and McAllister considers the situation in the framework of inflationary models and lists the basic aspects of inflationary model.

1. The Universe on large scales should be approximately homogenous, isotropic and flat.

2. The primordial scalar density perturbations should be correlated on super-horizon scales and be approximately Gaussian, adiabatic, and approximately scale-invariant.

In TGD framework inflationary cosmology is replaced with a cosmology fixed almost uniquely by the criticality of the mass density when combined with imbeddability to $N^4 \times CP_2$ as Lorentz invariant 4- surface [K6, K5]. The only free parameter is the finite duration τ of the critical period. This kind of critical - it seems even quantum critical - periods are predicted to appear in various scales so that Russian doll cosmology is strongly suggested as in case of inflationary models. Scalar fields (inflaton fields) are replaced with cosmic strings, which evolve by thickening their M^4 projections from string world sheets to 4-D ones. Magnetic energy replaces dark energy and has interpretation as counterpart for the energy of inflation field. Dark matter at magnetic flux tubes corresponds to large $\hbar$ phases [K1, K4, K3].

1. In TGD framework the long range correlations would be due to quantum criticality rather than extremely rapid expansion during inflationary period. The Universe in large scales should be also now homogenous, isotropic, and flat.

2. The primordial density perturbations reflect the presence of cosmic strings before the phase transition period. These cosmic strings have 2-D M^4 projection, which is minimal surface, so that these object behave for all practical purposes like strings, and CP_2 projection is e 2-D holomorphic surface in CP_2. During primordial period cosmic strings dominate and the mass density behaves like $1/a^2$, where a is proper time coordinate of the light-cone. The mass per comoving volume goes to zero at the moment of big bang so that initial singularity is smoothed out and big bang transforms to "a silent whisper amplified to big bang". For radiation dominated cosmology mass density would behave as $1/a^4$ giving rise to infinite energy per comoving volume at the moment of Big Bang.

3. Cosmic strings gradually thicken their M^4 projections and the huge primordial magnetic fields carrying quantized monopole flux weaken. These fields differ crucially from the ordinary magnetic fields in that no current is needed to create them - this is due the fact that CP_2 Kähler form defines a self-dual magnetic monopole (instanton). Amazingly, even the magnetic fields penetrating to super-conductors could be this kind and perhaps even those associated with ferromagnets.

   This can explain why primordial and recent Universe is full of magnetic fields in length scales, where they should not exist since the currents creating them cannot exist in long scales. The thickening of the remnants of cosmic strings would give rise to birth of galaxies organised like pearls in necklace along big cosmic strings: galaxies are indeed known to be organized into long string like structures and density perturbations would correspond to these strings.

   No vacuum expectations of Higgs like scalar fields are needed. Even in elementary particle physics Higgs expectation is replaced with string tension assignable to string like structures accompanying elementary particles.

   Cosmic strings would carry dark energy as magnetic energy and dark matter as phases with large values of Planck constant coming as integer multiple of ordinary Planck constant. Ordinary matter would be formed when cosmic strings and dark matter "burn" to ordinary matter: this would be the TGD counterpart for the decay of inflaton field to ordinary matter.

4. Cosmic strings would define the density perturbations having correlations on super-horizon scales. In the first approximation they are certainly Gaussian. Whether they are adiabatic (no exchange of heat with environment) is an interesting question: if they correspond to large values of Planck constant, this is certainly what one expects. The perturbations would be approximately scale invariant: p-adic length scale hypothesis would formulate this quantitatively by replacing continuum of scales with a hierarchy of discrete p-adic length scales coming as powers of square root of 2 (half octaves).

5. One can of course ask about spectrum of Planck constant coming as integer multiples of ordinary Planck constant: could it realize the presence of large number of length scales characterizing criticality? Could the spectrum of length scales implied by spectrum of Planck constants be the TGD counterpart for the inflationary expansion? Does the average value of Compton length or flux tube length proportional to h_{eff} increase with exponential rate during quantum criticality as larger and larger Planck constants emerge?

It seems that at this qualitative level TGD survives basic tests at qualitative level but without assuming inflation fields and exponentially fast expansion since quantum criticality predicting flat 3-space (dimensional parameters such as curvature of 3-space vanish). Cosmic strings would represent the long range fluctuations. A further bonus is that cosmic strings explain dark energy and dark matter, and also the presence of long range magnetic fields in cosmos.

3.1 Fluctuations of gravitational field

McAllister gives a nice overall summary about the physics involved if given by inflationary models.

1. It is not yet fully clear whether the fluctuations of gravitational field are quantum mechanical or classical. In TGD framework quantum classical correspondence suggests that quantal and classical identifications might be equivalent.
2. Just as the quantum fluctuations of inflaton field would give rise to the density fluctuations visible as temperature anisotropies and large scale structures, the quantum fluctuations of gravitational field would give rise to the observed B modes in inflationary scenario. The correlation functions of gravitons in the background metric would tell everything. The problem is that we do not yet have quantum theory of gravitation allowing to really calculate everything except in QFT approximation.
3. In TGD framework the fluctuations should physically correspond to cosmic strings and the question is whether gravitons can be identified as massless modes for the cosmic strings so that string like objects would give all. In fact, elementary particles are in TGD framework identified as string like objects! Ironically, TGD as generalization of string model realizes stringy dream in all scales and even for ordinary elementary particles!

Since gravitons couple to energy the formula for the energy density at which inflationary period begins should determine the spectrum of gravitational waves. Inflationary models predict this energy scale as the fourth root of the energy density in the beginning of inflation: the formula is given by in the article of McAllister. This formula contains single dimensionless parameter called r, and BICEP measurements give a rather large value $r = .2$ for it.

The natural expectation is that any theory explaining the findings in terms of gravitons produces similar prediction but with the energy density of scalar field replaced with something else. In TGD the energy density assignable to cosmic strings so that the square root of the energy density of cosmic string multiplied by some numerical factor should be the relevant parameter now.

3.2 Inflation should begin at GUT mass scale

The first implication of the findings is that if inflation explains the findings, it should have begun in GUT scale 10^{16} GeV, which is very high. The findings cut off a gigantic portion of the parameter space of inflationary models and leaves only inflation potentials that are approximately translationally invariant.

In TGD framework one expects that the energy scale corresponds to that in which quantum critical period begins after string dominated primordial period. This scale should be given by CP_2 mass scale apart from some numerical factor. CP_2 mass corresponds to $m(CP_2) = \hbar/R(CP_2)$, where $R(CP_2)$ is CP_2 radius. p-Adic mass calculations predict the value of electron mass and assign to electron the largest Mersenne prime M_{127} having the property that the p-adic length scales $\sqrt{p}R(CP_2)$ is not completely super-astronomical. This fixes $R(CP_2)$ and $m(CP_2)$. The outcome is $m(CP_2) \sim 4 \times 10^{15}$ GeV.

A numerical constant can be present in the estimate for the energy scale at which quantum critical period begins. In particular, the factor $1/\alpha_K^{1/4}$ should be present since Kähler action is proportional to $1/\alpha_K$, which by simple argument is in excellent approximation equal to the inverse of the fine structure constant equal to 137. This would rise the estimate for the energy scale to about 10^{16} GeV if the same formula for it is used also in TGD (which might of course be wrong!). With a considerable dose of optimism one could say that TGD allows to understand why the measured value of r is what it is.

4 Difficulties of the inflationary approach

What is nice that McAllister discusses also so the difficulties of inflationary approach.

1. So called Lyth bound gives lower bound for the distance that inflaton's vacuum expectation must move in field space in order to generate detectably large primordial waves: that is the duration of the inflationary expansion. The lower bound is given by Planck mass M_p: $\Delta\Phi > M_p$.
2. There is however a problem. This distance should be not larger than the cutoff scale Λ of the quantum field theory. But if standard wisdom is taken granted, Λ should be smaller than Planck mass M_p giving $\Delta\Phi < M_p$!

3. One can certainly invent all kinds of tricky mechanisms to circumvent the problem: the proposal considered by McAllister is that the couplings of Φ are suppressed to heavy degrees of freedom so that the UV theory respects the approximate shift symmetry $\Phi \rightarrow \Phi + \Delta\Phi$. This is true for massless scalar field but this field does not develop vacuum expectation value. McAllister mentions that for $V = m^2\Phi^2/2$ the approximate shift symmetry is true. Maybe it is for small enough values of m: exact symmetry would require $m = 0$.

4. The physical interpretation of masslessness implied by strict shift invariance would be in terms of conformal invariance. In TGD framework quantum criticality implies conformal invariance also in 2-D sense and quantum criticality corresponds to the absence of dimensional parameters from Higgs potential making Higgs mechanism impossible.

To my humble opinion, this difficulty means a strong blow against the idea about Higgs mechanism as source of vacuum energy density in cosmology. As already mentioned, the decay of the dark energy identifiable as magnetic energy and large h_{eff} dark matter associated with the evolving primordial cosmic strings would produce ordinary matter in TGD Universe.

Also the ordinary Higgs mechanism is plagued by the loss of naturalness and predictivity by the fact that the Higgs particle has too low mass and SUSY has not been found in low enough mass scales to stabilize Higgs mass. In TGD framework the string tension of string like objects assignable to elementary particles would give the dominating contribution to gauge boson masses and p-adic thermodynamics in its original form the dominating contribution to fermion masses [K2]. The couplings of fermions to Higgs are gradient couplings and the coupling is same for all fermions in accordance with naturality and universality [K7].

4.1 Could TGD allow inflationary cosmology?

A natural question is whether TGD could allow inflationary cosmology. In the lowest order this would require imbedding of the De Sitter space [**?**]. De Sitter space allows two basic coordinate slicings.

1. The first one corresponds to a stationary metric having interpretation in terms of interior of an object with constant mass density. The line element reads

$$\begin{aligned} ds^2 &= Adt^2 - Bdr^2 - r^2d\omega^2 \ , \\ A &= 1-(\frac{r}{l})^2 \ , \ B=\frac{1}{A} \ . \end{aligned} \tag{4.1}$$

   l has natural interpretation as outer boundary of the object in question. It will be found that TGD suggests 2-fold covering of this metric.

2. Second coordinatization has interpretation as simplest possible inflationary cosmology having flat 3-space:

$$ds^2 = d\hat{t}^2 - e^{2\frac{\hat{t}}{l}}dr^2 - \hat{r}^2d\omega^2 \ . \tag{4.2}$$

3. The two coordinatizations are related to each other by the formulas deducible from the general transformation property of metric tensor:

$$\begin{aligned} t &= \hat{t} + \frac{1}{2}log[1+(\frac{\hat{r}}{l})^2e^{2\frac{\hat{t}}{l}}] \ , \\ r &= e^{\frac{\hat{t}}{l}}\hat{r} \ . \end{aligned} \tag{4.3}$$

In TGD framework also the imbedding of space-time as surfaces matters besides the metric which is purely internal property. The most general ansatz for the imbedding of De Sitter metric into $M^4 \times CP_2$ is as a vacuum extremal for for Kähler action with the understanding that small deformation carries energy momentum tensor equal to Einstein tensor so that Einstein's equations would old true in statistical sense.

1. The general ansatz for the stationary form of the metric is of same general form as that for Schwartchild metric. One can restrict the consideration to a homologically trivial geodesic sphere S^2 of CP_2 with vanishing induced Kähler form and standard spherical metric. This means that CP_2 is effectively replaced with S^2. This imbedding is a special one but gives a good idea about what is involved.

   Denoting by (m^0, r_M, θ, ϕ) the coordinates of M^4 and by (Θ, Φ) the coordinates of S^2, a rather general ansatz for the imbedding is

$$\begin{aligned} m^0 &= t + h(r) \ \ , \ \ r_M = r \ \ , \\ R\omega \times sin(\Theta(r)) &= \pm\frac{r}{l} \ \ , \Phi = \omega t + k(r) \ \ . \end{aligned} \tag{4.4}$$

2. The functions $h(r)$, $k(r)$, and $\Theta(r)$ can be solved from the condition that the induced metric is the stationary metric. For Schwartschild metric $h(r)$ and $k(r)$ are non-vanishing so that the imbedding cannot be said to be stationary at the level of imbedding space since $t = constant$ surfaces correspond to $m_0 - h(r_M) = constant$ surfaces.

   De Sitter metric is however very special. In this case one can assume $h(r) = k(r) = 0$ for $R\omega = 1$. The imbedding reduces simply to an essentially unique imbedding

$$sin(\Theta(r)) \ = \ \pm\frac{r}{l} = \frac{r_M}{l} \ \ , \ \ \Phi = \frac{t}{R} = \frac{m^0}{R} \ \ . \tag{4.5}$$

   This imbedding is certainly very natural and would describe stationary non-expanding cosmology with constant mass density. Not that the imbedding is defined only for $r_M < l$. Unless one allows 3-space to have boundary, which for non-vacuum extremals does not seem plausible option, one must assume double covering

$$sin(\Theta(r)) \ = \ sin(\pi - \Theta(r)) = \pm\frac{r_M}{l} \ \ . \tag{4.6}$$

   Stationarity implies that there is no Big Bang.

3. The transition to the inflationary picture looks in TGD framework very much like a trick in which one replaces radial Minkowski coordinate with $\hat{r} = exp(-\hat{t}/l)r_M$ and in these new coordinates obtains Big Bang and exponential expansion as what looks like a coordinate effect at the level of imbedding space. Also the transition to radiation dominated cosmology for which the hyperbolic character of M^4_+ metric $ds^2 = da^2 - a^2(dr^2/(1+r^2) + r^2 d\Omega^2)$ is essential, is difficult to understand in this framework. The transition should correspond to a transition from a stationary cosmology at the level of imbedding space level to genuinely expanding cosmology.

The cautious conclusion is that sub-manifold cosmology neither excludes nor favors inflationary cosmology and that critical cosmology [K5] is more natural in TGD framework. In TGD Universe de Sitter metric looks like an ideal model for the interior of a stationary star characterized by its radius just like blackhole is characterized by its radius. It seems that TGD survives the new findings at qualitative and even partially quantitative level.

4.2 Quantum critical cosmology of TGD predicts also very fast expansion

TGD inspired critical cosmology [K5] relies on the identification of 3-space as $a = constant$ section, where a is Lorentz invariant cosmological time defined by the light-cone proper time $a = \sqrt{(m^0)^2 - r_M^2}$, and from the assumption that (quantum) criticality corresponds to a vanishing 3-curvature meaning that 3-space is Euclidian.

The condition that the induced metric of the $a = constant$ section is Euclidian, fixes the critical cosmology apart from its duration a_0 from the existence of its vacuum extremal imbedding to $M^4 \times S^2$, where S^2 homologically trivial geodesic sphere:

$$\begin{aligned}
ds^2 &= g_{aa}da^2 - a^2(dr^2 + r^2 d\Omega^2) \ , \\
g_{aa} &= (\frac{dt}{da})^2 = 1 - \frac{\epsilon^2}{1-u^2} \ , \ u = \frac{a}{a_0} \ , \ \epsilon = \frac{R}{a_0} \ . \\
sin(\Theta) &= \pm u \ , \ \Phi = f(r) \ , \\
\frac{1}{1+r^2} &- \epsilon^2 (\frac{df}{dr})^2 = 1 \ . \qquad (4.7)
\end{aligned}$$

From the expression for dt/da one learns that for the small values of a it is essentially constant equal to $dt/da = \sqrt{1-\epsilon^2}$. When a/a_0 approaches to $\sqrt{1-\epsilon^2}$, dt/da approaches to zero so that the rate of expansion becomes infinite. Therefore critical cosmology is analogous to inflationary cosmology with exponential expansion rate. Note that the solution is defined only inside future or past light-cone of M^4 in accordance with zero energy ontology.

After this a transition to Euclidian signature of metric happens (also a transition to radiation dominated cosmology is possible): this is something completely new as compared to the general relativistic model. The expansion begins to slow down now since dt/da approaches infinity at $a/a_0 = 1$. In TGD framework the regions with Euclidian signature of induced metric are good candidates for blackhole like objects. This kind of space-time sheets could however accompany all physical systems in all scales as analogs for the lines of generalized Feynman diagrams. For $sin(\Theta) = 1$ at $a/a_0 = 1$ the imbedding ceases to exist. One could consider gluing together of two copies of this cosmology together with $sin(\Theta) = sin(\pi - \Theta) = a/a_0$ to get a closed space-time surface. The first guess is that the energy momentum tensor for the particles defined by wormhole contacts connecting the two space-time sheets satisfies Einstein's equations with cosmological constant.

Quantum criticality would be associated with the phase transitions leading to the increase of the length and thickness of magnetic flux tubes carrying Kähler magnetic monopole fluxes and explaining the presence of magnetic fields in all length scales. Kähler magnetic energy density would be reduced in this process, which is analogous to the reduction of vacuum expectation value of the inflation field transforming inflaton vacuum energy to ordinary and dark matter.

At the microscopic level one can consider two phase transitions. These phase transitions are related to the hierarchy of Planck constants and to the hierarchy of p-adic length scales corresponding to p-adic primes near powers of 2.

1. The first phase transition increases Planck constant $h_{eff} = nh$ in a step-wise manner and increases the length and width of the magnetic flux tubes accordingly but conserves the total magnetic energy so that no magnetic energy is dissipated and one has adiabaticity. This sequence of phase transitions would be analogous to slow roll inflation in which the vacuum expectation of inflation field is preserved in good approximation so that vacuum energy is not liberated. The flux tubes contain dark matter.

2. Second phase transition increases the p-adic length scale by a power of $\sqrt{2}$ and increases the length and width of magnetic flux tubes so that the value of the magnetic field is reduced by flux conservation (magnetic flux tubes carry monopole fluxes made possible by CP_2 homology). This phase transition reduces zero point kinetic energy and in the case of magnetic fields magnetic energy transforming to ordinary and dark matter.

3. The latter phase transition can be accompanied by a phase transition reducing Planck constant so that the length of the flux tubes is preserved. In this transition magnetic energy is liberated and dark matter is produced and possibly transformed to ordinary matter. This kind of phase transitions could take place after the inflationary adiabatic expansion and produce ordinary matter. As a matter fact, I have originally proposed this kind of phase transition to be the basic phase transition involved with the metabolism in living matter [K8], which suggests that the creation of ordinary matter from dark magnetic energy could be seen as kind of metabolism in cosmological scales.

   In zero energy ontology one can ask whether one could assign to the Minkowskian and Euclidian periods a sequence of phase transitions increasing Planck constants but proceeding in opposite time directions.

4. During the inflationary period the size scale of the Universe should increase by a factor of order 10^{26} at least. This corresponds to 2^{87} - that is 87 2-foldings, which is a more natural notion than e-folding now. If the size of the sub-Universe is characterized by a p-adic length scale, this would correspond in the final state to $p \sim 2^{174}$ at least: this p-adic length scale is about 4×10^{-5} meters roughly and thus of order cell size.

5. How the transition to radiation dominated cosmology takes place is an interesting question. The decay of the magnetic energy to ordinary matter should take place during the Euclidian period initiating therefore the radiation dominated period. For the radiation dominated cosmology the scale factor behaves as $t \propto a^2$ so that dt/da approaches zero. Since this occurs also when the Euclidian period starts, the guess is that space-time sheets with radiation dominated sub-cosmologies assignable to sub-CDs (CD is shorthand for causal diamond) begin to be created.

Although this picture is only an artist's vision and although one can imagine many alternatives, I have the feeling that the picture might contain the basic seeds of truth.

4.3 Still comments abount inflation in TGD

Quantum criticality is the TGD counterpart of the inflation and the flatness of 3-space follows from the condition that no local dimensional quantities are present in 3-geometry. Also the imbeddability fo M^4 is an important piece of story and restricts the set the parameters of imbeddable cosmologies dramatically.

One can try to understand the situation microscopically in terms of the cosmic strings which gradually develop higher than 2-D M^4 projection during cosmic evolution and become magnetic flux tubes carrying magnetic monopole fluxes explaining the presence of magnetic fields in cosmology.

At microscopic level magnetic flux tubes are the key structural elements. The phase transitions increasing Planck constant for the matter associated with flux tubes and thus also the lengths of magnetic flux tubes should be important as also the phase transitions increasing p-adic prime and reducing Planck constant originally emerged in the modelling of TGD inspired quantum biology are highly suggestive. First transitions would mean adiabatic expansion with no heat generation and latter transitions would liberate magnetic field energy since flux conservation forces field strength to be reduced and leads to liberation of magnetic energy producing ordinary matter and dark matter. Dark energy in turn is identifiable as magnetic energy.

The key question concerns the mechanism causing the isotropy and homogeny of the cosmology. There are two possible identifications.

1. According to two decades old proposal [K5], primordial cosmology before the emergence of space-time sheets could be regarded as string gas in $M^4_+ \times CP_2$ at Hagedorn temperature determined by CP_2 radius: $T_H \sim \hbar/R_{CP_2}$. This phase could be present also after the transition to radiation dominated cosmology and consist of strings, whose thickness is gradually increasing and which contain carry dark energy and dark matter. The horizon radius is infinite for this cosmology thus providing at least partial explanation for the homogeny and isotropy and visible matter would represent deviations from it.

2. The accelerating expansion period towards the end of the critical period could smooth out inhomogenities and thus provide an additional mechanism leading to homogenous and isotropic Big Bang. This for given space-time sheet representing R-W cosmology: in many-sheeted cosmology one can imagine distribution of parameters for the cosmology. The rapid expansion period could however also develop large fluctuations! Indeed, the time $a_F < a_1$ (density would be infinite for a_1) for its end - and therefore local mass density - must have a distribution after the rapid expansion ends. This expansion would generate separate smoothed out radiation dominated space-time sheets with slightly different mass densities and cosmic temperatures. A splitting to smooth radiation dominated sub-cosmologies would take place.

Therefore TGD scenario could be very different from inflationary scenario. The problem is to decide which option is the most feasible one.

The formulas used to make back of the envelope(`http://motls.blogspot.fi/2014/03/inflation-on-back-o` `html`) calculations in inflation theory discussed in a quest posting in Lubos's blog given some idea about TGD counterpart for the generation of gravitons. Inflationary period is replaced with essentially unique critical cosmology containing only its duration as a free parameter. The fluctuations in the duration of this parameter explain scalar temperature fluctuations assoiated with CMB.

4.3.1 How the local polarization of CMB is generated?

There is a nice discussion about the mechanism leading to the generation of CMB polarization (`http://cosmology.berkeley.edu/~yuki/CMBpol/CMBpol.html`). The polarization is generated after the decoupling of CMB photons from thermal equilibrium and is due to the scattering of photons on free electrons during decoupling. This scattering is known as Thomson scattering. The page in question contains schematic illustrations for how the polarization is generated. The scattering from electrons polarizes the photons in direction orthogonal to the scattering plane. In thermal equilibrium the net polarization of scattered radiation vanishes. If however the scattered photons from two perpendicular directions have different intensities a net polarization develops.

Polarized photons could be produced only during a short period during recombination scattering from free electrons was still possible and photons could diffuse between regions with different temperature. Polarized photons were generated when electrons from hot and cold regions where scattering on same electrons. CMB polarization indeed varies over sky but not in long length scales since photons could not diffuse for long lengths.

So called quadrupole anisotropy of CMB temperature contains information about the polarization. There are `http://background.uchicago.edu/~whu/intermediate/Polarization/polar4.html`three contributions: scalar, vector, and tensor.

1. Scalar contributions is due to density fluctuations reflecting themselves as temperature fluctuations and does not distinguish between polarizations: this is what has been studied mostly hitherto. A natural TGD mechanism for their generation would be different time for the end of the critical period leading to splitting of critical cosmology to radiation dominated cosmologies with slightly different temperatures.

2. There is also so called vorticity distribution due to the flow which has vorticity and would due to defects/string like objects present also in TGD. The simplified situation corresponds to are region in which one has two flows in opposite direction locally. Depending on whether the scattering photons are upstream or down stream they are blue-shifted or red-shifter so that the temperatures are slightly different in up-stream and down.The flows in opposite direction give rise to a situation in which photons with different temperatures scatter and produce polarization. The effects of vorticity are expected to disappear during the fast expansion period. Probably because the gradients of velocity giving rise to vorticity are smoothed out.

3. The third contribution is tensor contribution and due to gravitons generating stretching and squeezing of space in two orthogonal directions defining polarization tensor. Stretching increases wavelengths and decreases temperature. Squeezing does the opposite. Therefore temperature differences distinguishing between the two directions are generated and the outcome is polarization of the CMB background much later. This corresponds to the so called E and B modes. One can decompose polarization as vector field to two parts: the first one - the E-mode - is gradient and thus irrotational and second is curl and thus rotational and with vanishing divergence (incompressible liquid flow is a good concrete example).

4.3.2 How the polarization anisotropies could be generated in TGD Universe?

One can try to understand microscopically how the polarization anisotropies are generated in TGD framework using poor man's arguments.

1. One can introduce a vision vision about fractal 3-D network of cosmic strings forming a kinds of grids with nodes in various scales. These grids would be associated with different levels of the hierarchy of space-time sheets associated with many-sheeted space-time. Coordinate grid is of course an idealization since three coordinate lines would meet in single node. A weaker form of grid would involve meeting of two coordinate lines at given node. There is data about our own galactic nucleus understood if it correspond to the node at which two magnetic flux tubes meet.

Ordinary visible matter would be generated in nodes. One might say that galaxies are due to traffic accidents in which dark matter arriving along two cosmic strings collides in the crossing of the roads. Flux tubes would be attracted together by gravitational attraction so from the crossing.

2. Amusingly, the notion grid emerged also TGD inspired quantum biology as a proposal for how living system codes morphogenetic position information. Flux tubes carry dark matter and ordinary matter is associated with the nodes at which coordinate lines meet each other. This web can give rise to a generalization of topological quantum computation using 2-braids. Coordinate lines define strings which can be knotted in 3-dimensions and define braids making possible topological quantum computation using macroscopic quantum phases defined by the dark matter. The time evolutions of coordinate lines defines string world sheets and in 4-D space-time the string world sheets can be knotted and braided so that also higher level TQC becomes possible with string reconnection and going above or below the other define two bits in each node.

3. The presence of grid could also explain the honeycomb like structure of Universe with the recent typical size of honeycomb about 10^8 ly.

4. In this framework the illustrations for how the gravitational waves induce the polarization of CMB. The radiation beams entering from opposite directions can be assigned with two magnetic flux tubes meeting at the node and in slightly different temperatures due to the interaction with gravitons much earlier. The gravitons can be regarded as larger space-time sheets at which the two flux tubes had contacts so that space associated with the flux tubes was forced to stretch or squeeze. This in turn increased of reduced photon wavelength so that photon temperature at flux tubes was different and the difference were preserved during subsequent evolution.

4.3.3 Back on the envelope calculations in TGD framework

One can modify the back on the envelope calculations of John Preskill (`http://motls.blogspot.fi/2014/03/inflation-on-back-of-envelope`). htmlLubos's blog to see what could happen in TGD framework. Now one however starts from the critical cosmology fixed apart from its duration and looks what it gives rather than starting from Higgs potential for inflaton field. The obvious counterpart for inflaton scalar field would be magnetic field intensity having same dimension but one should avoid too concrete correspondences.

The key question is whether the critical period generates the rapid expansion smoothing out inhomogenities or whether it generates them. The original guess that it smooths them out turns out be wrong in closer examination.

1. The basic equation in inflationary model is given by

$$(\frac{\dot{a}}{a)})^2 = \frac{V}{m_p^2}$$

If V is small this has as solution $a(t) = a(0)exp(Ht)$ if $G = \sqrt{V}/m_p$ is constant. De Sitter cosmology allows partial imbedding in TGD but the imbedding is naturally static and has interpretation as black-hole interior with constant mass density. One can find coordinates in which the solution looks like expanding cosmology without Big Bang but these coordinates are not natural from the view of imbedding space.

2. In TGD the expression for $\dot{a}$ for critical cosmology is

$$\dot{a} = \sqrt{\frac{a_0^2 - a^2}{a_0 2^{-} R^2 - a^2}} \ .$$

a_0 is roughly the duration of cosmology and R is CP_2 radius of order $10^{3.5}$ Planck lengths. The almost uniqueness follows from the condition that the imbedding is such that the induced metric at the 3-surfaces defined by intersections with hyperboloids of M^4_+ is flat rather than hyperbolic. This cosmology differs from de-Sitter cosmology.

3. For $a \rightarrow 0$ one has

   $$\dot{a} \simeq \frac{a_0^2}{a_0^2 - R^2} \simeq 1 \quad .$$

   so that one has $\dot{a} \simeq 1$ and $a \simeq t$ for small values of a in accordance with the replacement of Big Bang with a "silent whisper amplified to a Big Bang" (density of matter goes as $1/a^2$) Hubble constant goes like $H \propto 1/a$ so that Hubble radius divergence. This does not guarantee that horizon radius becomes infinite. Rather, the horizon is finite and given in good accuracy by the duration $a_1 = \sqrt{a_0^2 - R^2}$ of the period. One can however explain the isotropy and homogenity of the string gas in M_+^4 carrying flux tubes carrying dark matter and energy in terms of the infinite horizon of M^4.

   There is no exponential time evolution at this period since one has $a \simeq t$ in good approximation for $a/a_0 << 1$. The TGD counterpart of V would behave like $1/a^2$ which conforms with the idea that V corresponds to energy density.

4. As the limit $a \rightarrow a_1 = \sqrt{a_0^2 - R^2}$ is approached, the expansion rate approaches infinite and for $a > a_1$ at the latest one expects radiation dominated cosmology: otherwise a region of Euclidian signature of the induced metric results. The expectation is that a transition to radiation dominated cosmology takes place before $a = a_1$ at which also energy density would diverge. The question is whether this period means smoothing out of inhomogenities or generation of them or both.

Consider now what could happen near the end of the Minkowskian period of critical cosmology.

1. Although it is not clear whether rapidly accelerating expansion is needed to to smooth out homogenities, one can just find what conditions this would give on the parameters. For $a_i = kR$ at which phase transition began the condition that a was increased at least by factor $e^{50} \sim 5 \times 10^{21}$ (50 e-folds) this would give $a_1 \simeq a_0 > e^{50}kR$. For $k \sim 1$ this gives something like 10^{-18} seconds, which happens to correspond atomic length scale. Below it will be found that this period more naturally corresponds to the period during which large fluctuations in density distribution and metric are generated.

2. The earlier estimate for the emergence of radiation dominated cosmology discussed in [K5] assumed that the transition to radiation dominated cosmology takes place at CP_2 temperature defining Hagedorn temperature at which temperature of the string gas cannot be raised anymore since all the energy goes to the generation of string excitations rather than to kinetic energy, gives $a_F \sim 10^{-10}$ seconds, which is by factor 10^8 larger. If this were true, the fast expansion period a_F would increase the scale factor to about 68 e-folds equivalent to 98 2-folds. p-Adic prime $p \simeq 2^{196}$ would correspond to p-adic length scale about $L(196) \sim .1$ meters. The crucial assumption would be that the the time a_f at which the expansion ends is same everywhere. There is no reason to assume this and this would mean that the period in question generates inhomogenities and isotropies of mass distribution and temperature distribution.

   Note that if the distribution of the time $a_F < a_1$ at which the critical period ends is responsible for the CMB fluxtuations then the number of foldings characterizes the smoothness of given local radiation dominated cosmology and could be rather large.

3. The rapid accelerating expansion occurs as g_{aa} approaches zero. Indeed, for

   $$a \rightarrow a_1 = \sqrt{a_0^2 - R^2}$$

   a very rapid expansion occurs and $\dot{a}$ approaches infinite value. Near to a_1 one can write $a/a_1 = 1 - \delta$ and solve δ approximately as function of t as

   $$\delta = (\frac{3R^2}{4a_1^2})^{2/3}(\frac{t-t_1}{a_1})^{2/3} \quad , \quad t_1 = \int_0^{a_1} \frac{(1-\frac{a^2}{a_1^2})^{1/2}}{(1-\frac{a^2}{a_1^2})^{1/2}} \quad .$$

Hubble constant behaves as

$$H \equiv \frac{a}{a} = \frac{R^2}{2a_1^3}\delta^{-1/2} \quad .$$

4. What is interesting is that applying the naive dimensional estimate for the amplitude of gravitational fluctuations to be $\delta h_T^2 \sim H^2/m_P^4$. This would mean that at the limit $a \rightarrow a_F < a_1$ gravitational fluctuations become very strong and generate the strong graviton background. Same applies to fluctuations in mass density.

4.3.4 Summary

The possibility of very rapid expansion near $a = a_F < a_1$ leading to radiation dominated cosmology should have some deep meaning. The following tries to catch this meaning.

1. The explosive period could lead to a radiation dominated cosmologies from string dominated cosmology with Hagedorn temperature. It could involve h_{eff} increasing phase transitions for string gas during the initial period and liberation of magnetic energy during the end period as massless particles: this would explain why the mass density of the space-time sheet increases dramatically. The critical cosmology could correspond to a phase transition from a phase with Hagedorn temperature identified as $T_H \propto \hbar/R_H$ to radiation dominated cosmology.

2. The cooling of string gas would lead to the generation of hierarchy of Planck constants and liberation of the magnetic energy of strings as massless particles during the end of critical period topologically condensing to space-time sheets such as massless extremals. This process could correspond to the rapid increase of energy density towards the end of the critical period.

3. Isotropy and homogenity appear both at the level of imbedding space and space-time sheets. The infinite horizon of M^4_+ would explain the isotropy and homogenity of string gas in H both before and after the emergence of space-time sheets at Hagedorn temperature around $a \sim R_{CP_2}$. In particular, the smoothness of the cosmology of dark matter and dark energy would find explanation. The rapid expansion would in turn smooth out inhomogenities of individual space-time sheets.

4. The Hubble scale $1/H$ approaches to zero as $a = a_F < a_1$ is approached. The rapid expansion destroys anisotropies and inhomogenities of radiation dominated space-time sheet corresponding to particular value of a_F. The distribution for values of a_F in turn explains CMB scalar fluctuations since the energy density in final state is highly sensitive to the precise value of a_F. This distribution would be Gaussian in the first approximation. One can say that the fluctuation spectrum for inflaton field is replaced with that for a_F.

5. Also the generation of gravitational radiation and its decoupling from matter could take place during the same end period. After this gravitational fields would be essentially classical and assignable to space-time sheets. Essentially formation of gravitationally bound states would be in question analogous to what happens photons decouple from matter much later. The reduction of the temperature of string gas below Hagedorn temperature could generate also the massless graviton phase decoupling from matter and inducing the temperature fluctuations and polarization during decoupling.

   Gravitons and also other particles would topological condense at "massless extremals" (MEs,topological light rays) and particles - in particular photons - would interact with gravitons by generating wormhole contacts to gravitonic MEs. The interaction between MEs assignable to gravitational radiation and photons would have caused the fluctuations of CMB temperature.

To sum up, if the TGD inspired picture is correct then Penrose (`http://www.sciencefriday.com/segment/04/04/2014/sir-roger-penrose-cosmic-inflation-is-fantasy.html`) would have been correct in the identification of string theory as fashion and inflationary cosmology as fantasy (for the strong reaction of Lubos see http://motls.blogspot.fi/2014/04/roger-penrose-continues-his-weird-anti.html). Also the fact that inflationary cosmology is at the verge of internal contradiction due the fact that the assumption of field theoretic description is in conflict with the large graviton background suggests that inflationary cosmology is not for long with us anymore.

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