DARK MATTERS AND HIDDEN VARIABLES OF UNITARY SCIENCE:
HOW NEGLECTED COMPLEXITY GENERATES MYSTERIES AND CRISES, FROM QUANTUM MECHANICS AND COSMOLOGY TO GENETICS AND GLOBAL DEVELOPMENT RISKS

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Abstract

The unreduced many-body interaction problem solution, absent in usual science framework, reveals a new quality of emerging multiple, equally real but mutually incompatible system configurations, or "realisations", giving rise to the universal concept of dynamic complexity and chaoticity. Their imitation by a single, "average" realisation or trajectory in usual theory (corresponding to postulated "exact" or perturbative problem solutions) is a rough simplification of reality underlying all stagnating and emerging problems of conventional (unitary) science, often in the form of missing, or "dark", entities and "hidden variables". We show how the application of unreduced interaction problem solution and the ensuing concept of dynamic complexity provides the desired causally complete and intrinsically unified solutions to respective unitary science problems in the entire range of complexity levels, from elementary particles and cosmology to emergent consciousness and modern development crisis, implying real, essential and urgently needed progress.

Unitary science strongly reduces the dynamically multivalued result of any real interaction process, giving rise to violated causality and "unsolvable" problems [1-30]

The standard self-description of today's mainstream science results typically presents it as an "almost" complete and quasi-perfect system of knowledge (being the only possible rigorous/objective one), which is apparently confirmed by the spectacular progress of science-based modern technology. Even the obvious huge contradictions, persisting "mysteries" and growing "difficult" problems of the standard science framework, from quantum mechanics and cosmology to biology and consciousness (see e.g. [1,7-12,14,16-19,28-34]), are presented as "encouraging challenges", although they remain unsolved for many decades (or even a century) already, while the mainstream theories and the scientific method itself do not show any signs of real change and capacity to qualitatively evolve, within the dominating scholar science paradigm.

In order to understand the true origin of this evident conflict between the empirically based knowledge success and irreducible limits to the standard science development, we should specify the underlying key features of the scholar scientific method. Its well-known "positivistic" basis is reduced to "mathematically decorated empiricism", or mathematically ordered observations, not necessarily (and in fact rarely) supported by the *consistent* physical origin of proposed formal "laws". Thus, the main output in scholar theoretical physics, a "theory" supposed to account for observed phenomena, structures and behaviour, is reduced to purely abstract and simplified mathematical structures emerging in their own realm of "nicely symmetric" mathematical objects and rules and just arbitrarily assumed to correspond to observations.[1] Starting already from elementary particles and fields, the studied objects' physical nature, origin and properties, forming the fine-tuned,

[1] Hence the related esoteric idea, indistinguishable from irrational belief and favoured by many leading theoretical physicists, about the "mathematical reality" [35-43] underlying the observed physical reality and being not less objectively real, but much more fundamental than the latter.

cause-and-effect tissue of reality, are largely neglected in such purely mathematical "modelling" and its occasional (always only partial and inconsistent) correlations with real structure behaviour.

No wonder that this dominating formal kind of "explanation" tends to favour simplest possible mathematical structures in its abstract "theories", revealing no true, causally complete physical origin of described real structures and laws. These conventional theories are well represented by the paradigmatic example of yet rather tangible structure of "Newtonian trajectories", but strongly tend today to "phase space" and other purely abstract "spaces", ever more separated from real system behaviour and configuration in real physical space (the latter remaining itself a persistent mystery in scholar science, together with time). As we shall see below, the real, interaction-driven system dynamics and *emergent* structure, starting from the simplest objects of fundamental physics, are very far from those oversimplified "models" of positivistic "theories", which actually provide the *largest possible* simplification of reality. As opposed to *postulated* abstract and separated *structures* of conventional positivistic theories, the *emergent*, *interaction-driven* and *intrinsically unified* character of unreduced physical reality we *explicitly derive* in our approach implies the key role of *dynamics*.

If we want to avoid the fundamental deficiency of conventional positivism, we should start our consistent description of real world structure and dynamics from the *unreduced* analysis of the underlying universal process of *interaction*, which progressively gives rise to *all* observed structures, properties and laws of their behaviour. It is obvious that one should start from the *simplest* possible interaction configuration, without any additional assumptions and artificially introduced features.

Such simplest initial configuration of structure-forming interaction is given by two effectively structureless and homogeneously interacting entities, or "protofields" [1,2,5-12,14]. Taking into account the observed universal properties, one can specify one of them as the physically real *electromagnetic (e/m) protofield* (eventually responsible for electromagnetic features) and another one as the equally material *gravitational protofield* (leading to gravitational attraction), without any real limitation or special assumption for our unified interaction description. The homogeneous interaction between protofields in the form of their uniform attraction is the simplest

structure-forming kind of interaction, again without any special assumptions for the following interaction analysis.

The most general and assumption-free mathematical expression of this simplest interaction configuration is provided by the Hamiltonian form of *existence equation* [1,2,5-12,14] generalising e.g. the Hamilton-Jacobi and Schrödinger equations, but actually only fixing the fact of interaction and initial system configuration (it is also self-consistently confirmed by further analysis):

$$\left[h_{\mathrm{g}}(\xi)+V_{\mathrm{eg}}(\xi,q)+h_{\mathrm{e}}(q)\right]\Psi(\xi,q)=E\Psi(\xi,q), \qquad (1)$$

where ξ and q stand for the degrees of freedom of gravitational and e/m protofields respectively, $\Psi(\xi,q)$ is the system state function, $h_{\mathrm{g}}(\xi)$ and $h_{\mathrm{e}}(q)$ are the generalised Hamiltonians of free gravitational and e/m protofields, $V_{\mathrm{eg}}(\xi,q)$ is the potential of their (attractive) interaction, and E the system Hamiltonian eigenvalue, or generalised energy. As shown elsewhere (and below), the generalised Hamiltonian and energy express a suitable *measure of unreduced dynamic complexity*. We emphasize the *absence of time* in our initial problem formulation, since time, together with other intrinsic features, is an *emergent* entity in our fully consistent approach and appears *dynamically* in the interaction development process.

Note that all interactions between the protofield elements are included in the compact form of eq. (1) as expressed in a more explicit form of existence equation for arbitrary many-body interaction [1,2,11,13-24,28,29]:

$$\left\{\sum_{k=0}^{N}\left[h_k(q_k)+\sum_{l>k}^{N}V_{kl}(q_k,q_l)\right]\right\}\Psi(Q)=E\Psi(Q), \qquad (2)$$

where $h_k(q_k)$ is the generalised Hamiltonian of the k-th system component (here protofield element) in its "free", "integrable" state (in the absence of interaction), q_k stands for the degrees of freedom of the k-th component, $Q=\{q_0,q_1,...,q_N\}$ by definition, $V_{kl}(q_k,q_l)$ is the interaction potential between the k-th and l-th components, $\Psi(Q)$ is the system state function, and the summations are performed over all system components numbered from $k,l=0$ to $k,l=N$ (the total number of interacting entities). If we separate in $h_{\mathrm{g}}(\xi)$ all the free Hamiltonians $h_k(q_k)$ and interactions $V_{kl}(q_k,q_l)$ between the gravitational protofield elements (with all their degrees of freedom grouped in ξ) and in $h_{\mathrm{e}}(q)$ the corresponding free Hamiltonians and

interactions between the e/m protofield elements (grouping their degrees of freedom in q), then the detailed existence equation (2) is reduced to the compact form (1), with $V_{\mathrm{eg}}(\xi,q)$ representing the sum of interactions between elements of different protofields. Or if we are interested in detailed interactions only between the e/m protofield elements, while considering the gravitational protofield as a quasi-homogeneous underlying medium, or "matrix", then the same many-body existence equation (2) takes the form

$$\left\{h_0(\xi)+\sum_{k=1}^{N}\left[h_k(q_k)+V_{0k}(\xi,q_k)+\sum_{l>k}^{N}V_{kl}(q_k,q_l)\right]\right\}\Psi(\xi,Q)=E\Psi(\xi,Q), \quad (3)$$

where $q_0\equiv\xi$ groups the eventually "hidden" degrees of freedom of the gravitational protofield, $Q=\{q_1,...,q_N\}$ includes the explicitly appearing degrees of freedom of the e/m protofield, and k,l vary now between 1 and N. With $Q\to q$ in eq. (3), the latter turns again into the reduced notation of eq. (1), without any loss of generality.

The equivalence of various forms of existence equation (1)-(3) is confirmed by its further analysis in terms of (known) eigen-solutions for some, usually explicitly observed participants of the global interaction process, represented by the e/m protofield for eq. (1):

$$\Psi(\xi,q)=\sum_n\psi_n(\xi)\varphi_n(q), \quad h_{\mathrm{e}}(q)\varphi_n(q)=\varepsilon_n\varphi_n(q), \quad (4)$$

where $\{\varphi_n(q)\}$, $\{\varepsilon_n\}$ is the complete set of (orthonormalised) eigenfunctions and eigenvalues of the free e/m protofield, describing its *local* element excitations (with n enumerating localities and eigenvalues for them). Applying the standard procedure, we insert expansion (4) into eq. (1) and using the orthonormality of $\{\varphi_n(q)\}$ obtain the system of equations for $\psi_n(\xi)$, which is equivalent to *any* form (1)-(3) of existence equation:

$$\left[h_{\mathrm{g}}(\xi)+V_{nn}(\xi)\right]\psi_n(\xi)+\sum_{n'\neq n}V_{nn'}(\xi)\psi_{n'}(\xi)=\eta_n\psi_n(\xi), \quad (5)$$

where $\eta_n\equiv E-\varepsilon_n$ and $V_{nn'}(\xi)$ are matrix elements of the protofield interaction potential:

$$V_{nn'}(\xi)=\int_{\Omega_q}dq\varphi_n^*(q)V_{\mathrm{eg}}(\xi,q)\varphi_{n'}(q). \quad (6)$$

The obtained system of equations (5) describing the unreduced process of structure formation in the system of two coupled protofields (or

actually any other many-body system) is inevitably "unsolvable", i.e. nonintegrable and nonseparable, in terms of "exact" (closed-form) solutions and therefore replaced in usual theory approaches to various many-body interaction problems by essentially simplified, integrable "models" that can be generalised as a separable *"mean-field" interaction*, with its "exact" solutions and their further, equally "exact" *perturbative* extensions:

$$\left[h_{\mathrm{g}}(\xi)+V_{nn}(\xi)\right]\psi_n(\xi)=\eta_n\psi_n(\xi), \tag{7}$$

where $V_{nn}(\xi)$ is just one simplest example among various other mean-field expressions of similar dynamic origin. However, what is definitely lost in any such model is the structure-forming capacity of the unreduced system interaction, or "emergence" in popular complexity science expressions, which is due to essential, dynamically evolving links between all interacting modes in (5), while all usual approximate models (7) are reduced to mechanical reproduction of the initially fixed system configuration.

In order to overcome those key limitations of usual analysis, we try to solve the unreduced system of equations (5) by the *generalised effective (or optical) potential method* [1,3,44], where the "effective field" of *all* interactions acting on a given component mode is *not* simplified by any averaging of other mode dynamics and therefore acquires *qualitatively new* properties giving rise to rigorously describable features of *unreduced* interaction complexity. This is achieved technically by expression in (5) of $\psi_n(\xi)$ through $\psi_0(\xi)$ in all equations with $n\neq 0$ using the standard Green's function properties and further substitution of the obtained expressions in the equation for $\psi_0(\xi)$, leaving us with a single equation:

$$\left[h_{\mathrm{g}}(\xi)+V_{\mathrm{eff}}(\xi;\eta)\right]\psi_0(\xi)=\eta\psi_0(\xi), \tag{8}$$

where $\eta_n\equiv\eta_0$ is the eigenvalue to be found, the *effective potential (EP)* $V_{\mathrm{eff}}(\xi;\eta)$ is given by

$$V_{\mathrm{eff}}(\xi;\eta)\psi_0(\xi)=V_{00}(\xi)\psi_0(\xi)+$$
$$V_{0n}(\xi)\psi_{ni}^0(\xi)\int_{\Omega_\xi} d\xi'\psi_{ni}^{0*}(\xi')V_{n0}(\xi')\psi_0(\xi')$$
$$+\sum_{n,i}\frac{}{\eta-\eta_{ni}^0-\varepsilon_{n0}}, \tag{9}$$

$\varepsilon_{n0}=\varepsilon_n-\varepsilon_0$, $n\neq 0$ (also below), and $\{\psi_{ni}^0(\xi)\}$, $\{\eta_{ni}^0\}$ is the complete set of

eigenfunctions and eigenvalues for a truncated system of equations (system (5) without $\psi_0(\xi)$):

$$\left[h_{\mathrm{g}}(\xi)+V_{nn}(\xi)\right]\psi_n(\xi)+\sum_{n'\neq n}V_{nn'}(\xi)\psi_{n'}(\xi)=\eta_n\psi_n(\xi),\ \ n,n'\neq 0. \quad (10)$$

Solving the *effective interaction, or existence, equation* (8) for $\psi_0(\xi)$, we find other state-function components $\psi_n(\xi)$ with the help of mentioned Green's functions and then the total state-function $\Psi(\xi,q)$ according to the initial expansion (4) (see below) [1-3,8-23].

Despite its externally simple expression in eq. (8), the effective problem formulation is equivalent to the initial formulation (1)-(3), (5) and remains equally nonintegrable, because of the complicated EP dependence on the solutions to be found, eq. (9), *explicitly* revealing the *essentially nonlinear* system dynamics behind its seemingly linear initial formulation. Usual EP approach tries to get rid of those "unsolvable" difficulties by using perturbative simplification of the unreduced EP expression (9) (see e.g. [45]), leaving one with a version of ordinary mean-field approximation (7) and its severe limitations. If, however, we avoid any simplification of the full EP formalism (8)-(10), then it is not difficult to see that the revealed effective, *dynamic* nonlinearity leads to the *new quality* of the unreduced problem solution with respect to all usual, "exact" or perturbative, solutions.

This key new quality is obtained as the essential, universally derived growth of the number of interaction problem eigen-solutions beyond their ordinary, "normal" set completely sufficient to form just one its physically real configuration (as a result of interaction development). Indeed, the number of eigen-solutions of the effective existence equation (8)-(9) is determined by the highest power $N_{\max}$ of the characteristic equation for η:

$$N_{\max}=N_\xi\left(N_qN_\xi+1\right)=N_{\Re}N_{q\xi}+N_\xi\ , \quad (11)$$

where N_q and N_ξ are the numbers of summands in the sums over *n* and *i* respectively in eq. (9) (often $N_q=N_\xi=N$, where N is the total number of interacting modes or, in general, the number of mode combinations), $N_{q\xi}=N_qN_\xi$ is the ordinary eigen-solution number for a physically complete system configuration, and $N_{\Re}=N_\xi$ is the number of system *realisations*, i.e. its really emerging, *equally probable* but different configurations, each of them including the ordinary number of eigen-solutions $N_{q\xi}$ and therefore *incompatible* with any other, equally physically complete system realisation.

While in any usual model and conventional science in general (including its complexity imitations) $N_{\Re}=1$ (because the unreduced interaction problem (5) is always replaced by a "tractable" approximation like (7)), in our case of interacting protofields and for any other *real* system we have $N_{\Re}\gg 1$ (and in any case $N_{\Re}>1$ for any real interaction). In support of this algebraic derivation from the characteristic equation for the effective problem formulation, the plurality of (any real) system realisations is also obtained by the graphical analysis of the same equation (8) [1-4].

Equation (11) implies therefore that the mentioned *new quality* of the unreduced interaction problem solution due to its effective dynamic nonlinearity takes the form of *permanent change* of its plural, mutually incompatible realisations emerging in *dynamically random* order thus defined, as opposed to only one, unchangeable and fixed realisation (or trajectory) in any usual theory and description. We call the system dynamical splitting into many incompatible realisations, revealed as a *universal* property of unreduced interaction problem solution, *(fundamental) dynamic multivaluedness*, or *redundance*, while the unrealistic case of only one system realisation, invariably considered in standard theory, is referred to as *unitary* theory, description and science (including actually the entire body of standard scientific knowledge) [1-3,11,14,28-30]. Note that various semi-empirical (and "computational") *imitations* of complex dynamics in unitary science referring, in particular, to "multistability" and "multiple attractors" still contain *only one* system realisation of the same point-like unitary projection (corresponding to zero value of unreduced dynamic complexity, see below), since they deal always with a single trajectory structure or evolution, where different *compatible*, *coexisting* attractor structures or system states are consecutively taken by the smoothly evolving system with only formally inserted time variable (cf. our *emergent time* below).

As can be seen from eq. (11), in addition to $N_{\Re}$ physically complete ordinary, or *regular*, system realisations, each of them containing the full set of $N_{q\xi}$ eigenvalues of emergent interaction result (system configuration), there is one more, separate set of "incomplete" number of N_{ξ} eigenvalues insufficient to form a regular realisation and the corresponding observed interaction result. It is not difficult to see (also from the graphical analysis of the unreduced problem solution [1-4]) that this additional eigenvalue set constitutes the necessary special realisation taken by the system during its

transitions between regular realisations. This transient, distributed system realisation is called the *main*, or *intermediate*, *realisation* and provides the *universal, physically real extension* of the quantum-mechanical *wavefunction* and various *distribution functions* at respective complexity levels [1,2,5-11,14,19,28]. The reduced number of eigenvalues corresponds to transiently vanishing effective interaction between the system components in this "loose" realisation, where the system returns to a version of its initial state at the beginning of interaction process in order to form the next emerging strong-interaction state of regular, fully structured realisation.

At the considered lowest level of interacting, initially homogeneous protofields, each regular, strong-interaction realisation emerges physically in the form of squeezed and entangled concentration of the coupled protofield material called *virtual soliton* and giving rise to the localised, corpuscular state of thus *dynamically emerging elementary particle* and physical space point *x*, while the extended main realisation, ensuring system transitions between such concentrated regular realisations, corresponds to the physically real wavefunction of the particle, $\Psi(x)$, accounting for its undular properties. This rigorously confirmed result (see further details below) can be understood also in terms of physically transparent system *instability* with respect to regular realisation formation and change, where any small local density growth in the coupled protofield system gives rise to a self-amplifying protofield squeeze in that location followed by the equally inevitable extension after the maximum compression, driven by the same intrinsic instability of the neighbouring protofield interaction.

Returning to the rigorously specified dynamically multivalued structure of any real interaction process (1)-(5), we can now define the *dynamically determined*, *a priori probability*, α_r, of the *causally random* emergence of the *r*-th system realisation from the complete set of its $N_{\Re}$ realisations. Due to the equally probable emergence of each elementary realisation in the simplest, initially homogeneous system configuration, the dynamic realisation probability is obtained as

$$\alpha_r = \frac{1}{N_{\Re}} \ , \ \ \sum_r \alpha_r = 1 \ . \qquad (12a)$$

In the general case of inhomogeneous system, where elementary realisations may be not resolved individually and form actually observed dense groups, or *compound realisations*, we have

$$\alpha_r = \frac{N_r}{N_{\Re}} \ , \ \ \sum_r \alpha_r = 1 \ , \tag{12b}$$

where the *r*-th realisation contains N_r elementary, not directly observable realisations. In particular, the inhomogeneity of the intermediate, wavefunction realisation is due to its dependence on the emerging system configuration, or generalised "space coordinate", of respective regular realisations, $\Psi(x) = \Psi(x_r)$. The above expression for the dynamic realisation probability, eq. (12a), takes then the form of the *generalised Born rule*, now causally explained and extended to any system dynamics [1,2,5-12,14,19-23,28]:

$$\alpha_r = \left|\Psi\left(x_r\right)\right|^2 \ , \ \ \sum_r \left|\Psi\left(x_r\right)\right|^2 = 1 \ , \tag{13}$$

where the last equation reflects the probability normalisation to 1 (similar to eqs. (12)) taking the usual integral form of wavefunction normalisation condition in the limit of closely spaced, quasi-continuous realisation distribution. Note that for corpuscular levels of complexity with dominating localised structures one will usually have here the generalised wavefunction, or distribution function, value instead of its modulus squared.

Since emerging system realisations determine all observed structures and motions (as further confirmed below), expressions (12)-(13) for the dynamic realisation probability actually provide the rigorously substantiated, universal definition of omnipresent *dynamical chaos* in terms of unreduced, *multivalued* interaction dynamics, essentially extending usual definitions of chaoticity within the ordinary, dynamically single-valued (unitary) theory. We can see that it is the fundamental dynamic multivaluedness itself that provides the unique, universal basis for the *purely dynamic* emergence of randomness within *any* observed structure and process, equivalent thus to the consistent definition and unified, realistic *origin of (any) randomness* as such, together with other, now clearly unified concepts, including *nonintegrability*, *nonseparability, undecidability,* and *noncomputability* [1-4,11,14, 19,28,29]. While the standard unitary theory cannot consistently specify the intrinsic, fundamental origin of genuine dynamic randomness, replacing it with various imitative "signatures", our unreduced interaction analysis finds it within *any*, even externally regular, or *self-organised*, structure (corresponding to the above compound realisation of eq. (12b) with $N_r \cong N_{\Re}$, see also the fourth section below). In particular, we provide the consistent theory

of *genuine quantum chaos* correctly passing to (equally consistent) classical chaos under the standard transition to classicality ($\hbar \to 0$) [1-3,14,44], which solves the stagnating quantum chaos problem of usual theory.

We can now provide the consistent and *universal definition of dynamic complexity* of any system or interaction process as another aspect and quantitative expression of their *equally universal chaoticity*. Dynamic complexity, C, is defined as any growing function of the number of system realisations, $N_{\Re}$, or rate of their change, equal to zero for the unrealistic case of only one system realisation (uniquely considered in usual theory) [1-4,8-24,28]:

$$C = C\left(N_{\Re}\right),\ dC/dN_{\Re} > 0,\ C\left(1\right) = 0, \tag{14}$$

where, for example, $C(N_{\Re}) = C_0(N_{\Re} - 1)$ or $C(N_{\Re}) = C_0 \ln(N_{\Re})$. It means that it is the number of regular system realisations, beyond the special intermediate realisation of distribution (or wave) function, which determines the nonzero dynamic complexity of real systems. By contrast, the single realisation considered in usual theory often originates in the generalised distribution function, or main realisation, of the unreduced, dynamically multivalued system description, which reveals the nature of the unitary theory as *effectively zero-dimensional, point-like projection* of the unreduced, dynamically multivalued reality (also in connection to the generalised Born rule (13)). This unitary science projection may seem closer to reality for strongly localised self-organised behaviour with only one effectively observed compound realisation (cf. eq. (12b)) or "trajectory", but as it always contains many different (though similar) realisations within its pseudo-regular shape, any real-world structure is both truly chaotic and dynamically complex, $C > 0$ (and practically always $C \gg C_0 \simeq C(2)$). As we show here and elsewhere [1-30], *it is this rough, ultimately simplified projection* of dynamically multivalued reality onto zero-dimensional space of usual, unitary science which explains *all* its problems with "missing" matter, energy, "hidden variables" (i.e. *realisations*) and other apparent contradictions in *real-system* behaviour.

Another important property of the unreduced interaction result, complementing the key feature of dynamic multivaluedness, is the *dynamic entanglement* of interacting degrees of freedom (or system components) characterising the *tangible physical quality* (texture) of the emerging structure and expressed by the dynamically weighted combination of products of functions depending on individual interacting degrees of freedom (like ξ and q

in eq. (4), see also below, eq. (16)). This physically real property is ignored in abstract unitary models and further amplified in our unreduced interaction analysis by the eventual *dynamically fractal*, hierarchic *and* multivalued (probabilistically changing) structure of the ultimate problem solution, obtained by application of the same unified EP method to solution of the (finite) sequence of ever smaller truncated systems of equations, starting from eq. (10) [1,2,8-11,14,16-23,28]. It is evident that causally random change of regular system realisations with the dynamically entangled structure at any level of this fractal hierarchy occurs through the reverse process of *dynamic disentanglement* of interacting degrees of freedom in the transient phase of intermediate realisation, or generalised wavefunction, which further clarifies the physically real structure of the latter.

We can now further specify the physical configuration of the emerging first level of interaction of our two initially homogeneous protofields. The measurable *system density* $\rho(\xi,q)$ is obtained as the *dynamically probabilistic sum* of densities of all emerging, permanently changing system realisations, $\{\rho_r(\xi,q)\}$, each of them obtained as the modulus squared of respective state functions (4) found by solution of the system of equations (5) with the help of the generalised EP formalism (8)-(10) [1-6,8-12,14,28]:

$$\rho(\xi,q)\equiv\left|\Psi(\xi,q)\right|^2=\sum_{r=1}^{N_{\Re}}{}^{\oplus}\,\rho_r(\xi,q)=\sum_{r=1}^{N_{\Re}}{}^{\oplus}\left|\Psi_r(\xi,q)\right|^2, \tag{15}$$

$$\Psi_r(\xi,q)=\sum_i c_i^r\Big[\varphi_0(q)\psi_{0i}^r(\xi)+$$

$$+\sum_{n,i'}\frac{\varphi_n(q)\psi_{ni'}^0(\xi)\int\limits_{\Omega_\xi}d\xi'\psi_{ni'}^{0*}(\xi')V_{n0}(\xi')\psi_{0i}^r(\xi')}{\eta_i^r-\eta_{ni'}^0-\varepsilon_{n0}}\Big], \tag{16}$$

where the special sign $\oplus$ refers to the new, *dynamically probabilistic* meaning of the sum over realisations (implying their *permanent probabilistic change*, with the dynamic probabilities (12)-(13)), $n\neq 0$, $\varphi_0(q)$, $\varphi_n(q)$ are the known eigenfunctions of the e/m protofield Hamiltonian $h_{\mathrm{e}}(q)$ (see eqs. (4)), c_i^r are the state-function matching coefficients providing the rigorous derivation of the generalised Born rule (13) for realisation probabilities [1,5,6,8-12,14], and $\{\psi_{0i}^r(\xi),\eta_i^r\}$ is the set of the r-th realisation eigenfunctions and eigenvalues of the effective existence equation (8)-(9).

In accordance with the above physically transparent interpretation of the emerging protofield interaction result, it can be seen from eqs. (15)-(16) that due to the joint action of cutting integrals in numerators and resonant denominators each appearing *r*-th (regular) state-function realisation concentrates around one of its eigenvalues, η_r^r, naturally interpreted as emerging physical space point and elementary particle "hard core" (or "virtual soliton") [1,5,6,8-12,14].[2] This feature is self-consistently confirmed by a similar expression (9) for the effective potential, which will also show the highest magnitude of potential well of the same *r*-th realisation at $\eta \simeq \eta_r^r$. Permanent change of system realisations in causally random order, eq. (15), can therefore be specified as alternating protofield contractions (with their dynamic entanglement) and extensions (with disentanglement) around randomly chosen (but close enough) centres.

We call each such local, *spatially chaotic* and highly nonlinear self-oscillation process in the coupled protofield system *quantum beat* and show that it demonstrates all the observed physical properties of a (massive) *elementary particle*, now specified as an *intrinsically dualistic field-particle*, such as the *electron* [1-11]. Compound elementary particles, including essentially *hadrons*, contain several such variously coupled and mixed quantum beat processes (appearing e.g. as quarks). Different kinds of particles appear due to several possible global realisations of the EP magnitude, with stronger effective interaction between protofields for heavier particles (showing eventually stronger forces of interaction between them, see the next section). Massive localised field-particle emergence in the vast (practically "infinite") system of coupled protofields leads to growing tension of protofield sections between the particles (giving rise to their interactions, see below), so that for a fixed protofield coupling magnitude new massive particles with sufficiently strong protofield interaction and entanglement within them cannot form any more, leaving only possibilities for much smaller, *massless* protofield perturbations in inter-particle spaces, such as *photons* (still representing, however, a *coupled* state of the two protofields, in the form of very weakly dissipative *solitons*, see the next section).

In that way we obtain the key features and general picture of the observed *first level* of complex-dynamical protofield interaction results, or the

[2] We assume here the suitable choice of e/m protofield eigenfunctions $\varphi_0(q)$, $\varphi_n(q)$ in eqs. (4) as narrow peaks describing the eigenstates of its real, though maybe irresolvable, components.

first (dynamic) *complexity level* of the world (further details and higher complexity levels are specified below), *consistently derived* from the *unreduced* protofield interaction analysis, without any additional assumptions, "models", "principles", or pre-existing structures, either explicit, or "hidden", "dark", "parallel", etc. (as it is done in unitary theories). Two universal and deep distinctions of this and following results within our *emerging* and physically real world description from any unitary science model are that (1) *all* real-world structures are now obtained as *essentially complex, dynamically multivalued interaction processes*, and (2) any world structure or property is actually a manifestation, or feature, of interaction-driven, cause-and-effect *dynamics*, instead of the opposite dynamical features modelling by postulated, finally arbitrary, abstract-mathematical and fixed *structures* in the standard science framework. Various unitary *hidden variables*, in quantum mechanics and beyond, are now explicitly obtained in the form of *plural* system realisations, i.e. its real, dynamically emerging and *always changing* structures and regimes. Only the truly consistent, totally causal dynamical approach used here can (and naturally does) provide the *genuine theory of everything*, also beyond the limits of the currently empirically observable, today's "material" reality [2].

Emerging complexity features at its lowest sublevels: Space, time, mass, interactions, and quantum relativity

We can now further specify the dynamically emerging properties of the obtained first and then higher complexity levels of the interaction-driven real world system. We start with the already mentioned fundamental entities of *space* and *time*, none of them assumed or implied in any way in the initial interaction problem formulation, eqs. (1)-(3). The emergence of local quantum beat (self-oscillation) processes in the initially homogeneous system of coupled protofields, rigorously derived above by the unreduced interaction analysis (eqs. (8)-(9), (15)-(16)), provides already the physically transparent concept and origin of space and time as being due to, respectively, inhomogeneous, highly nonlinear *squeeze (reduction)* of the entangled protofields within the corpuscular *virtual soliton* state of thus obtained elementary field-particle (alternating with the opposite protofield extension and disentanglement) and permanent *change* of the centre of each next quantum beat reduction in *chaotic (dynamically random) order*. While the fundamental physical *space* is the emerging tangible, "material" *structure* of entangled protofields, *time* is the accompanying nonmaterial, spatially chaotic *process* of interaction-driven realisation change, reduced to *chaotic virtual-soliton wandering* at this first complexity level. Whereas the emerging space structure is *dynamically discrete* due to the finite amplitude of protofield compression, the related time flow is *intrinsically unstoppable* and *irreversible* due to the unstoppable realisation change and their causally random order of appearance.

These basic features of emerging space and time can be specified in a mathematically rigorous (and actually *universal*) way [2,9-11,15-24,28], where the *size* r_0 *of a physical point* of emerging real space is determined by the characteristic eigenvalue separation within one realisation of the effective existence equation (8)-(9), $r_0 = \Delta x_i = \Delta_i \eta_i^r$, while the *elementary length* $\Delta x = \lambda$ (the minimum distance between points) is determined by the eigenvalue separation between different (neighbouring) realisations, $\Delta x = \lambda = \Delta x_r = \Delta_r \eta_i^r$. The *elementary time interval* Δt is dynamically determined as

the *quantum beat period* τ, $\Delta t = \tau = 1/\nu$, where ν is the quantum beat *frequency*, actually expressing the *intensity* of *spatially chaotic* realisation change.[3] The Δt value can be conveniently obtained from the above elementary length λ and the velocity υ_0 of perturbation propagation in the e/m protofield (coupled to the gravitational protofield), $\tau = \lambda/\upsilon_0$, where υ_0 in this general expression is obviously identified at this lowest complexity level as the *speed of light c*, $\tau = \lambda/c$, because the e/m protofield excitations are observed as photons. Note that the intrinsic *universality* of the obtained space and time origin, qualities and definitions means that both entities can be defined for any higher complexity level, thus revealing their *multilevel* (and eventually dynamically fractal) structure naturally related to the emerging probabilistic fractal of the world complexity (see below).

We see that the first level of the world structure, in the form of *elementary particles*, *space* and *time*, is *explicitly, dynamically created* in the unified complex-dynamical (multivalued) process of quantum beat as a result of initially homogeneous interaction between the e/m and gravitational protofields. The emerging dynamically woven space and irreversibly flowing time constitute the elementary *forms of dynamic complexity* universally measured by a growing function of the number of consecutively taken system realisations, eqs. (14). It is not difficult to understand therefore that the fundamental *integral measure of complexity* is provided by *action-complexity* $\mathcal{A}$ generalising the notion of usual mechanical action as the simplest linear combination of (growing) space and time [1,2,5,6,8-24,28]:

$$\Delta\mathcal{A} = p\Delta x - E\Delta t, \tag{17}$$

where the coefficients p and E are recognised as (generalised) *momentum* and *energy* defined now as *universal differential complexity measures* (provided by spatial and temporal rates of realisation change respectively):

$$p = \frac{\Delta\mathcal{A}}{\Delta x}\Big|_{t=\text{const}} \simeq \frac{\mathcal{A}_0}{\lambda}\ , \tag{18}$$

[3] Note the fundamental importance of *dynamically random* character of each time-creating event of realisation emergence in our universal definition of real time flow, here and below, reduced to causally random choice of each next emerging realisation from the entire set of really (and equally) possible, but incompatible (redundant) realisations [1,2,10,14,28]. Real time is intrinsically related to fundamental, causal *unpredictability* of its emergence events, and that's exactly why it flows *irreversibly*. This crucially important link between time and *genuine* dynamic randomness does not even appear in any usual, dynamically single-valued theory, where the imitative unitary time-parameter is seen, on the contrary, as a result of *regular* (or arbitrary) sequence of predetermined, formal "events" (for example, in some recent versions of quantum gravity).

$$E = -\frac{\Delta \mathcal{A}}{\Delta t}\Big|_{x=\text{const}} \simeq \frac{\mathcal{A}_0}{\tau}, \tag{19}$$

with x and p understood in general as vectors and $\mathcal{A}_0$ expressing the characteristic action magnitude.

At the considered first level of complexity, the general definition (19) of the total energy (of the quantum beat process, or elementary field-particle) takes the form [1,2,5-12,14]:

$$E = -\frac{\Delta \mathcal{A}}{\Delta t}\Big|_{x=\text{const}} = \frac{h}{\tau} = h\nu, \tag{20}$$

where the quantum beat period $\tau = \Delta t\big|_{x=\text{const}}$ and frequency $\nu = 1/\tau$ hint already on the intrinsic and *physically real wave-particle duality* of complex-dynamical origin, while the *Planck constant* $h = \Delta \mathcal{A} = \mathcal{A}_0$ is now *rigorously derived* as the characteristic change and value of *action-complexity* remaining *discrete* (due to realisation discreteness) but also *fixed* and *universal* at this *lowest* complexity level (see also below, after eq. (42)).

We can now introduce the rigorous universal definition of the *state of rest* of any system as the one with the smallest dynamic complexity (specified as energy and always positive), while a *state of motion* is rigorously defined as any system state with energy-complexity above the minimum value of the state of rest. While these definitions do not depend on any intuitive ideas and empirical measurements, it follows from eq. (17) that the generalised momentum-complexity in the state of rest is absent, $p = 0$. The (state of) *rest energy*, E_0, of the elementary field-particle (quantum beat) is specified from eq. (20) as:

$$E_0 = \frac{h}{\tau_0} = h\nu_0, \tag{21}$$

coinciding with the famous suggestion by Louis de Broglie [46-49], now with the clearly understood, complex-dynamic origin of his postulated "periodic phenomenon" within the particle (our quantum beat process). In particular, in our description we deal with the *spatially chaotic* quantum beat pulsation equivalent to *chaotic wandering* of the squeezed corpuscular state of virtual soliton, which provides the total field-particle energy (the rest energy in (21)) with the intrinsic complex-dynamic property of *inertia*, thus properly completing another intuitively introduced de Broglie's idea, that of the "hidden thermodynamics" of the isolated particle [50-52].

In order to obtain the rigorous expression of inertia within intrinsic unification of quantum-mechanical and relativistic properties, we return to the general case of a moving field-particle, whose action-complexity contains space inhomogeneity due to the self-organised tendency of *global motion* in realisation probability distribution, $\mathcal{A} = \mathcal{A}(x,t)$, so that eq. (17) can be presented in the differential form as

$$\frac{\Delta\mathcal{A}}{\Delta t} = \frac{\Delta\mathcal{A}}{\Delta t}\Big|_{x=\text{const}} + \frac{\Delta\mathcal{A}}{\Delta x}\Big|_{t=\text{const}} \frac{\Delta x}{\Delta t} = p\upsilon - E\,,$$

or

$$E = -\frac{\Delta\mathcal{A}}{\Delta t} + p\upsilon = \frac{h}{T} + \frac{h}{\lambda}\upsilon = hN + p\upsilon\,, \tag{22}$$

where the total energy E is given by (20), while the global motion momentum p, universally defined by eq. (19), is specified for the field-particle as

$$p = \frac{\Delta\mathcal{A}}{\Delta x}\Big|_{t=\text{const}} = \frac{h}{\lambda}\,, \tag{23}$$

υ is the global motion velocity,

$$\upsilon = \frac{\Delta x}{\Delta t}\,, \tag{24}$$

$\tau = \Delta t\big|_{x=\text{const}}$ is the period of quantum beat (virtual-soliton realisation change) measured at a fixed space point, $\lambda = \Delta x\big|_{t=\text{const}}$ is the size of emerging spatial inhomogeneity of the average, global part of the moving system structure at a fixed time moment, and $\Delta t = T$ is the "total" value of the quantum beat period ($N = 1/T$ is the corresponding frequency) [1,2,5,6,8-12,14].

The total energy partition of the moving field-particle, eq. (22), has a deep physical, complex-dynamical meaning: its first summand, $hN = h/T$, describes purely random wandering of the virtual soliton around the ordered average tendency of global motion described by the second summand, $p\upsilon = h\upsilon/\lambda$.[4] This last tendency of global motion contains the *dynamically emerging* spatial structure with the characteristic length λ, easily recognised as the particle's de Broglie wavelength, $\lambda = \lambda_{\text{B}} = h/p$, appearing thus quite naturally, together with the physically real *wave-particle duality*, in the

[4] Note, however, that *each* virtual soliton leap, even within this "generally ordered" tendency, has a *dynamically probabilistic* origin, with (slightly) higher probability of staying in this global motion tendency, than deviating towards the purely random wandering tendency (the first summand in eq. (22)), in accordance with the general definition of dynamic realisation probabilities for compound, or "self-organised", realisations, eq. (12b). This fact is fundamentally important for (relativistic) mass involvement in quantum field-particle dynamics (see below).

multivalued quantum beat dynamics as a result of partial regularity of the global motion tendency [1,2,5,6,8-12,14]. This physically real duality means, as we have seen above and shall see below, that *all* quantum processes and interactions include as important underlying basis *permanent, physically real* quantum leaps of participating field-particles, with their *real transformation* between the corpuscular localised state of virtual soliton and the extended transient state of (physically real) wavefunction.

We can see now the physically transparent, causal origin of the "relativistic" limitation, $v < c$, introduced in usual relativity as a formal postulate: every massive particle (and thus eventually any material body) always moves globally, as a whole with a speed smaller than the perturbation propagation speed in the e/m protofield coupled to the gravitational protofield, $v_0 = c$, simply because the virtual soliton of its complex-dynamical quantum beat process must make many random deviations from the average global motion trajectory (while massless perturbations, such as photons, move with $v_0 = c$ by definition). As a matter of fact, all usual global motions of massive matter occur at "nonrelativistic" velocities $v \ll c$, meaning that virtual soliton leaps within the second-summand tendency of global motion in the total energy partition (22) constitute only a small proportion of the total energy-complexity (it is shown in detail below), while almost all particle's energy is spent on random deviations from the global motion tendency. It is a physically meaningful feature as it implies the well-formed and reasonably stable usual-world structures, while a relativistic situation with $v \to c$ corresponds to ephemeral and changeable structures tending eventually to massive, strong-interaction "photons".

These details of complex internal dynamics of a massive particle lead to the important quantitative relation between v and c. We note that during the time interval $\tau_1 = \lambda/c$ of one virtual soliton leap within the global motion tendency the same quantum beat system performs $n_1 = c/v$ leaps of purely random deviations from the global tendency of duration τ each (where τ is defined in eq. (20)). Hence $\tau_1 = n_1\tau$, or $\lambda = V_{\text{ph}}\tau$, where $V_{\text{ph}} = c^2/v$ is the fictitious superluminal "phase velocity" of matter wave propagation, appearing in the original derivation of de Broglie wavelength [49], which does not take into account the dominating chaotic, multivalued part and character of field-particle dynamics. Inserting the definitions of λ and τ, eqs. (23) and (20), into the obtained relation, we get the famous *relativistic dispersion relation*,

now *rigorously derived* from the underlying complex quantum beat dynamics (as opposed to the canonical relativistic postulates):

$$p = E\frac{v}{c^2} = mv\,, \tag{25}$$

where the *inertial mass-energy-complexity*, *m*, is introduced by a *rigorously substantiated* and *physically meaningful* definition [6-12]:

$$m = \frac{E}{c^2}\,. \tag{26}$$

Expressions (21) and (20) for the total energy-complexity of spatially chaotic quantum beat pulsation in the states of rest and motion take now their physically complete form:

$$E_0 = m_0c^2 = h\nu_0 = \frac{h}{\tau_0}\,, \tag{27}$$

$$E = mc^2 = h\nu = \frac{h}{\tau}\,. \tag{28}$$

We obtain thus the *rigorously derived* and *universally valid concept of inertial mass* (in its naturally emerging *relativistic* version *equivalent to energy*) as a differential complexity measure by the temporal rate of the spatially chaotic quantum beat (realisation change) dynamics within every elementary field-particle (and thus any compound particle or body), which does not need usual artificial introduction of additional, actually redundant entities as the "source of mass" (such as the purely abstract construction of the Higgs field and bosons in the Standard Model of official particle physics, showing a number of irreducible fundamental deficiencies and contradictions [11,12]). We also show (see below) that this concept of complex-dynamical mass naturally includes its (relativistic) gravitational aspect. These results demonstrate the *dynamically emerging* and *naturally unified* character of fundamental dynamic and intrinsic properties (like space, time and mass) in our approach, as opposed to their postulated, abstract and separated origins in usual, unitary theories. We complete below the number of fundamental properties thus causally explained within the same unified analysis of unreduced proto-field interaction process. Note also equally naturally emerging *unity of quantum and relativistic properties* as different but unified manifestations of the same complex interaction dynamics (we further specify it below). This unity is persistently missing in usual theory for the now evident reason of its artificial single-valued simplification of real, multivalued interaction dynamics.

Another remarkable feature of our complex-dynamical mass concept (25)-(26) is the usually postulated but now rigorously derived relation $p = m\upsilon$ equivalent to *rigorously derived Newton's laws of motion* (in their causal relativistic and actually quantum version) and hiding behind its externally simple form the nontrivial complex (multivalued) dynamics of the underlying protofield interaction process [6-12]. All the *emerging* notions, including that of motion itself, its laws, the entities of space, time, energy, momentum, and mass acquire now their genuine, intrinsically unified and causally complete complex-dynamical meaning and origin, where "quantum" (dynamically discrete and dualistic) and "relativistic" (dynamically driven) features are naturally unified from the beginning.

Inserting now the obtained dispersion relation (25) into the causal definition of the field-particle wavelength (23), we get the complete canonical expression for the *de Broglie wavelength of a massive particle* within the causally complete complex-dynamical picture of wave-particle duality:

$$\lambda = \lambda_{\mathrm{B}} = \frac{h}{m\upsilon} \ , \tag{29}$$

or $h = m\upsilon\lambda_{\mathrm{B}}$, where the Planck constant h represents "protofield interaction complexity dynamically quantised in action-complexity units of h", field-particle mass m measures "dynamic complexity of causally random virtual soliton wandering within the particle wavefield", υ is the speed of global particle (quantum beat) motion, and λ_{B} is the "dynamically emerging undular structure of the globally moving quantum beat process" [7]. The dynamically multivalued and deeply nonlinear character of externally simple and linear expression (29) (and other related wave formalism equations) becomes evident and provides the causally complete origin of "wave-particle duality" and other "quantum mysteries" [6-12] (see also below).

In the state of rest, we have only dynamically random virtual soliton leaps within its globally motionless wavefield, each of them performed with the speed of light c. The size of each leap, representing the above elementary length $\lambda = \Delta x_r$ at this lowest complexity level, can be specified either by the "heuristic" application of eq. (29) to a single virtual soliton leap or, more rigorously, by noting that the quantum beat frequency $\nu_0 = m_0 c^2 / h$ from eq. (27) corresponds to the wavelength

$$\lambda_0 = \frac{c}{\nu_0} = \frac{h}{m_0 c} \ . \tag{30}$$

For the *electron* with the rest mass $m_0 = m_e$ the size λ_0 of virtual soliton leap within the quantum beat process coincides with the *Compton wavelength* λ_C (up to a factor of the order of π, see below), providing its new interpretation in terms of *complex electron dynamics*:

$$\lambda_C = \frac{h}{m_e c} \ . \tag{31}$$

The emerging dynamically discrete, or *quantised*, undular structure of the field-particle naturally coexists with the equally dynamically emerging *relativity* of multivalued interaction dynamics. Since physically real time dynamically emerges within the same complex-dynamical process that gives rise to global motion, eqs. (20), (27), this motion will influence the real time flow. To specify that causally explained, complex-dynamical time relativity, we use eqs. (20) and (25) (the dynamically derived relativistic dispersion relation) in the energy partition equation (22) and obtain the *causal time dilation* effect as the relation between the externally and internally measured time periods (of quantum beat) τ and T for a moving particle:

$$\tau = T\left(1 - \frac{v^2}{c^2}\right) . \tag{32}$$

The physical meaning of this relation in terms of the underlying complex quantum beat dynamics is that with growing speed of global motion v ever larger part of the total energy goes from the "internal clock mechanism" to its global displacement, thus leading to relative slowing down of the internal time flow, $T > \tau$. The effect is universal and does not depend on the size and mechanism of any real time-measuring system, thus solving another persisting puzzle of usual relativity.

The causal quantum-relativistic time dilation effect of eq. (32) needs further refinement in terms of quantum beat period in the rest frame τ_0 (or its frequency $\nu_0 = 1/\tau_0$), which is related to T, τ (or N, ν) [1,5,6,8-12]:

$$N\nu = (\nu_0)^2 , \ T\tau = (\tau_0)^2 \ . \tag{33}$$

This relation describes the physically transparent conservation of the system realisation number expressed by frequencies in any reference frame, which is a manifestation of the universal complexity conservation law (see below). We use eq. (33) to eliminate not directly measurable τ from eq. (32) and obtain the canonical expression for the time dilation effect, now however *causally substantiated* by the underlying complex interaction dynamics,

without any postulated abstract "principles":

$$T=\frac{\tau_0}{\sqrt{1-\frac{\upsilon^2}{c^2}}}\ ,\quad N=\nu_0\sqrt{1-\frac{\upsilon^2}{c^2}}\ . \tag{34}$$

Using eqs. (27), (28) in combination with time dilation expression (34), we obtain the *causally derived* effect of *relativistic mass increase* emphasizing the role of dynamically random origin of every quantum beat leap of a massive field-particle, even within the externally regular global motion tendency:

$$m=\frac{E}{c^2}=\frac{m_0}{\sqrt{1-\frac{\upsilon^2}{c^2}}}\ . \tag{35}$$

Relativistic length transformation expression is also easily obtained from time dilation (34), thus completing our causal, complex-dynamical special relativity intrinsically unified with quantum behaviour [1,5,6,8-12].

We can now provide the detailed version of the complex-dynamical energy partition (22) demonstrating the unified origin of relativistic and quantum features and showing the proportions of global motion and random deviation tendencies depending on the particle/body global motion speed υ:

$$E=h\nu_0\sqrt{1-\frac{\upsilon^2}{c^2}}+\frac{h}{\lambda_{\mathrm{B}}}\upsilon=h\nu_0\sqrt{1-\frac{\upsilon^2}{c^2}}+h\nu_{\mathrm{B}}=m_0c^2\sqrt{1-\frac{\upsilon^2}{c^2}}+\frac{m_0\upsilon^2}{\sqrt{1-\frac{\upsilon^2}{c^2}}}, \tag{36}$$

where we have introduced de Broglie frequency, ν_{B}, according to

$$\nu_{\mathrm{B}}=\frac{\upsilon}{\lambda_{\mathrm{B}}}=\frac{p\upsilon}{h}=\frac{\nu_{\mathrm{B}0}}{\sqrt{1-\frac{\upsilon^2}{c^2}}}=\nu\frac{\upsilon^2}{c^2},\ \nu_{\mathrm{B}0}=\frac{m_0\upsilon^2}{h}=\nu_0\frac{\upsilon^2}{c^2}=\frac{\upsilon}{\lambda_{\mathrm{B}0}},\ \lambda_{\mathrm{B}0}=\frac{h}{m_0\upsilon}\ . \tag{37}$$

It is not difficult to see [5,8,10] that $\alpha_1=\upsilon^2/c^2$ and $\alpha_2=1-\alpha_1=1-\upsilon^2/c^2$ are the probabilities for the field-particle's virtual soliton to fall within the global-motion and random-deviation tendencies respectively, in accordance with the universal realisation probability expression of eq. (12b), which demonstrates once again the deep complex-dynamical link between "quantum" and "relativistic" aspects of the unreduced protofield interaction result. Usual, nonrelativistic global motions are mainly irregular, $\alpha_1\ll\alpha_2\approx 1$, due to the dominating rest mass chaoticity, while relativistic and ultra-relativistic

motions are ever more internally ordered as $v \to c$, $\alpha_2 \ll \alpha_1 \approx 1$, which explains, in particular, the well-defined swift-particle trajectories.

Let us consider now the equally dynamically emerging character of intrinsic *global properties of the world*, such as the origin and the number of spatial dimensions and fundamental interaction forces. The observed *number of spatial dimensions*, $N_{\mathrm{dim}} = 3$, is causally explained in our picture as the number of global system realisations equal to the number of global interacting degrees of freedom (in our case two protofields plus their uniform coupling). In general, a universe emerging from n protofields coupled by m global (universal) interactions should have at least $N_{\mathrm{dim}} = n + m$ global spatial dimensions. Depending on the protofield interaction details, the number of spatial dimensions may be given by another (growing) function $N_{\mathrm{dim}}(n,m)$ [1], but in each case there is the *exact correspondence* between the number of interacting global fields and the emerging number of spatial dimensions, since the latter are none other than the dynamically entangled states (realisations) of those global interacting entities. This *causal origin* of emerging physical space and its dimensions is very different from formal constructions of usual theory, where one can add various fields (such as the Higgs field) or "hidden dimensions", replacing the dynamic origin of intrinsic entities and properties, irrespective of the observed number of spatial dimensions.

The same kind of well-defined causal connection explains the observed number of fundamental forces between elementary field-particles, together with their transparent physical origin and properties. As each massive field-particle produces essential (propagating) deformation and tension in the surrounding protofield material due to its highly nonlinear quantum beat pulsation, other particles' quantum beat processes "feel" these changes, both in the form of direct mechanical attraction/repulsion and average, "entropic" (i.e. chaotically structured) change of properties. This is the physical origin of (maximum) mn *long-range particle interaction forces* of *n* different types (each type being transmitted through its own protofield). In the real simplest case of two interacting protofields ($n = 2$) with a single coupling ($m = 1$) we obtain long-range e/m and gravitational interactions (2 interactions of 2 types), explaining the names and roles of respective protofields. Due to the described physical transmission mechanism, their inverse-square spatial dependence, r^{-2}, is obviously determined by the causally derived number of spatial dimensions (it will be $r^{1-N_{\mathrm{dim}}}$ in the general case).

Short-range interactions are due to those between the protofield elements (within each protofield) and their minimum number is equal to *n* (as well as the number of their different types, each for its own protofield), with one "weak interaction" (within the e/m protofield) and one "strong interaction" (within the gravitational protofield) for the two interacting protofields in our real world construction. We thus immediately obtain a general idea of the physical origin and properties of the gravitational protofield as a kind of "quark(-gluon) condensate", where "individual" quarks may exist rather in the form of quantised excitations of a strong-interaction "liquid" condensate (in accord with recent experimental results for high-energy ion collisions [53], looking "surprising" in the framework of usual formal theory). This physically specified origin of quarks in the unified, interaction-driven world construction correlates well with their very special property of *confinement*, "explained" in usual theory in a quite contradictory way using largely unphysical assumptions. In reality those quark excitations of the quark-gluon condensate of the gravitational protofield matrix cannot appear individually not only due to their strong interaction with other, equally ill-defined quarks (which is a finite and thus surmountable barrier) but also because of the *omnipresent* "close" *reservoir* of strong-interacting "quark matter" that *must* provide some accompanying partners once the excitation energy exceeds the mass-energy interaction threshold. The observed quasi-stable quark combinations within hadrons are the smallest stable quanta, or "droplets", of the underlying quark-gluon "liquid", for which the internal binding forces (supported by the protofield interaction) can overbalance the separating influences of the surrounding liquid (protofield) volume.

In this way we obtain the *exactly defined* total number of $N_{\mathrm{F}} = n(m+1)$ *emergent* fundamental interaction forces between elementary particles of well-specified physical origin and qualities, giving the observed number of *four* interactions with their observed properties for our (simplest kind of) world emerging from two interacting protofields. We see again that the world's fundamental forces, fields and dimensions appear in exact, well specified numbers, qualities and relations to each other (e.g. $N_{\mathrm{F}} = n(N_{\mathrm{dim}} - n + 1) = (m+1)(N_{\mathrm{dim}} - m) = 2(N_{\mathrm{dim}} - 1)$, the last equality specified for our world with $m = 1$), so that it is impossible to introduce an additional global field, such as the Higgs field, while preserving the same number of dimensions and interaction forces (as it is done in usual theory, in various versions, including

equally redundant "hidden dimensions" or "dark-matter" particles, these cosmological "hidden variables" of unitary science). It is the concrete and essential difference between any conventional, unitary theory construction and the dynamically complete, emergent and therefore naturally "parsimonious" physical structure of the world in our interaction-based approach.

In relation to this feature, all the emerging structures and properties in our picture, including interaction forces, appear in their intrinsically, dynamically *unified* version, so definitely lacking in the Standard Model constructions (or any other versions of unitary description). All four (in general $n(m+1)$) interaction forces are *naturally unified by their dynamic origin*, the quantum beat process within any massive elementary particle (meaning also that they are *naturally quantised* from the beginning), with the most direct and complete unification in the maximum squeeze state of virtual soliton for hadrons. This general unification is subdivided into two (in general n) closer, "material" unifications between two (in general $m+1$) forces transmitted by the same protofield, one of them of short-range origin (from interaction between the protofield elements) and another one (in general maximum m) of long-range, deformation/depletion origin.

The standard, formally introduced "electroweak symmetry" acquires now the physically transparent origin and dynamics in terms of "material" unification of interactions by the e/m protofield. In particular, the "electroweak scale" of energy describes now simply the energetic "strength" of the e/m protofield (i.e. the binding energy of its elements or the highest nondestructive excitation energy), which naturally coincides, due to the general quantum-beat unification, with the heaviest particle (or nucleus) mass, $M_{\mathrm{P}} \sim 10^2$ GeV (cf. eq. (27)), without any additional "Higgs field" involvement or related "hierarchy problem" (see also below).[5]

[5] Let us emphasize the causally explained coincidence between the heaviest elementary particle mass scale and that of the heaviest nuclei (both of the order of 100 GeV), up to uncertainty due to instability effects. It becomes clear only within our causally unified picture why it should be like that: the strong internal interaction between hadrons (actually quarks) in any "compact agglomerate" of excited quark-gluon matter of the coupled protofields, be it a nucleus or an elementary particle, means that the largest possible mass of *any* such dynamically unified real object will be determined by the total strength of the coupled protofields, actually of the order of 100 GeV. It not only demonstrates the remarkable unification degree of our theory (including all fundamental interactions, their natural couples, and all real "coherent" species of strongly interacting particles), but also reveals *practical senselessness* of further search for ever heavier elementary particles and chemical elements (in accord with the related hierarchy problem solution, see below), which otherwise still goes on, blindly, without basic limits, in the official theory paradigm [6,11,12].

Another case of "material" unification, involving the gravitational protofield, is even more interesting as it introduces the *gravi-strong unification and symmetry* between the gravitational and strong interactions, totally unknown in any usual theory (in relation to its general hard problems with gravity, its true origin and quantisation). Our *dynamically emerging* gravity, transmitted by a dense "quark-gluon matter", provides a suitably compact and problem-solving construction, with natural, dynamic quantisation at its very origin, but absent conventional "gravitons" and improbable long-distance "gravitational waves" (see also below) [1,2,5,6,8-12].

The mentioned *natural quantisation* of long-range interaction forces due to their quantum-beat origin clarifies also another ambiguous idea of conventional theory, that of "exchange", or "gauge", or "virtual" bosons "transmitting" the quantised (in practice usually electromagnetic) interaction. Their inevitably "virtual" status in usual theory is now extended to that of quite real excitations (photons for e/m interactions), which inevitably appear as a result of interacting quantum beat dynamics (even though the gravitational protofield exchange bosons, or "gravitons", are not well-defined excitations due to their rapid decay in this dense, strong-interaction "liquid").[6] In general, those causal "exchange bosons", such as photons, appear in our description as real (protofield) excitations and not as an abstract result of mathematical "gauge symmetry" (where they are called "gauge bosons") that needs further introduction of additional, "symmetry-breaking" Higgs field leading to deep contradictions [11,12]. Those strangely "broken" (but nevertheless real) "symmetries" of usual unitary theory, giving rise to redundant abstract entities, are replaced in our provably parsimonious, "Ockham-friendly" description by the *universal* and *exact*, never broken *symmetry (or conservation by transformation) of complexity*, describing real structure formation within any unreduced, multivalued interaction process (see below).

To conclude this general overview of the lowest, "quantum" sublevels of emergent complex-dynamical world structure, we note that it is definitely

[6] The above physically real "gravi-strong unification" of gravitational and strong interactions through the gravitational protofield implies, in particular, that if gravitons could be stable enough, they would be realised as suitable combinations of gluons. Quarks cannot be present in these combinations because gravitons should be massless particles, which is an additional source of doubt about their reality, taking into account the dense, strong-interacting mixture of gluons and quarks within the gravitational protofield. In a way, gluons may be related to other exchange bosons, those observed as photons, if the e/m protofield originates as an excited state of gluon components of the primordial common origin of protofields, the true ground state of the quark-gluon condensate (see also the next section).

displaced, in the result of the driving protofield interaction, from the gravitational to the e/m protofield, where the majority of actually observed structures are made of the much more deformable and elastic material of the latter, while the former plays the equally important role of a much less changeable "supporting matrix" of the world, ensuring the proper dynamic stability of the entire strongly asymmetric construction. This is also the ultimate reason for the "mysterious" relative weakness of gravity, involving the natural solution to the "mass hierarchy problem" (see below).

We proceed by further specifying the causal, *dynamically unified origin* of intrinsic particle and interaction properties, which are simply postulated as separated abstract quantities in usual theory. On the electromagnetic, explicitly observable side of the world, we obtain the main e/m feature of *electric charge* of an elementary field-particle as just another manifestation of the same, complex quantum beat dynamics, reflecting its properties of e/m interaction through the e/m protofield and actually representing yet another measure of universal dynamic complexity. This properly understood *dynamic origin* of electric charge in quantum beat pulsation as its *complexity measure* is supported by the well-known proportionality relation between the elementary electric charge e and the fundamental dynamic complexity quantum in action units, the (reduced) Planck constant $\hbar = h/2\pi$ (see eqs. (21), (27)), $e^2 = \alpha c\hbar$, where α is the fine-structure constant. In such interpretation of this relation, it explains the electric charge quantisation and universality of its quantum by respective properties of the first levels of world's interaction complexity (in terms of h), naturally unified with the dynamically discrete structure of material reality in general (in "quanta" of massive elementary particles). While some other particle properties, such as mass, can vary from one particle to another, the quanta of electric charge and action-complexity apply everywhere and remain fixed as reflecting the unchanged mechanical features of the underlying e/m protofield coupled to the gravitational protofield (see also below). The *charge conservation law*, only postulated in usual theory, emerges now as a corollary to the rigorously substantiated universal symmetry of complexity (similar to mass-energy conservation and other fundamental laws and principles [1,2,28]).

Because of the direct mechanical character of e/m interaction between quantum beat processes, the e/m interaction force will depend on relative phases of quantum beat oscillations, so that with arbitrary relations between

phases, we would observe considerable uncertainty or fluctuations of e/m interaction between individual elementary particles, with further destructive consequences for higher, atomic and molecular structures and processes. On the other hand, as quantum beat pulsation determines the physically real time flow (see above, eq. (27)), its phase relations for different particles cannot vary either, in order to ensure the suitably "smooth" (coherent) time flow everywhere in the universe, tacitly underlying the totality of world descriptions and observations. These considerations lead to the only possible conclusion about the universal *phase synchronisation* between quantum beat oscillations of all field-particles (within "our" known and highly structured Universe), *up to phase inversion* [1,2,5,6,8-12,14]. Indeed, in this case we obtain not only the properly ordered e/m interaction forces and coherent time flow but also exactly *two, "opposite" kinds of electric charge* for field-particles with opposite in phase but otherwise synchronous quantum beat oscillations (where particles with the same kind of charge will, similar to antagonistic competitors, repel each other, while the oppositely charged, antiphase field-particles will "collaboratively" attract each other). It means that there is one, "fundamental", or "ground-state", quantum beat frequency (probably that of the electron, $\nu_e = m_e c^2 / h \simeq 10^{20}\,\mathrm{Hz}$) common to all electrically charged elementary particles throughout the universe, pulsating thus in phase or antiphase, while all higher quantum beat frequencies for heavier charged particles (in particular hadrons) are due to local high-frequency super-structures of the ground state pulsation. Thus introduced universal temporal phase synchronisation ensures also the possibility of quantum-wave *spatial coherence* in many-particle systems, which otherwise would hardly be compatible with globally ordered structures and dynamic processes and provides a local mechanism of global phase synchronisation establishment.

Another intrinsic field-particle property, remaining only formally postulated but physically unexplained within the usual theory framework, is elementary particle's *spin*. While, as we have seen, particle's electric charge is due to quantum beat oscillatory motion, the *dynamic origin of spin* is provided by another, rotational component of the same quantum beat pulsation, in the form of highly nonlinear *vorticity* of the e/m protofield increasingly squeezed towards its corpuscular state of virtual soliton. Similar to the dynamics of fluid forced to pass through a narrow outlet, it is eventually due to shear instability of the moving protofield matter. The causally substantiated

de Broglie relation for the field-particle rest energy, eq. (21), can now be re-written as $E_0 = h\nu_0 = \hbar\omega_0 = h\nu_0/2 + s\omega_0$, where $\omega_0 = 2\pi\nu_0$ is the quantum beat circular frequency, while $s = \hbar/2$ is the observed "anomalous" angular momentum of elementary spin (for the simplest fermion case). Note that the quantum beat oscillatory energy, $E_0/2 = \hbar\omega_0/2$, also coincides remarkably with the basic quantum expression for the oscillator ground state energy.

This dynamic origin of spin, deeply unified with those of electric charge and mass, provides not only the causally complete explanation for the observed spin properties (magnitude, quantisation, interactions and relation to the Planck constant) but also the unified causal origin of *magnetic field* as being due to the same spin vorticity (macroscopically, for many similarly oriented field-particle spins), rather in the extended phase of quantum beat pulsation. We obtain also the ultimate, physically complete origin of the laws of electrodynamics for thus explained magnetic and electric fields and charges [1], confirming the totally *emergent* character of all world structures, properties and laws in our description.

The other, gravitational protofield side of the same quantum beat processes within elementary field-particles gives rise, as noted above, to the second universal long-range interaction, *gravity*. Because of only indirect interaction transmission through highly dispersive gravitational protofield medium, no quantum beat phase synchronisation or real exchange-boson mechanism can be important for gravitational interaction, which leads to absence of different kinds of "gravitational charge" and only one, attractive kind of force. As gravitational field deformations are roughly proportional to quantum beat frequencies (at least for relatively weak, "nonrelativistic" gravitational interactions), the role of "gravitational charge" is played by inertial mass (or, in general, by its growing function), in accord with eqs. (27), (28), providing the causal explanation for the *"principle of equivalence"* of gravitational and inertial aspects of mass, which is only formally postulated in usual general relativity and absent from the Higgs mechanism of inertia.

Since our emergent gravity is explicitly driven by naturally quantised quantum beat processes, which both determine the time flow and modify the gravitational protofield density, one easily obtains the *dynamically quantised general relativity effects* [1,2,5,6,8-12,14], without any conventional postulates about "curved (abstract) space-time" and persisting ruptures between quantum and relativistic features (which are instead intrinsically unified in

our description as different manifestations of the same dynamic complexity of unreduced interaction processes). As the gravitational protofield density becomes inhomogeneous in the presence of quantum beat processes of massive particles and bodies, eq. (28) for the mass-energy-complexity of any (test) field-particle takes the generalised, coordinate-dependent form:

$$M(x)c^2 = h\nu(x) = mc^2\sqrt{g_{00}(x)}\,, \tag{38}$$

where $\nu(x)$ is the local particle quantum beat frequency (determining the local causal rate of time flow), $M(x)$ is its total mass, m its relativistic mass in the absence of gravitational field (i.e. other bodies), and usual theory's "metric" $g_{00}(x)<1$ actually describes spatial distribution of the gravitational protofield density/tension. Since for weak fields $g_{00}(x) = 1+2\varphi_g(x)/c^2$, where $\varphi_g(x)<0$ is the gravitational field potential [54], eq. (38) describes the causally derived, physically real origin of time dilation in gravitational field (as opposed to formal postulates about geometric "curvature" of arbitrary "mixture" of abstract space and time in usual theory), where both time and mass-energy (as well as space, through e.g. (23), (25), (29)) are now permanently and intrinsically quantised from the beginning.[7]

Thus rigorously derived effects of *emerging special and general relativity* are naturally unified with quantum effects by their common origin in complex (multivalued) interaction dynamics, while they differ mainly by relative observation scale: a global, fine-grained observation scale reveals rather the smooth relativistic dependence of intrinsic features on dynamics, while

[7] While the famous "Einstein field equations" of standard general relativity (actually involving "space-time curvature" in their canonical version) are obtained as formal mathematical generalisation of physical relations like eq. (38), it is not evident that such generalisation is as universally valid as usually assumed in the scholar science framework. In particular, they predict gravitational waves, which could hardly propagate over any sensible distances because of spreading and dispersion effects within the dense quark-gluon condensate of the gravitational protofield (despite their alleged, but very contradictory recent "registration"). This is only one particular illustration of fundamental limitations of Einstein's equations due to their total neglect of the underlying complex interaction dynamics within the gravitational protofield and its coupling to the directly observable interface of e/m protofield (while they do pretend to a quasi-complete description of gravity, contrary to much more limited and averaged particular relations like eq. (38) or Newton's theory). Another well-known problem is the fundamental contradiction between conventional relativity (including Einstein's equations) and quantisation, which, as we have seen, is also due to the dynamic single-valuedness of usual theory neglecting complex dynamics of underlying real interaction processes. In terms of mathematics, one can say that the symmetries of usual general relativity are too simplified with respect to the universal symmetry of complexity, the genuine, never broken symmetry of nature [1,2,28]. Therefore, it would be wiser not to advance too quickly to the ultimate Einsteinian, global-geometric generalisation of particular relativistic gravitational effects, which might eventually have a much more involved, if ever any compact, expression in terms of universal dynamic complexity equations.

coarse-grained, small and therefore strongly inhomogeneous scales demonstrate the detailed quantum origin and structure of that relativistic reality emerging in unreduced interaction processes. It is not surprising therefore that these "relativistic" and "quantum" manifestations of complex interaction dynamics are universal for all complexity levels and reappear with growing interaction complexity, up to conscious cognition processes, including respective special and general relativity effects [1,2,10,14,27]. Needless to say, that universal complex-dynamic origin and character of quantum and relativistic effects cannot be revealed in standard, unitary quantum mechanics and relativity, which provide not the causal, physically real origin but only formally "guessed", purely abstract postulation of quantum and relativistic features, despite the realistic preferences of the new-physics' fathers (including Max Planck, Louis de Broglie and Erwin Schrödinger) [7].

The obtained dynamically unified origin of emerging fundamental forces, space and time entities, elementary particle structure, intrinsic properties, and fundamental constants has further extensions from both gravitational and e/m protofield aspects. Gravitational aspects involve the well-known problem of *elementary particle mass hierarchy* (revealing also the actual absence of causal mass spectrum origin and structure in usual theories and their ongoing accelerator applications) and the related too extreme values of conventional *Planck units* (extensively used nonetheless in various foundational schemes of usual theory, including inflation cosmology, quantum gravity, string theory, and practically entire particle and high-energy physics). Indeed, while the observed particle mass-energy spectrum extends up to the order of $m_{\text{exp}}c^2 \simeq 100$ GeV (for exotic species and directly unobservable quarks), a "natural" combination of fundamental constants emerging in various estimates, the Planck mass $m_{\text{P}} = \sqrt{\hbar c/\gamma}$ (where γ is the gravitational constant), gives a very different limiting mass-energy scale, $m_{\text{P}}c^2 \simeq 10^{19}$ GeV (this *hierarchy problem* can be expressed also as inexplicably huge *relative weakness of gravity* with respect to electro-weak interactions). Whereas the unphysically huge gap of 17 orders between m_{exp} and m_{P} (and between the respective units of length, $l_{\text{P}} \ll l_{\text{exp}}$, and time, $t_{\text{P}} \ll t_{\text{exp}}$) is tentatively attributed in usual theory to arbitrarily introduced additional entities of e.g. "supersymmetric" solutions or strangely "hidden" (and never experimentally confirmed) dimensions in the brane world construction [55] (a kind of rough mechanistic imitation of our interacting protofield picture), it does not even

appear in our picture of naturally unified interactions, just due to their dynamic unification within the quantum beat process, leading to the *modified values of Planck units* [1,2,6,8-12].

Indeed, since all interaction forces (expressed by respective fundamental constants) are dynamically unified within the virtual soliton state of maximum compression of both protofields, it becomes evident that the "gravitational constant" in expressions for Planck units actually refers rather to a *short-range*, more strong (quark-gluon), than gravitational interaction between the system components (within a dynamic mixture of usually separated interaction forces), while the usual, macroscopic gravitational constant γ, always used in conventional Planck units (m_{P}, l_{P}, t_{P}), describes a very different, *long-range* and *indirect* interaction kind between *well separated* e/m protofield features by weak transmission between uncompressed, extended protofields and long-range propagation through the gravitational protofield. If the latter, usual (long-range) gravitational constant is designated as γ, then the *correct*, *modified* expressions for Planck units should contain a much larger, short-range, unified "gravi-strong" interaction constant $\gamma_0 \gg \gamma$, determined by the actually observed largest mass-energy ($m_{\mathrm{exp}}c^2 \simeq 100$ GeV) and smallest length (l_{exp}) and time (t_{exp}) scales as being close to real, modified Planck values of respective quantities (M_{P}, L_{P}, T_{P}):

$$M_{\mathrm{P}} = \sqrt{\frac{\hbar c}{\gamma_0}} \simeq 10^{-22} - 10^{-21}\ \mathrm{g}\ \left(10^2 - 10^3\ \mathrm{GeV}\right) = m_{\mathrm{exp}}\ , \tag{39a}$$

$$L_{\mathrm{P}} = \sqrt{\frac{\gamma_0 \hbar}{c^3}} \simeq 10^{-17} - 10^{-16}\ \mathrm{cm} = l_{\mathrm{exp}}\ , \tag{39b}$$

$$T_{\mathrm{P}} = \sqrt{\frac{\gamma_0 \hbar}{c^5}} \simeq 10^{-27} - 10^{-26}\ \mathrm{s} = t_{\mathrm{exp}}\ , \tag{39c}$$

with

$$\gamma_0 = \left(\frac{m_{\mathrm{P}}}{m_{\mathrm{exp}}}\right)^2 \gamma \simeq (10^{33} - 10^{34})\gamma\ . \tag{40}$$

The latter relation provides thus the natural solution to the "hierarchy problem" of usual theory, demonstrating the real physical origin of properly modified Planck units, the general, causally determined scale of the observed particle (as well as nuclear) mass spectrum, and the origin of the extreme weakness of gravity (together with gravi-strong force unification). This result, closely related to the dynamic unification of fundamental forces in our

theory, has strong consequences for various applications of Planck units and the entire *high-energy physics and accelerator strategy* [1,2,6,8-12]. While many key constructions in usual cosmology, quantum gravity and field theory become inapplicable to the real world, the dominating high-energy physics direction of blind search for ever heavier particle species becomes explicitly meaningless and should be replaced by the detailed studies of complex interaction effects *within the already achieved energy scales*.

Further extension of causally unified particle properties involves unreduced complexity features on the e/m protofield side, based on the standard relation between the elementary charge and Planck's constant, $e^2 = \alpha c\hbar$, already causally extended above, if we rewrite it as

$$E_e = m_e c^2 = \frac{2\pi}{\alpha}\frac{e^2}{\lambda_{\rm C}} = N^e_{\Re}\frac{e^2}{\lambda\!\!\!^{-}_{\rm C}},\ \ \lambda_{\rm C} = \frac{h}{m_e c},\ \ N^e_{\Re} = \frac{1}{\alpha},\ \ \lambda\!\!\!^{-}_{\rm C} = \frac{\lambda_{\rm C}}{2\pi}, \qquad (41)$$

where m_e is the electron rest mass and $\lambda_{\rm C}$ the Compton wavelength (see eq. (31)). It becomes evident from eq. (41) that $N^e_{\Re} = 1/\alpha$ ($\simeq 137$) is the *realisation number of the electron* as the dynamically multivalued quantum beat process and $\lambda\!\!\!^{-}_{\rm C} = \lambda_{\rm C}/2\pi$ ($\simeq 3.9\times 10^{-11}$ cm) the length of the electron quantum leap between its localised realisations (both defined up to a numerical coefficient of the order of π), in accord with the above interpretation of eqs. (30), (31) [1,2,5,8-12]. The fine-structure constant $\alpha = 1/N^e_{\Re}$ coincides thus with the electron realisation probability, $\alpha = \alpha_r$, where α_r is our universal dynamic probability of eq. (12a).

This causal complex-dynamic origin of fundamental constants is further specified by yet another form of the same e-$\hbar$ relation:

$$\hbar = N^e_{\Re}\frac{e^2}{c} = \lambda\!\!\!^{-}_{\rm C} p_e,\ \ \lambda\!\!\!^{-}_{\rm C} = N^e_{\Re} r_e\ , \qquad (42)$$

where $p_e = m_e c = E_e/c$ and $r_e = e^2/m_e c^2$ ($\simeq 2.8\times 10^{-13}$ см) is the standard "classical electron radius". As mentioned above (see the end of the first section), each elementary particle kind can be considered as a global, compound (many-particle) realisation of the effective potential of protofield interaction. Therefore the first relation of eq. (42) can be interpreted as the expression for the particle's EP well "volume" given by $\hbar$, while $N^e_{\Re}$ or $\lambda\!\!\!^{-}_{\rm C}$ express its width and e^2/c or p_e its depth. The *ultimate causal origin of the Planck constant* and *its absolute universality* (for various quantum systems) emerges now as the fixed EP well volume, while its width and depth vary for different

species. The EP well volume is fixed due to the mechanical balance between shallow but wide and deep but narrow protofield deformations with the same EP volume, naturally expressed in units of action-complexity. Global realisations of light, leptonic particles, such as the electron, correspond to wide and shallow EP with $N_{\Re} \gg 1$ and $\alpha_r, \alpha \ll 1$ (for respective interaction constants), while the heaviest hadronic species produce deep and narrow EP wells with $N_{\Re}, \alpha_r \sim 1$. The entire diversity of dense enough, "quantum" particle species and agglomerates (e.g. nuclei) falls in between those limiting cases, thus supporting the unified dynamic origin of emerging particle species, fundamental constants and interaction forces in our theory.

The second expression of eq. (42) implies also that the size of each regular, corpuscular realisation of the electron (i.e. the virtual soliton of its quantum beat) is r_e, since the EP width $\lambda\!\!\!^{-}_{\mathrm{C}}$ contains exactly $N^e_{\Re}$ elements of that size, filling densely the available EP width. This conclusion corresponds to the conventional origin of the classical electron radius, as well as to the general rule that the regular realisation size expresses the size of real space "point" of a given complexity level, $r_0 = \Delta x_i = \Delta_i \eta_i^r$ (see the beginning of this section), so that for this, lowest complexity level $r_0 = r_e$ (up to a moderate numerical coefficient of the order of π), which emerges as a new, natural but deeper interpretation of the classical electron radius.

In summary, we obtain thus the unified complex-dynamical, interaction-based origin of all observed fundamental structures, properties and constants c, h, α, e, and γ (including causal explanation of their universality), while usual theory simply postulates these properties and constants as separated, empirically based but basically abstract features. This key difference is important, in particular, for natural solution of cosmological fine-tuning problem (see the next section). The same advantage leads to the well-defined dynamic origin and finite spectrum of elementary particles and their masses, without any inexplicable "gap" (the "hierarchy problem") or additional, abstract and contradictory entities of unitary theory (such as the Higgs field or "hidden" dimensions), where the highest observed mass-energy features (such as the presumed "Higgs boson mass" of standard theory) simply correspond to the unified "breaking point" of the coupled protofields, their highest interaction amplitude, and "electro-weak energy scale" (the e/m protofield strength in our interpretation) [11,12].

Complex-dynamic cosmology and the emerging global features of the Universe without missing entities

As demonstrated in the previous section, our unreduced, dynamically multivalued interaction analysis provides a "naturally cosmological", *emergent* picture of the world structure. However, some "global", Universe-wide and properly cosmological features of thus obtained complex-dynamic reality need special attention, also because they are essentially different from the usual theory framework and contain natural solutions to persisting and growing "difficult" problems of standard cosmology [9-11].

We have seen, in particular, that global, physically real space with exactly three dimensions (dynamic degrees of freedom) and permanently irreversibly flowing time naturally emerge as the dynamically multivalued, always changing entanglement of interacting e/m and gravitational protofields. The unidirectional time flow has additional cosmological implication: according to the universal definition of energy-complexity, eq. (19), positive time increment, $\Delta t > 0$, with always decreasing action-complexity, $\Delta \mathcal{A} < 0$ (due to the dynamically random realisation change [1,2,28]), gives *strictly positive total energy*, $E > 0$, including that of the *entire Universe*. This conclusion is at variance with standard theory, which insists on the zero value of the total Universe energy (thus permitting its emergence "from nothing"), which then splits into positive mass-energy and negative energy of gravitational attraction compensating each other exactly. This difference has various important consequences and a deep physical meaning as the total energy positivity in our description originates in chaotic change of multiple system realisations, which are artificially reduced to only one, unchanged (timeless), realisation in conventional unitary "models" (thus pushing the rest of real, multivalued system dynamics to "hidden" and "dark" matters).

The Universe energy-complexity positivity and the related direction of physically real time flow can be expressed in other words as *intrinsic dynamic creativity* of any real, complex-dynamical, interaction-driven universe (in opposition to absent real time, null total energy of the Universe and its non-

emergent, only artificially inserted structure in usual, unitary cosmology). This important property can be rigorously and universally expressed by the *universal symmetry, or conservation and transformation, of complexity* [1,2,9-11,14-24,28]. It is based on the fact that the system realisation number $N_{\Re}$ and thus the total system complexity $C(N_{\Re})$ (see eq. (14)) is determined by the number of interacting degrees of freedom or their combinations (see eq. (11)) fixed by the initial system configuration and remaining therefore unchanged during further structure development process.

The total dynamic complexity C of any (isolated) system or interaction process, including the Universe, is thus absolutely and universally conserved, $\Delta C = 0$. However, something should change in such global system characteristic as complexity during its structure formation and evolution, and it is the *form* of dynamic complexity, changing from the *potential form* of always decreasing *dynamic information*, I, to permanently increasing *dynamic entropy*, S, expressing the dynamic complexity of *already appeared* structures, so that their *sum*, the *total dynamic complexity* $C = I + S$, remains unchanged: $\Delta S = -\Delta I > 0$. Complexity conservation is thus realised *only by its unstoppable, interaction-driven transformation* from the latent form of dynamic information to the explicit form of dynamic entropy, which is equivalent to the universal *symmetry* (of complexity) of emerging structures, their dynamics and evolution (whereas in unitary theory its postulated, abstract and often "spontaneously broken" conservation laws are related to but different from respective symmetries). And since action-complexity $\mathcal{A}$ introduced above (see eq. (17)) is a unified decreasing measure of complexity, it is naturally identified as the universal expression of dynamic information, $\mathcal{A} = I$, so that the *universal symmetry of complexity*, describing the *creative evolution* of any real system, including the Universe, is expressed mathematically as

$$\Delta S = -\Delta \mathcal{A} > 0 \ . \qquad (43)$$

A major implication of this unified "creativity law" for the observed Universe properties appears as the naturally *self-tuning* character of its structures, parameters and evolution, resolving the corresponding stagnating "mystery" of standard unitary cosmology. Since the latter does not consider universe structure emergence as a result of unreduced interaction process, postulating instead its over-simplified mechanistic models, it always remains with a mystery of "strange" coincidence between various parameter

values, without which no sensible world structure could ever exist. Our causally complete picture of unreduced protofield interaction does not contain this contradiction already due to its intrinsically interactive, emergent character, where any given, generic interaction magnitude *dynamically produces* respective structures, interactions and parameters, whose "happy coincidence" is ensured by their dynamic origin described above. It is illustrated by the clearly specified *dynamic origin of fundamental constants* c, h, α, e, γ and their relations (see the previous section, eqs. (40)-(42)).

If we consider the origin of the material content of the Universe, then we see that according to the complexity symmetry, eq. (43), the initial complexity stock in the potential form of global dynamic information of protofield interaction will progressively produce the corresponding quantity of dynamic entropy-complexity of real world structures, organised in the fractal hierarchy of complexity levels. Expressed in the *differential* form of, respectively, initial potential interaction energy in the system of coupled protofields, $V_{\text{init}} = -\Delta\mathcal{A}/\Delta t$, and mass-energy-complexity of emerging universe structures, $M_{\text{univ}}c^2 = \Delta S/\Delta t$, this symmetry of creative evolution means that

$$V_{\text{init}} = M_{\text{univ}}c^2 \ , \tag{44a}$$

where the internal adaptable splitting into suitable levels of complex-dynamical structures and interactions is assumed by the unreduced interaction development, in the form of dynamically multivalued fractal entanglement of interacting components (see the first section):

$$\begin{aligned} M_{\text{univ}} &= \sum_{s,l}\left(N_{sl}m_{sl} + \frac{V_{sl}}{c^2}\right) = \\ &= \sum_{\text{part}} N_{\text{part}}m_{\text{part}} + \frac{V_{\text{fund}}}{c^2} \to \sum_{\text{atom}} N_{\text{atom}}m_{\text{atom}} + \frac{V_{\text{chem}}}{c^2} \to \dots \ , \end{aligned} \tag{44b}$$

with N_{sl} structures (numbered by s) with masses m_{sl} and interactions V_{sl} dynamically emerging at the l-th complexity level, starting from elementary particles (N_{part}, m_{part}) and their fundamental interactions V_{fund} as described in the previous section,[8] followed by atoms (N_{atom}, m_{atom}) and their chemical

[8] Note that the emergence of exactly one light (the electron) and one heavy (proton) stable elementary particle in our initial configuration of coupled e/m and gravitational protofields, with the natural relation of each of those particles to its "native" protofield (see the previous section), can also be explained by complexity conservation or the number of global realisations in the protofield interaction transformation into particle species at the first complexity level.

interactions V_{chem}, then forming molecules and further higher-complexity structures and interactions.

This dynamic fine-tuning property of the interaction-driven complex-dynamical universe will thus automatically produce a reasonably structured universe for various reasonable, generic parameters of initial protofield interaction. Only exceptional, too low or too high, interaction magnitudes would produce trivial, small and chaotic or permanently collapsed and dense, universe structures.

The possibility of suitable, "generic" protofield interaction parameters is additionally supported by the probable dynamic origin of the coupled protofield system from the initial "equilibrium" state of totally "collapsed" protofields, forming a single primordial quark-gluon condensate in its ground state (see also footnote 6 in the previous section). Indeed, if we assume that a certain, large enough volume of such primordial, effectively structureless ground-state of a quark-gluon condensate is excited by separation of its light and elastic gluon component(s) from the remaining heavy and rigid quark "matrix", then we obtain a suitable version of our coupled protofield system, with the necessary "reasonable" parameters of the e/m protofield (gluon-based changeable and directly perceived "surface"), the gravitational protofield (the remaining dense quark-gluon matrix) and their natural coupling (due to the matrix depletion of gluonic fields) of a suitable "medium" magnitude. Thus originating protofield system with suitable structure-forming coupling will then naturally develop the properly fine-tuned consecutive levels of complexity, starting from physically real space, time, elementary particles with their intrinsic properties and fundamental interactions, as described above. While the origin of initial condensate excitation from its ground-state remains fundamentally unknown (in particular, it could result from a big enough fluctuation within a yet much larger quark-gluon condensate volume), it is evident that this or another way of introduction of the initial system action-complexity (dynamic information) stock is absolutely necessary, according to the undeniable complexity conservation law, which unifies causally extended versions of all known correct laws and principles, with their supporting observations [1,2,9-11,14-24,28] (whereas zero-energy-complexity universe models of usual unitary cosmology demonstrate heavy fundamental deficiencies, including absent time and only formally postulated abstract structures).

Thus emerging complex-dynamical, interaction-driven universe with positive energy-complexity has essentially different kind of global dynamics with respect to the unitary zero-energy model of conventional cosmology. The high positive value of real-universe complexity is actually due to its hierarchy of multiple realisations permanently changing in chaotic order, with the resulting highly *irregular* kind of dynamics and evolution, appearing as "dissipative", "nonlinear" and "turbulent" at larger macroscopic scales, in contrast to mechanically ordered, over-simplified and "one-component" (single-valued) dynamics of standard unitary models. The latter underlie, in particular, the main *Big Bang idea* of global Universe dynamics in the standard unitary cosmology, considered as a simple, regular mechanical motion within a single homogeneous body of weak-interaction, e.g. gas-like, internal behaviour, which must either expand or contract under the influence of global gravitational and thermodynamic/mechanical forces.

The real, complex-dynamical system of basically the same observed material content, driven by the unreduced interaction of its components, will demonstrate a *qualitatively different* kind of behaviour dominated by *dissipative*, *self-organised* and *chaotic* processes of all scales that account for the main part of high positive energy of the Universe and do *not* imply any global simplified motion like uniform expansion or contraction. Hence the key Big-Bang idea of standard cosmology (actually experiencing huge difficulties and growing contradictions [56,57]) becomes *fundamentally irrelevant* for real Universe dynamics and evolution, including all related unitary mathematical models from classical and quantum cosmology (e.g. inflation theory with implications), astrophysics, field theory and particle physics, which *cannot* be valid, even approximately, as a reasonably complete description of reality, while preserving their formal "validity", similar to the Ptolemaic system. By contrast, the unreduced, multivalued and multilevel protofield interaction development provides various "nonlinear" features to cosmic structure dynamics, explaining the otherwise ever more "mysterious" and scandalously dominating contributions of "dark matter" and "dark energy" to the observed Universe dynamics [9-11] (see below).

One can say, in other words, that the real Universe driven by the unreduced, multilevel interaction process is an intrinsically *creative*, structure-forming and in that sense "living" system, as opposed to its global vision of a simple, mechanically expanding or contracting "body" in the standard

cosmology. This dominating structure creation capacity of the real world, replacing its mechanical Big Bang expansion of the unitary model, is largely due to the *exponentially huge efficiency* of the dynamically probabilistic fractal of the unreduced interaction result, explaining also the "magic" properties of life, intelligence and consciousness [2,11,14-24,28]. Extremely large numbers of permanently breeding and interactively changing realisations of the dynamically multivalued fractal structure correspond to the underlying *symmetry of complexity* of the protofield interaction process maintained by permanent *transformation* of potential information-complexity to the dynamic entropy-complexity of emerging universe structures. The key point of the dynamic redundance paradigm, resolving various problems of standard cosmology, is that *any*, however externally ordered structure creation process corresponds to the dynamic entropy *growth*, rather than fall in unitary theory, due to the growing numbers of *randomly changing* incompatible realisations, even within any externally regular shape (explaining also the omnipresent intrinsic *time flow* within any process or object) [1,2,9-11,28].

We thus obtain the permanently *essentially* changing, *intrinsically creative* Universe without global mechanical expansion (replaced by complex-dynamical structure formation on any scale), which therefore does not contain any persisting problems of the standard Big Bang cosmology, such as the observed Universe flatness or the horizon problem (hence we don't need any contradictory "inflation"), as well as various problems with the mechanistic "age of the Universe" badly interfering with the Big Bang and particular structure dynamics. In addition to the natural dynamic "fine tuning" of the emerging universe structures described above, we have the rigorously derived causal origin and explanation for the *universality* of fundamental constants, particle properties and time flow throughout the Universe, due to the underlying (synchronised) quantum beat dynamics in the system of coupled protofields (see the previous section). These properties are just taken for granted in usual cosmology, but they actually need and do have a well-specified and deeply rooted dynamic origin.

One should separately mention two major features as if "definitely confirming" the Big Bang assumption, the *microwave background radiation* and the *redshift* of light arriving from distant sources. In fact, our complex-dynamic cosmology provides different, much better substantiated explanations

for these features and avoids serious contradictions in their conventional Big-Bang interpretation.

The *background radiation* emerges in our description as the inevitable consequence of the coupled protofield system perturbation by the quantum beat processes of massive elementary field-particles and the hierarchy of their interactions leading to the quasi-equilibrium "thermal" photon distribution at a given (advanced) stage of Universe complexity development. Because of the fine-tuned saturation of the developed universe structure with massive particles described above, their further interactions and energy-exchange processes can produce only massless photonic excitations in the coupled protofield system (and maybe neutrino excitations, which do not change the conclusion). While higher energy photons participate in various local, nonequilibrium interactions, the low-energy, "background" part of photonic radiation congregates into a thermalised radiation peak, without any relation to the Big Bang history of the Universe assumed in conventional cosmology. Such "thermodynamic" origin of the microwave background radiation is actually obtained within any reasonable cosmology without expansion [58], while our unreduced description of complex protofield interaction dynamics provides additional refinement of the sources of photonic excitations and their fine-tuned adjustment to the complex interaction dynamics of the coupled protofield system of the Universe.

The *redshift* interpretation in our approach, equally avoiding any Big Bang expansion hypothesis, bears a much deeper relation to the detailed complex dynamics of the coupled protofield system and related physical origin of photons. We note, first of all, that the conventional implicitly postulated assumption about the absolutely nondissipative nature of photons contains a very general and fundamental contradiction to the principle of energy degradation (the second law of thermodynamics) that can be formulated in a general form just as impossibility of such real nondissipative structures in the interactive universe environment (as further specified by our universal symmetry of complexity, see above in this section, eq. (43)). This contradiction appears, in particular, in the conventional redshift interpretation as being due to nondissipative photon frequency change (decrease) as a result of a Doppler kind of purely mechanical effect (irrespective of its detailed explanation by "space extension" etc.). If now we do accept the necessary dissipativity of real photons, then we can immediately see its origin in the moving

photon interaction with the underlying gravitational protofield material represented most probably by a dense quark-gluon condensate (see above). The small magnitude of this interaction and related photon dissipativity is due to the relatively small effective protofield coupling for these weak e/m protofield perturbations.

This cosmologically important feature of photon energy dissipation is closely related to the causal, physically real photon nature remaining unspecified in standard theory. In our unified complex dynamics of the Universe, photons naturally emerge as relatively weak excitations of the e/m protofield coupled to the gravitational protofield, which cannot develop into much stronger, highly nonlinear deformations of quantum beat processes for massive elementary particles because of the essentially higher e/m protofield tension saturated by the already existing massive particles. It explains the validity of basically linear description of e/m waves/photons, as well as of a somewhat similar state of the intermediate realisation of the wavefunction for massive particles introduced in the first section (Schrödinger equation, see [1,2,9-11]). However, as the protofield coupling never vanishes, even this weak, externally linear photonic excitation of the e/m protofield should possess its dynamically nonlinear core and behaviour. Indeed, although the e/m protofield Hamiltonian $h_{\mathrm{e}}(q)$ in the system existence equation (1) could describe small quasi-linear oscillations, its interaction with the omnipresent gravitational protofield, $h_{\mathrm{g}}(\xi)+V_{\mathrm{eg}}(\xi,q)$, leads necessarily to the dynamic nonlinearity in the form of effective self-interaction, according to the unified EP mechanism, eqs. (8)-(9) (where ξ can stand for the emerging space coordinate or respective degrees of freedom of the e/m protofield).

The obtained small but internally nonlinear e/m protofield excitations can be modelled e.g. by a nonlinear Schrödinger equation with dissipation, being one of the reduced versions of our general EP equation (8)-(9). This kind of equation possesses *soliton* solutions, which will show dissipation for the case of dissipative terms due to irreducible coupling to the gravitational protofield degrees of freedom (represented most probably by a quark-gluon condensate with strong internal interactions). The protofield coupling provides therefore the double effect of dynamic shape-preserving nonlinearity of these e/m protofield solitons (due to attraction to the underlying gravitational protofield) and their weak dissipativity, appearing as slow energy degradation in long-distance propagation. These are just the desired properties

of the observed e/m quanta, or photons, explaining the origin of both their localised, corpuscular behaviour (different from quantum-beat behaviour for massive particles) and the cosmological redshift as *inevitable* and now *unified* features provided always by the *same driving protofield interaction*, without any additional assumptions or entities (like the Big Bang or various higher-level photon interactions). The linear wave behaviour of these internally nonlinear photons is provided by extended oscillations surrounding the nonlinear soliton core. These conclusions are partially confirmed by recent soliton model of the photon [59], even though the underlying protofield interaction and related weak redshift dissipation are not considered in this purely electromagnetic model.

Further important observed feature of the cosmological redshift, naturally explained within this dissipative soliton dynamics of photons (and remaining ever more mysterious within usual theory) is the "accelerated Universe expansion" phenomenon appearing as nonlinear redshift growth with distance and giving rise to the major unsolved problem of *"dark energy"* (see e.g. [60,61]). In our picture it becomes evident that photon energy dissipation can and even should depend on propagation distance in a generally nonlinear way, without any necessity for new entities that should give rise to the dark-energy repulsion and accelerated expansion in the standard mechanistic universe model. Moreover, the same complex-dynamical redshift origin should give rise to numerous observed *anomalous redshift features* for particular distant objects (being otherwise another mystery of usual cosmology, cf. [56,57]) due to the respective object mass-energy and gravitational protofield density influence. While further detailed studies (e.g. of interaction-based dissipative soliton dynamics for photon redshift effects) compared to various observations can provide a more comprehensive description of our complex-dynamic Universe parameters, there is little doubt that already the combination of major features mentioned here, including the inevitable photon dissipativity, *cannot* be consistently described in any essentially simplified way, such as the conventional Big Bang or any other mechanistic, dynamically single-valued universe model.

One should mention here another related and persisting mystery of conventional cosmology, the *cosmological constant (or vacuum energy) problem*. Quantum vacuum energy, presumably giving rise to the positive cosmological constant that contributes to the mechanical Big Bang expansion of

standard cosmology, originates in "quantum fluctuations" of the vacuum in the form of virtually appearing particles as a result "quantum energy-time uncertainty principle". Energy density calculations for such virtual particle processes within usual theory give values exceeding the observed maximum (small) values of the cosmological constant by many orders of magnitude. Contrary to these formal calculations, our *complex-dynamical mass-energy origin* in the form of clearly specified quantum beat processes in the dynamically unified protofield system, together with the universal *complexity conservation law*, implies that *no* massive particle can actually emerge from "nothing" in vacuum, even "virtually" (for a short time), except massless photons (and maybe other quasi-massless species), which do not provide noticeable vacuum energy and cosmological constant values and practically appear rather as microwave background radiation specified above (in other frequency ranges, they also account for the observed Casimir effect and Lamb shift in atomic energy spectra). In relation to the self-tuned particle emergence in our *dynamically adaptable* universe described above, it means simply that local mechanical properties of the "vacuum" of coupled protofields can permit only small photonic, massless perturbations to appear in a basically developed, massive-particle-saturated and thus mechanically "strained" universe, which in any case will produce or swallow its structures, rather than mechanically expand or contract as a whole.

In summary, either excessive vacuum energy and huge cosmological constant or repulsive dark energy of unknown origin simply do not appear in our description (as well as the related "mysteries" of usual cosmology), due to the causally complete, self-adaptable construction of the Universe, with only explicitly, dynamically emerging entities and laws naturally corresponding to observations.

Another series of standard-cosmology problems of the same "missing-complexity" origin appear as *dark matter* effects [61-67]. While the above dark energy illusion is due to microscopic protofield interaction effects not taken into account in standard mechanistic Universe models, the apparent dynamic influences of invisible, or "dark", mass are due to equally neglected *dynamically multivalued* motions within a wide range of complexity levels, from protofields to big astrophysical objects and structures [2,9,10]. For a concrete but actually general enough demonstration of those "dark matter" effects of macroscopically missing dynamic complexity, one can start with

the standard virial theorem (see e.g. [68]) often applied to galaxy velocity (and thus mass) distribution estimates:

$$2\overline{T} = -\overline{U}\,, \tag{45}$$

where $\overline{T}$ and $\overline{U}$ are time-averaged values of kinetic and potential energy for a system of gravitationally interacting bodies. However, in real, *multivalued* system dynamics this *regular*, dynamically single-valued kinetic energy from the usual virial theorem, $\overline{T} = \overline{T}_{\text{reg}}$, is only a *small* part of the real, *chaotic* kinetic energy $\overline{T}_{\text{real}}$:

$$\overline{T}_{\text{real}} = \overline{T}_{\text{reg}} N_{\Re}\,, \tag{46}$$

where $N_{\Re} \gg 1$ is a certain "effective" number of realisations for the considered system and observation kind.

While the *observed* object potential energy $\overline{U}_{\text{obs}}$ corresponds to the *real* kinetic energy, $2\overline{T}_{\text{real}} = -\overline{U}_{\text{obs}}$, the unitary, deficient version of system dynamics (45) states that $2\overline{T}_{\text{reg}} = -\overline{U}_{\text{obs}}$, leading to the false discrepancy, δ:

$$\delta = \frac{\overline{T}_{\text{real}}}{\overline{T}_{\text{reg}}} = N_{\Re}\,, \tag{47}$$

in accord with eq. (46). Within the unitary model it can only be explained as being due to the "invisible", or "dark", but actually present matter mass, $M_{\text{dark}} = M_{\text{real}} - M_{\text{reg}}$, so that

$$\frac{M_{\text{real}}}{M_{\text{reg}}} = \frac{\overline{T}_{\text{real}}}{\overline{T}_{\text{reg}}} = \delta = N_{\Re} \quad \text{or} \quad M_{\text{dark}} = M_{\text{reg}}\left(N_{\Re} - 1\right) \cong M_{\text{reg}} N_{\Re}\,. \tag{48}$$

In reality it means that instead of additional mass there is excessive, chaotic *motion*, or (deviating) *velocity* υ, in the unreduced system dynamics as compared to reduced unitary expectations: as $\overline{T} \propto \overline{M\upsilon^2}$, eq. (47) gives

$$\left(\overline{\upsilon^2}\right)_{\text{real}} = N_{\Re}\left(\overline{\upsilon^2}\right)_{\text{reg}}\,. \tag{49}$$

This result is generalised for the distance-dependent case of "rotational curves" for galaxies (or other structures), where the "anomalous" dependence of (average) rotational velocity on the distance from the centre of mass, $\upsilon(r)$, is not due to anomalous mass distribution $M(r)$ (attributed to "dark matter halos") but due to "unexpected" (in the unitary model), complex-dynamical contributions to $\upsilon(r)$, which are proportional not to $\sqrt{M_{\text{reg}}(r) + M_{\text{dark}}(r)}$ but to $\sqrt{N_{\Re}(r)}$ (see eqs. (48), (49)), so that

$$\upsilon(r) = \sqrt{\frac{\gamma N_{\Re}(r) M_{\text{obs}}(r)}{r}} \quad \text{or} \quad N_{\Re}(r) = \frac{r\upsilon^2(r)}{\gamma M_{\text{obs}}(r)}\,, \tag{50}$$

where $M_{\text{obs}}(r) = M_{\text{real}}(r)$ is the ordinary, "visible" mass within radius *r*, and one can *derive* the features of *chaotic* system dynamics, $N_{\Re}(r)$, from the observed dependencies $\upsilon(r)$ and $M_{\text{obs}}(r)$. In particular, the observed growth of thus defined $N_{\Re}(r)$ just in "looser", more chaotic system parts, as well as its large variation for different kinds of cosmic structures, correspond well to fundamental laws of unreduced chaotic dynamics [2,9,10].

As a result, one can advance a general qualitative rule for the behaviour of real, complex-dynamical systems of many bodies mutually attracted according to the inverse-square law (any nondissipative attraction in three-dimensional space), in particular, many-body astrophysical structures. Due to the interplay between the "ordering" attraction to the global and local centres of mass (or another relevant "charge") and disordering influence of multivalued chaotic trajectories, such generic systems would tend to a somewhat smeared splitting into more regular system cores around centres of mass and much more chaotic "outskirts" farther from big attraction centres accumulating various chaotic "debris" expulsed from the "self-organised" core regions and following "nonclassical", explicitly multivalued dynamic behaviour laws, which appear, in particular, as the observed "dark matter" effects.

The detailed mechanism of such "chaotic halos" creation would include the multivalued chaos-driven sub-barrier tunnelling [1] from the potential well of the well-known classical "effective potential" of motion in the central inverse-square field [68]:

$$V_{\text{eff}}\left(r\right) = -\frac{\gamma m M}{r} + \frac{L^2}{2mr^2},$$

where in our case M is the (big) central mass, m is the (smaller) mass of a moving body, L is the (conserved) angular momentum of the moving body, the first term is the direct (here gravitational) attraction, and the second term is the "centrifugal force" contribution. This effective potential function has the form of a smooth asymmetric potential well with the depth $\Delta V_{\text{eff}} = \gamma^2 M^2 m^3 / 2L^2$ ([68], § 15). While in this simplest one-body formulation ΔV_{eff} remains fixed, the multivalued fluctuations in the real many-body system dynamics will produce random increases of L, lowering the barrier and initiating the (quite classical) subbarrier tunnelling effect (see also section 2.4 in ref [2] for the general causal theory of subbarrier tunnelling).

In other words (see also section 8.2 in ref. [2]), because of smaller interaction of outgoing system components with the inner system mass, the

net result of the emerging dynamical chaos will be the permanent, progressive diffusion of higher-speed "off-track" chaotic components from inner, higher-speed trajectories to outer trajectories and eventually vast regions (including the system's "free space", e.g. beyond the galactic disk plane for spiral galaxies). In one way or another, due to the intrinsic and often strong chaoticity, large quantities of "anomalous" high-speed components accumulate just in those "chaotic outskirt" regions of many-body gravitational systems, where they behave in a highly random way, contributing to the increased $N_{\Re}(r)$ from eq. (50) in these system parts.

It is important to note that complex-dynamical contributions to the observed velocity, or motion, in more chaotic system parts with higher $N_{\Re}(r) \gg 1$ can come from various components of multivalued system dynamics, including not only multivalued chaotic trajectories and larger quantities of smaller, directly unobservable "junk" elements intensely pushed to such chaotic outskirts but also more subtle effects of underlying inhomogeneous gravitational protofield density induced by the directly observed e/m protofield dynamics. Indeed, while the gravitational protofield density grows within massive objects due to their quantum beat processes, it should be respectively depleted just around their denser central parts and again increase at larger distances, which may have the effect of additional "invisible mass". In other words, the dark matter effects may partially result from *complex dynamics of the underlying (and directly indeed unobservable) gravitational protofield* itself represented most probably by a strong-interaction quark-gluon matter. It is the relative importance of these various possible contributions to chaotic dynamics of astrophysical objects that should constitute a major direction of further experimental and theoretical research in astronomy and cosmology, as opposed to the dominating applications of deeply incorrect unitary models (including the popular MOND hypothesis [61,62,66,67]). In a general sense, those different "dark matter realisations" of multivalued cosmic structure dynamics correspond to the *intrinsically creative* Universe dynamics driven by its unreduced interactions and just missing par excellence in heavily reduced unitary models of conventional cosmology, hence unable to solve this yet another "puzzle" within its artificial limitations.

In summary of our causally complete complex-dynamical (multivalued) cosmology as compared to mystified and puzzling unitary cosmological models, we return to the lowest complexity level of our unified,

physically real elementary particles and fields (see the previous section) to conclude that the natural richness of *multivalued* interaction dynamics permits us to avoid a plethora of artificial, abstract, separated and strangely "invisible" entities (fields, particles and dimensions) that still do not solve the growing unitary-science problems, in favour of naturally emerging, intrinsically unified and sufficient properties, features and structures of unreduced, multivalued dynamics of the underlying multilevel but unified protofield interaction process. That causal completion of the fundamentally deficient unitary model can be conveniently generalised by saying, in accord with the unified relations (19), (26)-(28), that we provide, in our complex-dynamical description, various levels and aspects of the otherwise heavily *missing total mass-energy-complexity* of the Universe structure, from our universal inertial and gravitational mass definition to naturally absent "dark" matter and energy and strictly positive (and high) total energy-complexity of the Universe.

A major kind of fundamentally redundant entities of unitary theory, invented to replace real but "hidden" features (or "variables") of complex interaction dynamics, is represented by additional, in particular scalar, fields and particles, including the Higgs field and bosons. While their existence is at variance with the observed, minimum number of dimensions and interaction forces (see the previous section), an additional consideration implies that *scalar fields are rather improbable as such* [12] because their interaction with other fields would provide their quanta with nonzero spin, similar to spin emergence in interaction between the e/m and gravitational protofields, unless they *simulate* the gravitational protofield itself. This conclusion invalidates so many abstract constructions of unitary cosmology and field/particle theory just relying on the assumed existence of additional, often scalar fields.

Another redundant feature of standard cosmology is the fundamental Big Bang expansion itself (and its related previous or next possible contraction). While we explained above why this mechanistic feature is absent in real complex-dynamical Universe (being replaced by multilevel and highly nonlinear structure creation processes with growing entropy-complexity), one may also think about the *"edge of the Universe"* and its dynamics in this real world, driven by the unreduced protofield interaction. In our case it depends on the assumed origin of the coupled protofield system. If we apply the Ockham's principle of parsimony to this "pre-cosmological" process (see previous sections), we should conclude that the e/m protofield coupled to

the gravitational protofield emerges as a result of initial excitation of a large enough portion of basically gluonic components from the primordial ground-state quark-gluon condensate thus transformed to the gravitational proto-field. While the edge of this initial global excitation can move in an arbitrary (unknown) way, the observed Universe structure is determined by the proto-field interaction results and can advance, in particular, by propagation of the global quantum-beat synchronisation process that gives rise to the universal real time flow and electric charge with its exactly two "opposite" kinds (see the previous section).

While this real Universe edge dynamics has nothing to do with the global Big Bang expansion (or any other mechanistic universe dynamics) replaced by local complex-dynamical structure creation, it can produce large-scale inhomogeneities of Universe properties, which could contribute to the origin of "nonlinear redshift" or (seeming) "dark energy" problem at larger distances and for some distant and peculiar super-high-energy objects and events. In other words, those extreme domains and objects could contain more unstable, still forming fundamental structures of space, time and field-particles, as described in our emergent universe picture, in this and the previous section. Such special cases can provide a unified diversity of origins of various observed "deviations" and "inexplicable" effects in redshift and energetic radiation distribution and production.

Another related group of accumulating "difficult" problems of usual cosmology is that of the *age of the Universe*, where its "well-established" Big-Bang value (of around 14 billion years) seems to be at variance with the age of some ultimately distant and thus "very young" but already well-formed detected objects (such as galaxies). These problems are related to the over-simplified model of mechanistic global dynamics of usual cosmology. Correspondingly, they do not even appear in the complex-dynamical, interaction-driven universe picture, where the age of the Universe is determined by extremely complicated detailed evolution of the huge hierarchy of unreduced dynamic complexity of universe structure. It could be provided with a more definite basis, if observations finally reveal the above moving "synchronisation" (and structure-formation) edge of the Universe (and the accessible large-distance data should be studied more attentively from that point of view). In any case the obtained age of real, complex-dynamical Universe will be much greater than the mechanistic Big-Bang age already because the

speed of complex-dynamic synchronisation and structure-formation propagation should be essentially smaller than the speed of light arriving from respective, already quite distant "event horizon". This conclusion corresponds to the generally much longer, multi-stage and "entangled" process of complex-dynamical structure formation and evolution as compared to straightforward mechanical expansion or contraction. As a result, we obtain a quite *different strategy and direction of observational cosmology research* based on the search for and understanding of real, explicit universe structure formation, rather than any simplified mechanistic model of its evolution.

The ultimate edge of the Universe in our picture would be the border of the Universe volume along which the two coupled but separated protofields collapse onto one another to form the primordial ground state of the quark-gluon condensate outside the Universe. While this ultimate frontier of the Universe may well be beyond any observational limits and much farther than the real "synchronisation edge" of usual Universe structure described above, it probably has its local internal version in the form of now realistically explained black hole "singularities". Indeed, the origin of these central singularities and black holes in general is naturally seen in our universe construction as small local remnants of the primordial "collapsed", ground-state quark-gluon condensate prior to the protofield separation in the Universe volume. They actually serve as additional structure-regulating feature, where the protofields are locally "pinned" to each other, thus maintaining their necessary tension and matter-carrier properties in large spaces around and between relatively dense structures (usually galactic centres). It is quite probable that at least a part of (greater) black hole "singularities" thus explained exist since the Universe creation (e.g. by initial protofield separation) as real remnants of the primordial ground-state condensate, which would explain contradictions around younger black hole age. Other black holes could emerge by standard mechanisms of gravitational collapse, but now understood as eventual collapse of the protofields (within the central "singularity") returning them to their primordial state of lowest energy, complexity and structure.

The physically real structure of these causally understood black hole cores can be seen as a spectrum of possible ultimately dense states of "condensed" field-particles (quantum beat processes), being denser analogues of neutron stars (they could be called correspondingly "quark-gluon stars" or

"Planck stars"). The highest density limit is provided by the closely packed species with the parameters of modified Planck units (see eqs. (39)-(40)), $\rho_{\rm P} \simeq M_{\rm P}/(L_{\rm P})^3 = c^5/(\gamma_0)^2\hbar \sim 10^{27} - 10^{29}$ g/cm^3 [1]. This is some 14 orders of magnitude higher than the nuclear star or nucleus density $\rho_{\rm nucl}$, and various intermediate densities $\rho_{\rm nucl} \ll \rho < \rho_{\rm P}$ can also be realised. They will vary with the condensed species mass M approximately as M^4 ($\rho \simeq M^4 c^3/\hbar^3$), up to more involved structure of condensed phases. In all cases, the microscopic *dynamic* origin of major *properties of a black hole* is clarified: virtually no e/m protofield excitations (either photons or massive particles) can escape this highly condensed core of the collapsed protofields because of its "closed" dynamics, where almost all excitations are immediately absorbed in the same condensate (in some relation to the quark confinement interpretation in our theory, see the previous section).

Finally, we mention an interesting new fundamental feature of our complex-dynamical Universe structure related to its quantum beat synchronisation being at the origin of electric charge and physically real time continuity throughout the Universe (as shown in the previous section). It provides a new outlook on the old and stagnating problem of the *wavefunction of the Universe*, originating in conventional "quantum cosmology". While it may seem that modern, predominantly "classical" state of the Universe is incompatible with the idea of a single wavefunction for the entire universe, the quantum beat synchronisation for all field-particles of the world, combined with our causal interpretation of the wavefunction (see the first section), points to the fact that the wavefunction of the Universe can still be considered as a real entity represented by the unified, simultaneously taken intermediate realisation of all quantum beat processes of the Universe. It can hardly be spatially coherent throughout the entire Universe and in this sense is closer to the classical distribution-function version of the wavefunction. However, the unique temporal coherence of this undular state of the e/m protofield in our picture permits us to see it as a deep enough version of the global wavefunction of the world, confirming its interaction-driven dynamic unity. The entire Universe in this global wavefunction realisation simultaneously "changes its face" towards the diversity of next regular, localised realisations by transiently returning to its structureless initial state, within the *global quantum beat process of the Universe* thus obtained.

In summary, we obtain variously dynamically unified and intrinsically creative, truly "cosmological" and "emergent" structure of complex-dynamical Universe, including not only the described fundamental but also all higher-complexity objects, in the form of dynamically probabilistic fractal [1,2,9-11,28]. The omnipresent fractal interaction web, in its unreduced, dynamically multivalued version, explains also the observed *large-scale quantisation* of planetary systems and greater structures [69,70], otherwise lacking a real physical substantiation (see ref. [2], section 8.2 for more details). And although many features of the presented *complex-dynamic (multivalued) cosmology* need further detailed study, the already obtained results and especially the *unified* and *qualitatively totally consistent* general dynamical structure of the Universe point to the necessity of the corresponding decisive *complexity transition* in cosmology, *essentially extending* its artificially limited unitary, mechanistic framework and *naturally solving* all the accumulated problems of the latter.

Causally complete structure emergence and dynamics at higher complexity levels: Unreduced nanobiotechnology, reliable genetics, integral medicine, demystified consciousness, and sustainable world development without crises

In previous sections we reviewed the causally complete universe structure emergence mainly at the few lowest sublevels of the fundamental unifying process of interaction between two primordial protofields, as well as its global, cosmological features for all complexity levels involved. Starting from the level of physically well-defined elementary field-particles (as described in the first two sections), the unified complex-dynamical interaction process, eqs. (1)-(3), proceeds to higher levels of interacting particles, including causally complete quantum measurement, genuine quantum chaos and dynamically emerging classical behaviour for elementary bound systems like atoms [1-11,13-15], and then further on to macroscopic bodies and structures while always preserving its *causally complete dynamics* without postulated mysteries, hidden variables, or dark matters of respective unitary science results [1,2,14-29]. All artificial limitations of the latter disappear due to our *unreduced* interaction analysis revealing the key extension to the fundamental *dynamic multivaluedness* of interaction results (see the first section).

It is those dynamically multivalued results of any real interaction process that constitute the unified "hidden" variables (or dimensions, or particles/energy, or "many worlds") of unitary science, desperately lost within its artificially simplified, dynamically single-valued framework. Rather than being mysteriously hidden from direct observation, these unreduced, dynamically multivalued versions of all real interaction processes *permanently appear and disappear* in *dynamically random* order, giving rise to universally defined chaoticity, complexity and naturally irreversible time flow.

Before briefly outlining below the results of this universal and causally complete interaction development process at higher complexity levels, we emphasize its unified guiding laws and features [1,2,10,28-30]. The main encompassing law is the *universal symmetry of complexity* introduced in the

previous section, which is the unified and causally derived extension of all (correct) particular laws and "principles" of real world dynamics, now also liberated from their formally postulated, abstract and mysterious origin in unitary theory. In its integral form, the unified complexity symmetry is expressed as the permanent transformation of the potential quantity of action-complexity (or dynamic information) $\mathcal{A}$ to the equal amount of unfolded quantity of action-entropy (or dynamic entropy) S, eq. (43).

In cases of relatively smooth (fine-grain) dynamics within a given complexity level, the differential form of the same complexity symmetry can be more useful. It is obtained by division of eq. (43) by the dynamically discrete time element, $\Delta t\big|_{x=\text{const}}$, leading to the discrete (in general) version of the generalised Hamilton-Jacobi equation:

$$\frac{\Delta\mathcal{A}}{\Delta t}\Big|_{x=\text{const}} + H\left(x, \frac{\Delta\mathcal{A}}{\Delta x}\Big|_{t=\text{const}}, t\right) = 0 \ , \quad H = E > 0 \ , \tag{51}$$

which is accompanied by the universal Schrödinger equation for the generalised wavefunction (or distribution function) Ψ introduced in previous sections and describing the intermediate, or main, realisation state [1,2,7,10,11, 18-24,28,29]:

$$\mathcal{A}_0 \frac{\Delta\Psi}{\Delta t}\Big|_{x=\text{const}} = \hat{H}\left(x, \frac{\Delta}{\Delta x}\Big|_{t=\text{const}}, t\right)\Psi(x,t) \ , \tag{52}$$

where the *generalised Hamiltonian*, $H = H(x,p,t)$, is *rigorously defined* as a differential version of the unfolded, *entropic* complexity, $H = (\Delta S/\Delta t)\big|_{x=\text{const}}$ (justifying the initial interaction problem formulation (1)-(3)), in accord with the above definition of its eigenvalue of generalised (total) energy E, eq. (19), and the generalised momentum definition, eq. (18), while the momentum operator $\hat{p} = \mathcal{A}_0(\Delta/\Delta x)\big|_{t=\text{const}}$ in eq. (52) replaces the momentum variable $p = (\Delta\mathcal{A}/\Delta x)\big|_{x=\text{const}}$ and the causal Born rule, eq. (13), relating the generalised wavefunction values with the realisation probability distribution is added to the generalised Schrödinger formalism (52). Universal equations (51), (52) (together with the Born rule (13)) constitute the unified and causally complete Hamilton-Schrödinger formalism for any system dynamics, which generalises various particular dynamic equations and takes a simpler, time-independent form for isolated systems:

$$H\left(x, \frac{\Delta\mathcal{A}}{\Delta x}\right) = E \ \ (>0) \ , \tag{53}$$

$$\hat{H}\left(x,\frac{\Delta}{\Delta x}\right)\Psi(x)=E\Psi(x)\ . \qquad (54)$$

The obtained differential expression of the universal complexity symmetry, eq. (51), contains also the *dynamically derived arrow of time*, directed to *entropy-complexity growth* (or action-complexity decrease), $H, E>0$, which is the generalised, differential version of the energy degradation principle (entropy growth, or the "second law of thermodynamics"), equivalent to its equally general integral version of eq. (43). It is important that in our description it is an intrinsic part of the law of *conservation*, *balance*, or *symmetry* of complexity that replaces various separated, biased and inconsistent extremum "principles" of unitary theory (like maximum entropy production, least action, etc.).

Due to the fundamental dynamic multivaluedness of all real interaction processes (see eqs. (1)-(16)), the permanent entropy-complexity growth in all real systems, objects and interaction processes emerges as the unique way to maintain the universal complexity conservation, or symmetry, thus resolving numerous contradictions between the entropy growth law and emergence of any quasi-regular object or dynamics within unitary (dynamically single-valued) theory. We see now that all real structures, however regular they may look or behave externally, consist of large numbers of very similar but still different realisations replacing one another in dynamically random order. This kind of behaviour determines the concept of extended, dynamically multivalued self-organisation, or self-organised criticality (SOC) in the general case of multiple complexity sublevels in many-body systems, leading to the *unified quantitative criterion of the degree of chaos/regularity* and related *classification of all existing dynamical regimes and structures* [1-3,10,11, 13-15,19-22,28,29]. As follows from the main EP formalism expression for the unreduced interaction dynamics, eqs. (8), (9), the degree of chaoticity is universally determined by the *chaoticity parameter* κ defined as

$$\kappa\equiv\frac{\Delta\eta_i}{\Delta\eta_n}=\frac{\omega_\xi}{\omega_Q}\ , \qquad (55)$$

where $\Delta\eta_i=\Delta\eta_{ni}^0$, $\omega_\xi=\Delta\eta_i/\mathcal{A}_0$ and $\Delta\eta_n\sim\Delta\varepsilon$, $\omega_Q=\Delta\eta_n/\mathcal{A}_0$ are eigenvalue spacings and respective motion frequencies for "structural", inter-element and internal, intra-element dynamics or other relevant kinds of system dynamics involved, while $\mathcal{A}_0$ is the characteristic action value.

If we start with the externally quasi-regular limiting regime of *dynamically multivalued self-organisation or SOC*, emerging at $\kappa \ll 1$, then we obtain a densely grouped realisation set, where one or few low-frequency "meta-realisations" (of the emerging higher complexity level) contain many closely spaced and quickly chaotically changing but externally (almost) unobservable elementary realisations, $N_r \sim N_{\Re}$, $\alpha_r \sim 1$ in eq. (12b). As can be seen from eq. (9), in this case we obtain the approximately local, quasi-regular (single-valued) EP due to the quasi-independent summation over i in the numerator of the EP kernel expression [1-3,10,11,28]. One should not forget, however, that although this dynamically single-valued approximation can be good enough in the SOC limit ($\kappa \ll 1$), the exact solution of eqs. (15)-(16) remains multivalued and thus internally chaotic, with important consequences, including *real time flow* and *universal growth of entropy-complexity* in *any*, even externally "ordering" structure-formation processes, which is to be compared with fundamentally incomplete conventional schemes of unitary, imitative self-organisation (see e.g. [71-88]).

Another important point of our extended vision of (multivalued) self-organisation regime at $\kappa \ll 1$ (or $\kappa \gg 1$, see below) is that it actually *unifies* the properly extended versions of various popular "ordered" regimes remaining separated in usual theory, including besides *self-organisation* itself, *self-organised criticality*, *synergetics*, *control of chaos*, *synchronisation*, *any control* of any dynamics, *mode locking*, and various *attractors*. We obtain thus the truly universal classification of all dynamic regimes in arbitrary systems in this limit of quasi-ordered structure, continuing then to other, more chaotic but equally unified regimes (see below). We also clarify numerous confusions and "difficult problems" in standard, unitary interpretation of each of those cases. Thus, we can confirm the "enslavement" principle of Haken's "synergetics" [80-85] but in a much more transparent, universal formulation, adding essential chaoticity of the "enslaved" fast modes, which changes dramatically the involvement of the *entropy growth principle* already mentioned above and avoids various ambiguities about the necessity of "open" or "dissipative" system dynamics, etc. In a similar way, the presence of intrinsic, *fractally structured* chaoticity in this regime (in relation to the *dynamically probabilistic fractal* introduced above) clarifies persisting problems of usual SOC [86-88] and simultaneously shows that in reality *every* regime of self-organisation (dominating external regularity) is a case of that extended,

dynamically multivalued SOC (hence this our most comprehensive name for this dynamic regime). We show also that contrary to unitary scheme illusions [89-94], *no* control (or synchronisation) of any system can lead to real regularity and therefore the *principle of realistic, complex-dynamical control* itself should be essentially modified in favour of the *symmetry (conservation and development) of complexity* of the compound, both controlled and controlling, system [14,15,18-22] (see also below). As to the popular subject of attractors, our causally complete problem solution shows that any real system attractor is fundamentally "strange", i.e. chaotic, but on the other hand, the real strange attractor structure is produced not by "exponentially diverging trajectories" of usual theory but by *permanent, dynamically random realisation change*, with *power-law* (rather than exponential) evolution of system state and structure [1,2]. Neither should one confuse conventional, unitary attractors created by system trajectory evolution with our plural, mutually *incompatible* realisations that form the structure of a real "strange attractor" (probabilistic fractal in real space) due to their permanent change in random order by transitions through the intermediate realisation of the wavefunction.

The opposite, strongly chaotic limiting regime of arbitrary system dynamics occurs at *resonance* between characteristic system frequencies or level separations, $\Delta\eta_i \simeq \Delta\eta_n \sim \Delta\varepsilon$, or $\omega_\xi = \omega_Q$, and the chaoticity parameter $\kappa \cong 1$ in eq. (55), providing thus the *global chaos criterion*. As can be seen from the main EP formalism equations (8)-(9), (15)-(16) (and the corresponding graphical analysis of refs. [1-4]), in that case the eigenvalues of individual realisations are so inseparably intermingled that they cannot be classified into quasi-independent groups unifying similar realisation configurations as it occurs in the opposite limit of self-organisation ($\kappa \ll 1$), so that now, at $\kappa \cong 1$, *essentially different* realisations replace one another at a not too high and not too low rate close to major system frequencies, $N_r \sim 1$, $\alpha_r \sim 1/N_{\Re} \ll 1$. This kind of dynamics creates the situation of strongest possible chaotic fluctuations quasi-evenly distributed over the accessible motion space, whence the name of *global*, or *uniform*, *chaos* for this limiting regime. Correspondingly, the general EP and state-function expressions, eqs. (9), (16), show highly nonlocal, dynamically "smeared" features, far from their local approximations in the opposite, quasi-regular self-organisation regime.

Note also that the unified global chaos criterion, $\kappa \cong 1$, reveals the genuine, deep meaning of the "well-known" *phenomenon of frequency resonance*

in real, dynamically multivalued systems as the condition of *strongly chaotic*, "explosive" system behaviour (rather than only anomalous growth of the oscillation amplitude, in usual theory), which may lead to intense interaction development, with destruction of the former and creation of a new structure. The "resonant" meaning of strong chaoticity criterion becomes also physically evident (and therefore shockingly missing in usual theory): comparable mode frequencies increase dramatically "irreconcilable mode competition" that excludes the regularising "enslavement agreement" of self-organisation limit and inevitably leads to their endless chaotic replacement.

If the chaoticity parameter κ grows well beyond the value of global-chaos transition, $\kappa \sim 1$, we obtain, at $\kappa \gg 1$, another quasi-regular, self-organised kind of dynamics, where now the slow intra-element motion "enslaves" the rapid inter-element dynamics and determines the emerging system behaviour usually having, however, more trivial nature, like spatially uniform (and small) energy-level shift. Therefore, a given initial system configuration determines the really interesting interval of κ variation approximately between 0 and 1, where the system passes by the whole range of possible dynamic regimes, from (external) quasi-regularity of multivalued SOC at $\kappa \simeq 0$ to global chaos at $\kappa \simeq 1$.

Similar to the particular case of quantum (and eventually classical) chaos in periodically perturbed oscillator [1-3,14], in this arbitrary system case chaoticity growth from the self-organised external regularity at $\kappa \simeq 0$ to the global chaos at $\kappa \simeq 1$ occurs by uneven steps appearing each time κ passes by a higher resonance condition at $\kappa \simeq m/n$, with small integers *m*, *n*, $m < n$. One obtains thus the *unified* "fractal structure of chaos" (e. g. in a system parameter space or "phase space") concentrating progressively around lower-degree resonances. This picture provides also the *essential extension and generalisation of usual KAM theory* applicable only to classical mechanical systems under condition of small perturbation of the trivial integrable system configuration (with the trivial result of preservation of its regular phase space structure for weak enough perturbation). In our extended version we can see what happens in a system of arbitrary origin and complexity level with arbitrary interaction (including quantum and classical mechanical systems), far from any integrable configuration. While the regular "tori" structure of the "phase space" (or corresponding parameter space) becomes ultimately smeared and unreal, the new, intrinsically chaotic (dynamically

multivalued) structure emerges, with its key features concentrating in the above fractal web around major frequency resonances [1,14].

As a result, we obtain the *unified classification of all dynamic (fundamentally multivalued) regimes* in *any* kind of system or process, varying between dynamically multivalued SOC and global (uniform) chaos depending on the chaoticity parameter κ of eq. (55) that varies respectively between 0 and 1 (it can be further expressed through the detailed system parameters for each particular case) [1,2,9-11,13-15,18-22,28]. Moreover, the explicitly *emerging* character of all world structures obtained as a result of *physically unified* interaction process development implies the approximate intermittence of more regular, SOC-type and highly chaotic regimes, with their mutual transformation in fractally structured interaction development and complementary roles of rigid structural basis and chaotic search for further interaction development ways. The only essential addition to this picture is due to the special case of *turbulence*, providing a peculiar combination of highly ephemeral but still quite distinguishable structure features as a result of particularly small separation of complexity sublevels comparable to characteristic interaction parameter variation (e. g. in terms of action-complexity) for each complexity sublevel [1].

The described self-developing fractal structure of unreduced, dynamically multivalued (and therefore chaotically changing) interaction results realises the *exponentially huge power* of natural many-body interaction processes, which is the true essence of dynamic adaptation and "intelligent" structure creation phenomena explaining the "magic" properties of life, intelligence and consciousness [2,13-23,28]. The total realisation number $N_{\Re}$ of unreduced interaction dynamics in a real many-body system and thus its full operation power $P \propto N_{\Re}$ is determined by the number of combinations of its $N = N_{\text{unit}} n_{\text{link}}$ modes or essential interaction links (where N_{unit} is the number of interaction elements and n_{link} the average number of modes or interaction links per element):

$$P \propto N_{\Re} \simeq N! \simeq \sqrt{2\pi N}(N/e)^N \sim N^N \ . \qquad (56)$$

Since N is already a large number for many real systems, we obtain the *exponentially huge* operation power P for such free-interaction system, including all its essentially quantum, chaotic, transitional and classical processes, as opposed to only power-law dependence of operation efficiency on

N for any unitary, dynamically single-valued operation of traditional devices, $P_0 \sim N^{\beta}$ ($\beta \sim 1$), $P/P_0 \sim N^{N-\beta} \sim N^N \to \infty$. For a quite modest estimate of $N \sim 10^3 - 10^4$, we have $N_{\Re}$, $P/P_0 \sim 10^{3000} - 10^{40000}$, which is to be compared with "ultimate" and "fundamental" estimates of P_0 for the most powerful unitary "quantum" computer of the entire Universe by the numbers of its bits $\sim 10^{90}$ and ever performed operations $\sim 10^{120}$ [95] and obviously yet much smaller values of ultimate capacities of a realistic in size unitary computer [96]. That huge difference between the greatest unitary imagination results and the natural, ordinary operation power of real, dynamically multivalued systems provides, in particular, the causal explanation of the "magic" (in usual theory) properties of *life, intelligence and consciousness*, taking into account that for both genome and human brain $N \geq 10^{12}$ [2,14-22,28].

This exponentially huge efficiency of natural interaction adaptability is a consequence of the above universal symmetry of complexity (43) determining the probabilistically fractal structure of multivalued interaction dynamics, eqs. (8)-(16). In general, one obtains *three* such universal corollaries of the symmetry of complexity called *complexity principles*, which appear in applications and have particular practical importance [2,15,18-22]. These three laws are the complexity correspondence principle, the complex-dynamical control principle, and the unreduced (free) interaction principle.

The *complexity correspondence principle* implies essential or interesting complexity development mainly in interaction between systems of comparable complexity. In particular, a system of certain complexity can be efficiently simulated, controlled, designed, or modified only by a system of (reasonably) higher but not lower complexity.

The *complex-dynamical control principle* states that traditional regular control idea and result can never be realised in real system management because of inevitable dynamic multivaluedness of any controlling interaction result and should be replaced by suitable, progressive complexity development, in the form of entropy-complexity growth, eq. (43). Genuine sustainability of system dynamics implies thus its suitable chaotic changes and transformation, with growth or preservation of desired essential properties, instead of inevitable and often catastrophic degradation within usual, "protective" schemes of unitary control approach. This law becomes especially important in efficient design, management and control of today's "globalised" world system dynamics of superior complexity level (see also below).

The *unreduced (free) interaction principle* refers to the above feature of exponentially huge power of dynamically probabilistic fractal operation, eq. (56), for natural, multicomponent interaction processes, as opposed to power-law efficiency of their conventional unitary models. In particular, this law underlies and explains the key features of life and intelligence always remaining mysterious within unitary theory but now acquiring quite realistic origin and new realisation possibilities in artificial nanobiosystems or macroscopic systems of genuine artificial intelligence and machine consciousness (see below).

We can proceed now with particular *applications* of the above unified complexity laws and features to various levels of progressively growing dynamic complexity, which demonstrate their causal completeness, wholeness and universality, leaving no place to unsolvable problems and growing contradictions of official science development (clearly appearing now as a result of specific, artificial limitations of just that, unitary science approach).

We have shown, in previous sections, how the unreduced interaction between two effectively structureless protofields gives rise to emerging, *physically real elementary particles* and all their causally specified properties, in the form of internally chaotic (dynamically multivalued) quantum beat processes. These causal particle properties include unified and causally complete quantum and relativistic dynamical features as manifestations of complex interaction dynamics, thus solving all respective unitary science "mysteries", paradoxes and contradictions. The observed *fundamental interactions* between particles through the coupled protofield media (their perturbations) are also causally specified, in their intrinsically unified origin and dynamics, and they naturally give rise to the *next emerging level* of interaction complexity, including Hamiltonian interaction and genuine quantum chaos, quantum measurement phenomena and emergent intrinsic classical behaviour of elementary bound systems [1-11,14].

In the case of nondissipative particle interaction in a closed system we obtain the *causally derived*, complex-dynamical Schrödinger or Dirac equations (which are special cases of the universal Schrödinger formalism of eqs. (52), (54) at the lowest, quantum-mechanical complexity sublevels), including wave-particle duality and universal complex-dynamical mass definition without redundant Higgs-like entities. Many-body particle interaction entering those equations gives rise to the *genuine quantum (Hamiltonian) chaos*

involving true randomness of quantum interaction dynamics and passing consistently to respective classical chaos under the usual quasi-classical transition, $\hbar \to 0$ [1-3,10,11,13-15,44]. This result solves the stagnating unitary-theory problem of "absent" (genuine) quantum chaoticity due to the dynamic multivaluedness of unreduced interaction process, eqs. (2)-(16).

The *quantum measurement* situation corresponds to the same general kind of dynamically multivalued, intrinsically chaotic quantum behaviour but occurring in the presence of small dissipativity and system openness realising the measurement process development towards higher (eventually macroscopic) complexity levels [1,2,4]. The key point here is that the measured quantum object or system *permanently* performs its *chaotic* quantum jumps between the measured eigenstates even *without* (both before and after) any measurement interaction (i.e. in its closed, Hamiltonian state), thus *actually taking* all its "quantum possibilities" in causally random order, with respective dynamic probabilities (12) obeying the causally derived Born rule (13). The impossibility of such behaviour in any version of unitary theory forced to impose its "inexplicable" and heavily mystified "quantum postulates" or external influences ("decoherence" and "dynamic reduction" theories [97-103]) underlies the stagnating impasse of conventional quantum theory putting its obvious absence of elementary causality at the very basis of science, with all the massively studied quantum applications.

Finally, the simplest *classical, permanently localised behaviour* naturally emerges as a *higher complexity sublevel* of *elementary bound systems*, such as atoms, only due to their internal chaotic dynamics, without any external "decoherence" of unitary theory [1,2,7,8,10,14]. In this case the chaotic quantum-beat dynamics of each atomic bound system component strongly limits the whole system's ability to perform larger sequence of quantum jumps in any given direction. This totally causal and intrinsic origin of classical behaviour as a higher level of interaction complexity naturally explains also the observed transient revivals of essentially quantum (undular) behaviour in interacting many-body systems, such as large molecule diffraction or superfluidity, directly contradicting all decoherence-based unitary theories.

The importance of this causally complete and problem-solving theory of complex interaction dynamics within a group of complexity sublevels from interacting elementary particles to atoms and their agglomerates is greatly amplified due to recent technological progress (real and promised) related

to quantum applications and nanobiosystems [13-15]. We should note, first of all, that our fundamental, causally derived conclusion of ubiquity of genuine quantum chaos in quantum interaction processes and systems (including their "pure", totally Hamiltonian versions without any dissipativity) [1-3,10,11,13-15] implies practical *impossibility of unitary quantum computers and any other quantum machines* (even in the absence of any noise-induced decoherence), together with their promised magic efficiency deeply related to their dynamically single-valued, non-chaotic dynamic assumed in standard unitary theory. The same is true for any *unreduced nanobiosystem dynamics*, which will be close to essential chaoticity criterion, $\kappa \sim 1$ (see eq. (55)), at least for some its truly nanoscale interacting components, just due to their minimum sizes and maximum frequencies implied by the Bohr frequency origin [13-15]. In particular, the key operation processes of resonant excitations and quantum transitions correspond by definition to the global chaos condition $\kappa \simeq 1$. Note also that ubiquitous quantum computing would contradict the universal complexity correspondence principle mentioned above [14,15].

However, the impossible high efficiency of unitary quantum machines *can be recovered* in another way in real, complex-dynamical (chaotic) quantum and classical nanobiosystems due to the exponentially huge efficiency of unreduced complex dynamics, eq. (56), and the related free interaction principle. Intrinsic system chaoticity is transformed here from a problem in unitary approach to advantage of unreduced interaction dynamics, actually realised in natural living systems and explaining the "magic" properties of life, intelligence and consciousness [13-22]. Similar features can now be reproduced in artificial and mixed nano-bio-structures, within properly organised "production lines", from essentially chaotic processes with $\kappa \sim 1$ (quantum chaos, quantum measurement) to more regular, SOC-type output structure dynamics with $\kappa \ll 1$ (emerging complex-dynamic classicality of elementary bound systems), involving multiple transitions and switches between them. Hence e.g. the idea of the totally new, *complex-dynamical nano-metal (and nano-solid-state) physics*, where instead of macroscopic (and basically regular) manifestations of specific properties of metallic (or other solid-state) atom electrons for the bulk material properties, one will deal with the properly specified, complex nanoscale dynamics for *individual* interacting metal (and other) atoms, electrons and their agglomerates, similar to

biomolecule and biostructure dynamics in living organisms, with their superior efficiency. In fact, practically *any* sensible case of "strong interaction" in ordinary solid-state physics (including e.g. high-temperature superconductivity) appears now as unrecognised result of unreduced complex, dynamically multivalued interaction process [1,2].

The next higher group of unreduced dynamic complexity sublevels includes *life-science applications* specified by *molecular and macroscopic biofractal structures*, *reliable complex-dynamical genomics* and related ideas of *causally complete, integral medicine* [2,16-18,28]. They all use the exponentially huge efficiency of unreduced, multivalued many-body interaction dynamics, eq. (56), corresponding to the truly causal, reliable understanding of life dynamics, as opposed to strongly limited unitary guesses of the standard life-science framework always using its basically linear, one-way approach and logic. In particular, those real *biological fractals* of unreduced living-system interactions and dynamics are quite different from unitary, purely mathematical fractals and realise the huge efficiency (56) of our dynamically probabilistic fractal [2,9-11,13-23,28] due to its universal symmetry of complexity (as opposed to the simplified "self-similarity" of usual fractals, only occasionally observed in external shapes of life).

Applying the concept of unreduced dynamically probabilistic fractal to *genome interaction analysis*, we arrive at the situation of *reliable, causally complete genomics*, where every smallest element of genome structure (its base pair) effectively interacts in average with any other one [16-18], thus realising the case of ultimately strong many-body interaction basically neglected in practical, purely empirical genome modifications. As a result, the latter practice of unitary logic application is close to almost blind manipulation with the extremely complex interaction network, which can only lead to catastrophic changes, in addition tending to accumulate in time due to relative system resistance to changes. Hence the idea of qualitatively extended, reliable complex-dynamical genomics considering all essential genome interactions [2,16-18,28]. This approach also properly explains and takes into account the role of large noncoding genome sequences, which appear now as the necessary vast *interaction space* ensuring the above exponentially huge efficiency of life dynamics.

The proposed causally complete genomics constitutes the necessary complex-dynamical basis for the objective understanding of living organism

dynamics, which further develops in the same form of dynamically multivalued interaction fractal to higher levels of biological structure complexity. The concept of *integral medicine* [2,16-18,28] implies the causally complete understanding of this entire complex-dynamical biofractal hierarchy, with respective visualisation of the multidimensional map of all its essential links and changes for each individual organism, providing its *unreduced, complex-dynamical structure* that can now be treated in a truly reliable way (using the same causally complete, dynamically multivalued interaction analysis).

Further interaction complexity development in the same branch leads from living to intelligent and conscious systems. It is confirmed by *rigorous and universal definitions* of *intelligence* and *consciousness* within our unreduced interaction analysis [2,19-22,28], obtained as *emerging superior levels* of the *same* unified dynamic complexity (14) that accounts for the (equally emerging) properties of life at its lower sublevels described above. While the unified complexity level of usual, empirical, or "animal", intelligence is determined by (and actually is somewhat greater than) the unreduced complexity level of the entire environment interacting with the intelligent system, the property of consciousness emerges from this minimum intelligence as a superior complexity level corresponding to well-defined, permanent bound-state emergence in the brain space of intelligent system (in rather exact similarity to classical behaviour emergence as elementary bound states of purely quantum objects at the lowest complexity levels, as described above). These complexity levels of intelligence and consciousness are realised in natural intelligent systems within their global interaction dynamics in the brain in the form of *generalised quantum beat* constituting either a nonlocal and highly chaotic "quantum" (undular and dualistic) kind of behaviour in the case of minimum, empirically driven intelligence or a more regular, SOC, or "classical" (permanently localised, trajectorial) behaviour in the case of genuine consciousness [2,19]. The universal Schrödinger equation for the generalised wavefunction, eq. (52), describes now the generalised quantum dynamics of the *brainfunction* $\Psi(\chi,t)$ in the space χ of entangled electro-chemical degrees of freedom of the brain [2,19].

These rigorous concepts of intelligent and conscious system dynamics, reproducing *all essential features* of respective behaviour types, are *absolutely universal* and do not depend on the physical (biological, artificial, or mixed) nature of the system, thus allowing for any application, including

artificial intelligence and *machine consciousness* [2,19]. The advantage of these unreduced concepts is that they reveal the dynamic origin and essence of all major manifestations of intelligent and conscious behaviour, as opposed to arbitrary guesses and huge simplification of usual, unitary approaches to artificial intelligence and consciousness, with the inevitable consequences for their realisation and use. And even in cases of limited practical realisation of pseudo-intelligent robotic, control and computer system behaviour, it is important to have the causally complete understanding of unreduced natural prototypes in order to properly design and develop those limited artificial-intelligence tools in exact correspondence to respective particular tasks and applications [19-22]. As complex computer, artificial intelligence and machine consciousness systems can be described as high-level control systems, there is the essential link here to the above complex-dynamical control principle, showing that unreduced complexity development elements should be used in efficient operation of any intelligent system.

The same causally complete understanding of complex interaction dynamics is equally indispensable to another group of applications to superior complexity levels including *social and economic development problems* of modern planetary civilisation and its local communities [1,2,23-26]. The universal complexity symmetry, in the form of permanent transformation of unreduced dynamic complexity C from its hidden form of action-complexity $\mathcal{A}$ to the explicit form of entropy-complexity S, eq. (43), provides the necessary fundamental, rigorous basis for these applications, whose absence in the standard unitary science framework (including all its "models" and *imitations* of complexity) leads to the characteristic non-causal, broken and contradictory state of knowledge in respective fields of economics, finance and development science. We thus discover, first of all, that the unified, unstoppable complexity development process of the world civilization and all its societies (their dynamic entropy growth) occurs in big steps, due to the fundamental discreteness of unreduced interaction process development. Correspondingly, the achieved causal understanding of characteristic features of each stage of this highly inhomogeneous process provides the *universal, objectively specified guiding line* for efficient development control and optimization, beyond any unitary-science guesses and subjective social interests.

It is shown, in particular, that the world complexity development has attained today the unprecedented and critical transition point, called

complexity, or *sustainability*, or *globalisation*, *transition*, or *threshold*, where the fundamental development instability and bifurcation point inevitably appear, after which the civilisation complexity development becomes highly globalised (strongly interactive at any scale) and *cannot* continue in the same, basically *unitary* (mechanistic, hierarchically split, profit-based and intrinsically unstable) way, irrespective of any efforts. It will instead either perform a stepwise growth to superior entropy-complexity level of *harmonical* system development (creative, distributed, reason-based and truly sustainable entropy-complexity growth without crises) or pass to the *destructive, low-energy branch* of dynamic entropy growth [1,2,23-26]. Based on our interaction complexity analysis, we specify respective changes in all major aspects of life (production, lifestyle and infrastructure, governance, knowledge role and development), together with the related efforts needed to establish the progressive development branch of harmonical system and avoid the dangerously growing (and the only existing) alternative of destructive branch of the naturally decaying unitary system. The universal complex-dynamical concept of *generalised system birth, life, and death* [1,2,23,24,28], together with the above unified complexity principles, is quite useful here, providing fundamentally substantiated, objectively optimal problem solutions for extremely complicated processes of global dynamics with huge numbers of ultimately diverse interaction participants.

This unreduced analysis of the world interaction processes show also that economic, or ecologic, or climate-related processes cannot (and should not) be separated from other development aspects, especially after the globalisation transition and world's complexity threshold (situated around the last millennium border), so that respective, characteristically isolated fields of unitary science (economics, ecology, climate science, etc.) *lose their meaning and any validity* as such and must instead be included in the *unified civilisation complexity analysis* outlined here as its particular aspects that can develop progressively or destructively after the current bifurcation point only together with the entire global interaction system. In particular, application of the unified development and unreduced interaction analysis to economic aspects and features provides the *universal and rigorously specified complex-dynamical concept of sustainable economic and financial risk management without crises and destructive losses* [26]. We provide the exact definition of risk magnitude distribution in terms of entropy-complexity growth rate and

the respective dynamic equation for this quantity as a form of our generalised Hamilton-Jacobi formalism (51). Using this unified equation and its unreduced, dynamically multivalued solution (16), one can efficiently control risk evolution within the necessary sustainability borders for any economic and social system. In simpler situations of local system and enterprise dynamics at a given dynamic regime, one can also efficiently avoid dangerous instabilities of emerging chaoticity by using our unified criterion of global chaos around major system resonances, $\kappa \sim 1$ (see eq. (55)).

In summary, we obtain thus the *naturally unified*, *causally complete* and *problem-solving* picture of intrinsically complex (multivalued) world dynamics at all complexity levels, from elementary particles to consciousness and world development, with no place for any "hidden variables", "dark matters", inexplicable "mysteries" and "unsolvable" problems of unitary science, actually appearing due to its *strongly missing dynamical content* of plural and permanently changing system realisations. All related notions of *nonintegrability (nonseparability)*, *undecidability*, or *noncomputability* emerge now as *rigorously specified and unified versions* of our *universal dynamic randomness (chaoticity) and complexity* determined by *multiple, equally real but incompatible realisations* (system configurations) produced in any unreduced interaction process within any real system or object. These notions appear not as unclear, separated, difficult and unsolvable features of simplified mathematical models of reality (as it occurs in unitary science) but rather as the unified key *advantages* of the unreduced world dynamics giving rise to all its "magic" properties and unlimited development possibilities to be used in applications. The latter include, in particular, the "edge research" agenda of unlimited but always *causally complete* complexity structure exploration even *beyond the conventional material borders of reality* [2]. While all "hidden" variables of artificially limited unitary knowledge are transformed into quite real structure of the multivalued fractal of world dynamics, the genuine borders of knowledge are pushed to infinity within its intrinsically complete version of the universal science of complexity.

References

[1] A. P. Kirilyuk, *Universal Concept of Complexity by the Dynamic Redundance Paradigm: Causal Randomness, Complete Wave Mechanics, and the Ultimate Unification of Knowledge* (Naukova Dumka, Kyiv, 1997). ArXiv:physics/9806002.

[2] A. P. Kirilyuk, *Theory of Everything, Ultimate Reality and the End of Humanity: Extended Sustainability by the Universal Science of Complexity* (LAP LAMBERT Academic Publishing, Beau Bassin, 2017). ViXra:1802.0168.

[3] A. P. Kirilyuk, "Quantum chaos and fundamental multivaluedness of dynamical functions", *Annales de la Fondation Louis de Broglie* **21** (1996) 455. ArXiv:quant-ph/9511034, 35, 36.

[4] A. P. Kirilyuk, "Causal Wave Mechanics and the Advent of Complexity. IV. Dynamical origin of quantum indeterminacy and wave reduction", *ArXiv:quant-ph/9511037* (1995).

A. P. Kirilyuk, "Causal Wave Mechanics and the Advent of Complexity. V. Quantum field mechanics", *ArXiv:quant-ph/9511038* (1995).

A. P. Kirilyuk, "New concept of dynamic complexity in quantum mechanics and beyond", *ArXiv:quant-ph/9805078* (1998).

[5] A. P. Kirilyuk, "Double Solution with Chaos: Dynamic Redundance and Causal Wave-Particle Duality", *ArXiv:quant-ph/9902015* (1999).

A. P. Kirilyuk, "Double Solution with Chaos: Completion of de Broglie's Nonlinear Wave Mechanics and its Intrinsic Unification with the Causally Extended Relativity", *ArXiv:quant-ph/9902016* (1999).

[6] A. P. Kirilyuk, "Universal gravitation as a complex-dynamical process, renormalised Planckian units, and the spectrum of elementary particles", *ArXiv:gr-qc/9906077* (1999).

[7] A. P. Kirilyuk, "75 Years of Matter Wave: Louis de Broglie and Renaissance of the Causally Complete Knowledge", *ArXiv:quant-ph/9911107* (1999).

A. P. Kirilyuk, "100 Years of Quanta: Complex-Dynamical Origin of Planck's Constant and Causally Complete Extension of Quantum Mechanics", *ArXiv:quant-ph/0012069* (2000).

A. P. Kirilyuk, "75 Years of the Wavefunction: Complex-Dynamical Extension of the Original Wave Realism and the Universal Schrödinger Equation", *ArXiv:quant-ph/0101129* (2001).

[8] A. P. Kirilyuk, "Quantum Field Mechanics: Complex-Dynamical Completion of Fundamental Physics and Its Experimental Implications", *ArXiv:physics/0401164* (2004).

A. P. Kirilyuk, "Electron as a Complex-Dynamical Interaction Process", *ArXiv:physics/0410269* (2004).

[9] A. P. Kirilyuk, "Cosmological Problem Solution by Complex-Dynamical Interaction Analysis", *Nanosystems, Nanomaterials, Nanotechnologies* **12** (2014) 809. ArXiv:physics/0510240, hal-00012639.

[10] A. P. Kirilyuk, "Consistent Cosmology, Dynamic Relativity and Causal Quantum Mechanics as Unified Manifestations of the Symmetry of Complexity", Report presented at the Sixth International Conference "Symmetry in Nonlinear Mathematical Physics" (Kiev, 20-26 June 2005), *ArXiv:physics/0601140; hal-00017268*. Russian version: *Nanosystems, Nanomaterials, Nanotechnologies* **11** (2013) 437.

[11] A. P. Kirilyuk, "Complex-Dynamical Solution to Many-Body Interaction Problem and Its Applications in Fundamental Physics", *Nanosystems, Nanomaterials, Nanotechnologies* **10** (2012) 217. ArXiv:1204.3460.

[12] A. P. Kirilyuk, "What Do They Actually Probe at LHC?", *Nanosystems, Nanomaterials, Nanotechnologies* **11** (2013) 217. Hal-00740459, viXra:1210.0162.

A. P. Kirilyuk, "Causally Complete Higgsless Theory from Complex Dynamics of Unreduced Interaction", *Nanosystems, Nanomaterials, Nanotechnologies* **13** (2015)161. Hal-01185647, viXra:1508.0174.

[13] A. P. Kirilyuk, "Complex Dynamics of Real Nanosystems: Fundamental Paradigm for Nanoscience and Nanotechnology", *Nanosystems, Nanomaterials, Nanotechnologies* **2** (2004) 1085. ArXiv:physics/0412097.

[14] A. P. Kirilyuk, *Complex Dynamics of Real Quantum, Classical and Hybrid Micro-Machines* (LAP LAMBERT Academic Publishing, Saarbrücken, 2013). ArXiv:physics/0211071.

[15] A. P. Kirilyuk, "Complex-Dynamical Nanobiotechnology Paradigm and Intrinsically Creative Evolution", *Nanosystems, Nanomaterials, Nanotechnologies* **14** (2016) 1. Hal-01342331, viXra:1607.0145.

[16] A. P. Kirilyuk, "The Universal Dynamic Complexity as Extended Dynamic Fractality: Causally Complete Understanding of Living Systems Emergence and Operation", In: *Fractals in Biology and Medicine, Vol. III*, Eds. G. A. Losa, D. Merlini, T. F. Nonnenmacher, and E. R. Weibel (Birkhäuser, Basel, 2002), p. 271. ArXiv:physics/0305119.

[17] A. P. Kirilyuk, "Complex-Dynamical Extension of the Fractal Paradigm and Its Applications in Life Sciences", In: *Fractals in Biology and Medicine, Vol. IV*, Eds. G. A. Losa, D. Merlini, T. F. Nonnenmacher, and E. R. Weibel (Birkhäuser, Basel, 2005), p. 233. ArXiv:physics/0502133.

[18] A. P. Kirilyuk, "New Mathematics of Complexity and Its Biomedical Applications", *Banach Center Publications* **109** (2016) 57. Hal-01147395, viXra:1506.0089.

[19] A. P. Kirilyuk, *Complex-Dynamic Origin of Consciousness and Sustainability Transition* (LAP LAMBERT Academic Publishing, Saarbrücken, 2014). ArXiv:physics/0409140.

[20] A. P. Kirilyuk, "Unreduced Dynamic Complexity: Towards the Unified Science of Intelligent Communication Networks and Software", In: *IFIP, Vol. 229, Network Control and Engineering for QoS, Security, and Mobility, IV*, Ed. D. Gaïti (Springer, Boston, 2007), p. 1. ArXiv:physics/0603132, hal-00020771.

[21] A. P. Kirilyuk and M. Ulieru, "IT Complexity Revolution: Intelligent Tools for the Globalised World Development", In: *IT Revolutions*, Eds. M. Ulieru, P. Palensky, and R. Doursat (Springer, Berlin Heidelberg, 2009), p. 1. ArXiv:0910.5495.

[22] A. P. Kirilyuk, "Unreduced Complex Dynamics of Real Computer and Control Systems", *Proceedings of the 20th International Conference on Control Systems and Computer Science (27-29 May 2015, Bucharest, Romania)*, Eds. I. Dumitrache, A. M. Florea, F. Pop, and A. Dumitraşcu (IEEE Computer Society CPS, Los Alamitos, 2015), Vol. 2, p. 557. Hal-01162395, viXra:1507.0038.

[23] A. P. Kirilyuk, "Towards Sustainable Future by Transition to the Next Level Civilisation", In: *The Future of Life and the Future of Our Civilisation*, Ed. V. Burdyuzha (Springer, Dordrecht, 2006), p. 411. ArXiv:physics/0509234.

[24] A. P. Kirilyuk, "Dynamic Origin of Evolution and Social Transformation", *Nanosystems, Nanomaterials, Nanotechnologies* **11** (2013) 1. ArXiv:1212.1939, hal-00760100.

[25] A. P. Kirilyuk, "Sustainable Reason-Based Governance after the Globalisation Complexity Threshold", submitted for the *Global Challenges Prize 2017*, 17 p. (2018). Hal-01736865, viXra:1803.0275.

[26] A. P. Kirilyuk, "Unified Complex-Dynamical Theory of Financial, Economic, and Social Risks and Their Efficient Management: Reason-Based Governance for Sustainable Development", In: A. P. Kirilyuk, *Theory of Everything, Ultimate Reality, and the End of Humanity: Extended Sustainability by the Universal Science of Complexity* (LAP Lambert Academic Publishing, Beau Bassin, 2017), section 8.4, pp. 194-199 (2018). Hal-01797479, SSRN-3183233.

[27] A. P. Kirilyuk, "Complex-Dynamic Origin of Quantised Relativity and Its Manifestations at Higher Complexity Levels", In: A. P. Kirilyuk, *Theory of Everything, Ultimate Reality, and the End of Humanity: Extended Sustainability by the Universal Science of Complexity* (LAP Lambert Academic Publishing, Beau Bassin, 2017), section 8.3, pp. 186-194 (2019). Hal-02107696, PhilPapers, viXra:1904.0449.

[28] A. P. Kirilyuk, "Universal Science of Complexity: Consistent Understanding of Ecological, Living and Intelligent System Dynamics", *ArXiv:0706.3219* (2007). Russian version: *Nanosystems, Nanomaterials, Nanotechnologies* **11** (2013) 679.

A. P. Kirilyuk, "Universal Symmetry of Complexity and Its Manifestations at Different Levels of World Dynamics", *Proceedings of Institute of Mathematics of NAS of Ukraine* **50** (2004) 821. ArXiv:physics/0404006.

A. P. Kirilyuk, "Dynamically Multivalued Self-Organisation and Probabilistic Structure Formation Processes", *Solid State Phenomena* **97-98** (2004) 21. ArXiv:physics/0405063.

[29] A. P. Kirilyuk, "Extended Mathematics of Unreduced Dynamic Complexity: The Exact Image of Unified Reality, from the Electron to Consciousness", *2015 FQXi essay contest, http://fqxi.org/community/forum/topic/2398*, 10 p. (2015). Hal-01173946.

A. P. Kirilyuk, "The Unified Complex-Dynamic Origin of Time, Intention, Life, and Everything", *2016-17 FQXi essay contest, http://fqxi.org/community/forum/topic/2774*, 10 p. (2017). Hal-01611317.

A. P. Kirilyuk, "Objective Fundamental Reality Structure by the Unreduced Complexity Development", *2017-18 FQXi essay contest, https://fqxi.org/community/forum/topic/3052*, 7 p. (2018). Hal-01715223.

[30] A. P. Kirilyuk, "The Last Scientific Revolution", in *Against the Tide. A Critical Review by Scientists of How Physics and Astronomy Get Done*, Eds. M. Lopez-Corredoira and C. Castro Perelman (Universal Publishers, Boca Raton, 2008), p. 179. ArXiv:0705.4562.

A. P. Kirilyuk, "From the End of Unitary Science Projection to the Causally Complete Complexity Science: Extended Mathematics, Solved Problems, New Organisation and Superior Purposes", In: A. P. Kirilyuk, *Theory of Everything, Ultimate Reality, and the End of Humanity: Extended Sustainability by the Universal Science of Complexity* (LAP Lambert Academic Publishing, Beau Bassin, 2017), section 8.5, pp. 199-209. Hal-01864363, vixra:1808.0643.

[31] J. Horgan, *The End of Science. Facing the Limits of Knowledge in the Twilight of the Scientific Age* (Addison-Wesley, Helix, 1996).

J. Horgan, "The Final Frontier", *Discover Magazine*, October (2006), http://discovermagazine.com/2006/oct/cover.

[32] J. Horgan, "From Complexity to Perplexity", *Scientific American*, June (1995) 74.

[33] J. Horgan, *The Undiscovered Mind: How the Human Brain Defies Replication, Medication, and Explanation* (Touchstone/Simon & Schuster, New York, 1999).

[34] M. Lopez-Corredoira and C. Castro Perelman, Eds., *Against the Tide. A Critical Review by Scientists of How Physics and Astronomy Get Done* (Universal Publishers, Boca Raton, 2008); http://philsci-archive.pitt.edu/4046/, http://vixra.org/abs/0909.0002, http://www.archivefreedom.org/tide.htm.

[35] J. A. Wheeler, “Information, Physics, Quantum: The Search for Links”, in *Complexity, Entropy and the Physics of Information*, Ed. W. Zurek (Addison-Wesley, 1990), p. 3. First edition: 1989.

[36] B. Greene, *The Elegant Universe: Superstrings, Hidden Dimensions, and the Quest for the Ultimate Theory* (Vintage Books, New York, 2000). First edition: 1999.

[37] A. Connes, “La réalité mathématique archaïque”, *La Recherche*, No. 332, Juin (2000) 109.

[38] J. B. Barbour, *The End of Time: The Next Revolution in Physics* (Oxford University Press, 2001).

[39] R. Aldrovandi and A.L. Barbosa, “Spacetime algebraic skeleton”, *ArXiv:gr-qc/0207044*.

[40] M. Bounias and V. Krasnoholovets, “The Universe from Nothing: A Mathematical Lattice of Empty Sets”, *International Journal of Anticipatory Computing Systems* **16** (2004) 3. ArXiv:physics/0309102.

[41] M. Tegmark, “The Mathematical Universe”, *Found. Phys.* **38** (2008) 101. ArXiv:0704.0646.

M. Tegmark, *Our Mathematical Universe: My Quest for the Ultimate Nature of Reality* (Vintage Books, New York, 2015). First edition: 2014.

[42] R. Penrose, “What Is Reality?”, *New Scientist*, 18 November (2006) 32.

[43] R. Penrose, *Shadows of the Mind* (Oxford University Press, New York, 1994).

[44] A. P. Kirilyuk, “Theory of charged particle scattering in crystals by the generalised optical potential method”, *Nucl. Instr. Meth.* **B69** (1992) 200.

[45] P. H. Dederichs, “Dynamical Diffraction Theory by Optical Potential Methods”, *Solid State Physics: Advances in Research and Applications*, Eds. H. Ehrenreich, F. Seitz and D. Turnbull (Academic Press, New York) **27** (1972) 136.

[46] L. de Broglie, “Ondes et quanta”, *C. R. Acad. Sc.* **177** (1923) 507.

[47] L. de Broglie, “Quanta de lumière, diffraction et interférences”, *C. R. Acad. Sc.* **177** (1923) 548.

[48] L. de Broglie, “Les quanta, la théorie cinétique des gaz et le principe de Fermat”, *C. R. Acad. Sc.* **177** (1923) 630.

[49] L. de Broglie, “Recherches sur la théorie des quanta”, Thèse de doctorat soutenue à Paris le 25 novembre 1924, *Annales de Physique (10e série)* **III** (1925) 22. Reproduced in:

L. de Broglie, *Recherches sur la théorie des quanta* (Fondation Louis de Broglie, Paris, 1992).

[50] L. de Broglie, “Sur la thermodynamique du corpuscule isolé”, *C. R. Acad. Sc.* **253** (1961) 1078.

L. de Broglie, “Quelques conséquences de la thermodynamique de la particule isolée”, *C. R. Acad. Sc.* **255** (1962) 1052.

[51] L. de Broglie, *La thermodynamique de la particule isolée (thermodynamique cachée des particules)* (Gauthier-Villars, Paris, 1964).

[52] L. de Broglie, “Le mouvement brownien d'une particule dans son onde”, *C. R. Acad. Sc. (série B)* **264** (1967) 1041.

[53] J. Adams et al. (STAR Collaboration), *Nucl. Phys. A* **757** (2005) 102. ArXiv:nucl-ex/0501009.

[54] L. D. Landau and E. M. Lifshitz, *Field theory* (Nauka, Moscow, 1989). Sixth edition.

[55] L. Randall and R. Sundrum, *Phys. Rev. Lett.* **83** (1999) 3370. ArXiv:hep-ph/9905221.

L. Randall and R. Sundrum, *Phys. Rev. Lett.* **83** (1999) 4690. ArXiv:hep-th/9906064.

[56] M. López-Corredoira, "Observational Cosmology: Caveats and Open Questions in the Standard Model", In: *Recent Research Developments in Astronomy & Astrophysics, vol. 1*, Ed. S. G. Pandalai (Research Signpost, Kerala, 2003), p. 561. ArXiv:astro-ph/0310214.

M. López-Corredoira, "Non-standard Models and the Sociology of Cosmology", *Studies in History and Philosophy of Science B* **46A** (2014) 86. ArXiv:1311.6324.

[57] E. J. Lerner and J. B. Almeida (Eds.), *1st Crisis in Cosmology Conference, CCC-I* (AIP, Melville, 2006). Contents accessible at http://scitation.aip.org/content/aip/proceeding/aipcp/822. See also http://cosmology.info/ccc1/index.html.

[58] R. E. Criss and A. M. Hofmeister, *Geochimica et Cosmochimica Acta* **65** (2001) 4077.

[59] I. Bersons, "Soliton model of the photon", *Latv. J. Phys. Tech. Sci.* **50** (2013) 60.

I. Bersons, R. Veilande and A. Pirktinsh, "Three-dimensional collinearly propagating solitons", *Phys. Scr.* **89** (2014) 045102.

I. Bersons, R. Veilande and O. Balcers, "Soliton model of a photon propagating in dielectrics", *Phys. Scr.* **91** (2016) 065201.

[60] R. Hodson (Ed.), "The Dark Universe", *Nature* (Nature Outlook) **537**, Iss. 7622 (2016) S193.

S. Battersby, "Staring into Darkness", *Nature* **537**, Iss. 7622 (2016) S201.

[61] M. Lopez-Corredoira, "Problems with the dark matter and dark energy hypotheses, and alternative ideas", In: *Cosmology on Small Scales 2018: Dark Matter Problem and Selected Controversies in Cosmology*, Eds. M. Krizek and Y. V. Dumin (Inst. Mathematics, Czech Acad. Sciences, Prague, 2018), p. 14. ArXiv:1808.09823.

[62] V. Sahni, "Dark Matter and Dark Energy", *Lecture Notes in Physics* **653** (2005) 141. ArXiv:astro-ph/0403324.

[63] S. Khalil and C. Munoz, "The Enigma of the Dark Matter", *Contemp. Phys.* **43** (2002) 51. ArXiv:hep-ph/0110122.

[64] K. A. Olive, "TASI lectures on dark matter", *ArXiv:astro-ph/0301505*.

[65] J. Hecht, "What's the matter", *Nature* **537**, Iss. 7622 (2016) S194.

[66] R. Scarpa, "Modified Newtonian Dynamics, an Introductory Review", In: *1st Crisis in Cosmology Conference, CCC-I*, Eds. E. J. Lerner and J. B. Almeida (AIP, Melville, 2006), p. 253. ArXiv:astro-ph/0601478.

[67] M. Milgrom, "New Physics at Low Accelerations (MOND): an Alternative to Dark Matter", *AIP Conf. Proc.* **1241** (2010) 139. ArXiv:0912.2678.

[68] L.D. Landau and E.M. Lifshitz, *Mechanics* (Nauka, Moscow, 1988), fourth Russian edition.

[69] L. Nottale and G. Schumacher, "Scale relativity, fractal space-time and gravitational structures", In: Ed. M. M. Novak, *Fractals and beyond : Complexities in the Sciences* (World Scientific, Singapore, 1998), p. 149.

[70] *Quantization of parameters of cosmic systems*, Wikiversity, https://en.wikiversity.org/wiki/Quantization_of_parameters_of_cosmic_systems.

[71] P. Glansdorf and I. Prigogine, *Thermodynamic Theory of Structure, Stability and Fluctuations* (John Wiley & Sons, New York, 1971).

[72] I. Prigogine and I. Stengers, *Order out of Chaos* (Heinemann, London, 1984).

[73] G. Nicolis and I. Prigogine, *Exploring Complexity* (Freeman, San Francisco, 1989).

[74] G. Nicolis, "Physics of far-from-equilibrium systems and self-organisation", In *The New Physics*, Ed. P. Davies (Cambridge University Press, 1989), p. 316.

[75] T. Y. Petrosky and I. Prigogine, "Laws and events: The dynamical basis of self-organisation", *Can. J. Phys.* **68** (1990) 670.

[76] I. Prigogine, *La fin des certitudes. Temps, chaos et les lois de la nature* (Éditions Odile Jacob, Paris, 1996, 1998).

[77] T. Petrosky and I. Prigogine, "Poincaré Resonances and the Extension of Classical Dynamics", *Chaos, Solitons and Fractals* **7** (1996) 441.

[78] T. Petrosky and I. Prigogine, "Thermodynamic limit, Hilbert space and breaking of time symmetry", *Chaos, Solitons and Fractals* **11** (2000) 373.

[79] I. Antoniou, I. Prigogine, V. Sadovnichii and S.A. Shkarin, "Time operator for diffusion", *Chaos, Solitons and Fractals* **11** (2000) 465.

[80] H. Haken, "Cooperative phenomena in systems far from thermal equilibrium and in nonphysical systems", *Rev. Mod. Phys.* **47** (1975) 67.

[81] H. Haken, *Synergetics. An Introduction,* 3rd ed. (Springer-Verlag, Berlin, 1983).

[82] H. Haken, *Advanced Synergetics* (Springer-Verlag, Berlin, 1983).

[83] H. Haken, *Information and Self-Organisation: A Macroscopic Approach to Complex Systems* (Springer-Verlag, Berlin, 1988).

[84] *Interdisciplinary Approaches to Nonlinear Complex Systems*, Eds. H. Haken and A. Mikhailov (Springer-Verlag, Berlin, 1993).

[85] H. Haken, "Slaving principle revisited", *Physica D* **97** (1996) 95.

[86] P. Bak, *How Nature Works: The Science of Self-Organised Criticality* (Copernicus/Springer, 1996).

[87] A. Csilling, I. M. Jánosi, G. Pásztor and I. Scheuring, "Absence of chaos in a self-organized critical coupled map lattice", *Phys. Rev. E* **50** (1994) 1083.

[88] M. de Sousa Vieira and A. J. Lichtenberg, "Presence of chaos in a self-organized critical system", *Phys. Rev. E* **53** (1996) 1441.

[89] S. Boccaletti, C. Grebogi, Y.-C. Lai, H. Mancini and D. Maza, "The Control of Chaos: Theory and Applications", *Phys. Rep.* **329** (2000) 103.

[90] R. L. Viana and C. Grebogi, "Unstable dimension variability and synchronization of chaotic systems", *Phys. Rev. E* **62** (2000) 462. ArXiv:chao-dyn/9911027.

[91] W. van der Water and J. de Weger, "Failure of chaos control", *Phys. Rev. E* **62** (2000) 6398.

[92] L. Viola, S. Lloyd and E. Knill, "Universal Control of Decoupled Quantum Systems", *Phys. Rev. Lett.* **83** (1999) 4888. ArXiv:quant-ph/9906094.

[93] A. C. Doherty, S. Habib, K. Jacobs, H. Mabuchi and S. M. Tan, "Quantum feedback control and classical control theory", *Phys. Rev. A* **62** (2000) 012105. ArXiv:quant-ph/9912107.

[94] S. G. Schirmer, H. Fu and A. I. Solomon, "Complete controllability of quantum systems", *Phys. Rev. A* **63** (2001) 063410. ArXiv:quant-ph/0010031.

[95] S. Lloyd, "Computational capacity of the Universe", *Phys. Rev. Lett.* **88** (2002) 237901. ArXiv:quant-ph/0110141.

[96] S. Lloyd, "Ultimate physical limits to computation", *Nature* **406** (2000) 1047. ArXiv:quant-ph/9908043.

[97] J.-M. Raimond and V. Rivasseau (Eds.), *Quantum Decoherence* (Birkhäuser, Basel, 2006).

[98] A. Bassi and G. C. Ghirardi, "Dynamical Reduction Models", *Physics Reports* **379** (2003) 257. ArXiv:quant-ph/0302164.

[99] R. Omnès, "Decoherence and wave function collapse", *Found. Phys.* **41** (2011) 1857. ArXiv:1105.0831.

[100] W. H. Zurek, "Decoherence, einselection, and the quantum origins of the classical", *Rev. Mod. Phys.* **75** (2003) 715. ArXiv:quant-ph/0105127.

[101] W. H. Zurek, "Quantum Darwinism", *Nature Physics* **5** (2009) 181. ArXiv:0903.5082.

M. Zwolak, C. J. Riedel and W. H. Zurek, "Amplification, Redundancy, and the Quantum Chernoff Information", *Phys. Rev. Lett.* **112** (2014) 140406. ArXiv:1312.5373.

[102] J. P. Paz and A. J. Roncaglia, "Redundancy of classical and quantum correlations during decoherence", *Phys. Rev. A* **80** (2009) 042111. ArXiv:0909.0474.

[103] L. Diósi, " Does wave function collapse cause gravity?", *J. Phys: Conf. Ser.* **174** (2009) 012002. ArXiv:0902.1464.