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Consistent Cosmology, Dynamic Relativity and Causal Quantum Mechanics as Unified Manifestations of the Symmetry of Complexity [0]

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Abstract. The universal symmetry, or conservation, of complexity underlies any law or principle of system dynamics and describes the unceasing transformation of dynamic information into dynamic entropy as the unique way to conserve their sum, the total dynamic complexity. Here we describe the real world structure emergence and dynamics as manifestation of the universal symmetry of complexity of initially homogeneous interaction between two protofields. It provides the unified complex-dynamic, causally complete origin of physically real, 3D space, time, elementary particles, their properties (mass, charge, spin, etc.), quantum, relativistic, and classical behaviour, as well as fundamental interaction forces, including naturally quantized gravitation. The old and new cosmological problems (including "dark" mass and energy) are basically solved for this explicitly emerging, self-tuning world structure characterised by strictly positive (and large) energy-complexity. A general relation is obtained between the numbers of world dimensions and fundamental forces, excluding plausible existence of hidden dimensions. The unified, causally explained quantum, classical, and relativistic properties (and types of behaviour) are generalised to all higher levels of complex world dynamics. The real world structure, dynamics, and evolution are exactly reproduced by the probabilistic dynamical fractal, which is obtained as the truly complete general solution of a problem and the unique structure of the new mathematics of complexity. We outline particular, problem-solving applications of always exact, but irregularly structured symmetry of unreduced dynamic complexity to microworld dynamics, including particle physics, genuine quantum chaos, real nanobiotechnology, and reliable genomics.

Key words: complex interaction dynamics; dynamic multivaluedness; chaos; dynamically probabilistic fractal; quantum gravity; dark matter; Planckian units; causal mass spectrum

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1 Universe structure emergence by the symmetry of complexity

1.1 Unreduced interaction dynamics and elementary particle structure

The *universal symmetry (conservation and transformation) of complexity* underlies any real interaction process development (any system dynamics and evolution) and constitutes both the origin and the result of structure emergence at any level of world dynamics, providing a large scope of problem-solving applications [1–15]. Contrary to usual symmetry expression by *externally imposed*, formal *operators* [16–18], the symmetry of complexity expresses *real interaction dynamics* in the form of unceasing chaotic *transitions* between system realisations and complexity levels [2]. In this report we consider explicit emergence of the lowest complexity levels of the universe, represented by elementary particles, fields, all their properties and interactions, as

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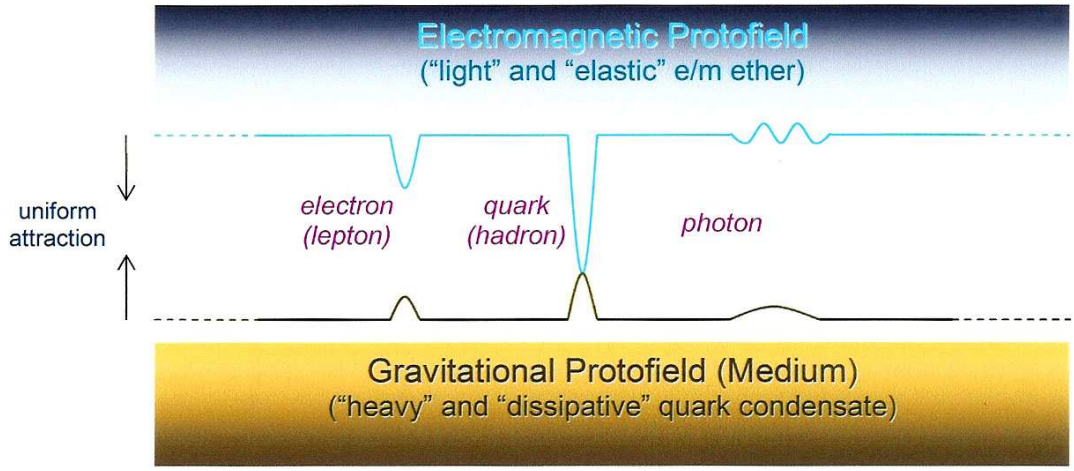

Figure 1. Scheme of protofield interaction configuration and development, giving rise to *emerging* elementary particles, fields, their properties and interactions (progressively derived).

well as global and cosmic structure (cosmological) features [1,4,7–10]. We demonstrate how the symmetry of complexity determines the properties of *real-world* structures and provides *solution* to fundamental and practical problems remaining otherwise unsolved or even growing (e. g. in cosmology, quantum and classical gravity and field theory).

The "fundamental" world structures of lowest complexity emerge necessarily from the *simplest* possible interaction configuration, which is uniquely represented, at the universe scale, by two homogeneous, physically real protofields *uniformly attracted* to each other (Figure 1). The dense and dissipative gravitational protofield, or medium, plays the role of inert world "matrix" and eventually gives rise to (dynamically emerging) universal gravitation, while light and elastic electromagnetic (e/m) protofield is the "swift" system component that underlies e/m properties. Interaction development in the protofield system leads first to emergence of most fundamental world structures, elementary particles (and fields), and we are going to *explicitly obtain* them as *unreduced solutions* of a quite general equation, called *existence equation* and actually only fixing the initial system configuration (it also generalises various "model" equations):

$$[h_{\rm g}(\xi) + V_{\rm eg}(\xi, q) + h_{\rm e}(q)]\,\Psi(\xi, q) = E\Psi(\xi, q)\,, \tag{1}$$

where $\Psi(\xi, q)$ is the system state-function expressing its state and development (to be found), $h_{\rm g}(\xi)$ and $h_{\rm e}(q)$ are generalised Hamiltonians for the free (non-interacting) gravitational and e/m protofields (i. e. measures of dynamic complexity defined below), $V_{\rm eg}(\xi, q)$ is arbitrary (but actually attractive and binding) interaction potential between the fields of ξ and q, and E is the generalised Hamiltonian eigenvalue (energy). The Hamiltonian form of existence equation generalises various, linear and "nonlinear", models and is self-consistently confirmed below (section 1.2) as *unified* expression of the *symmetry of complexity* (the latter can already be traced in equation (1) as the expressed permanence of energetic system content). The starting problem formulation of equation (1) does not contain either space or time that will be obtained as *emerging*, real manifestations of universe structure development (section 1.3.1).

Expressing $\Psi(q, \xi)$ in terms of the free e/m protofield eigenfunctions, $\{\phi_n(q)\}$, we get

$$\Psi(\xi, q) = \sum_n \psi_n(\xi)\phi_n(q)\,, \qquad h_{\rm e}(q)\,\phi_n(q) = \varepsilon_n\phi_n(q)\,, \tag{2}$$

which after substitution into equation (1) and standard eigenfunction separation gives a system of equations for $\psi_n(\xi)$, equivalent to the starting existence equation (1) [1,2,7–9]:

$$[h_{\rm g}(\xi)+V_{00}(\xi)]\,\psi_0(\xi)+\sum_n V_{0n}(\xi)\,\psi_n(\xi)=\eta\psi_0(\xi)\,,$$
$$[h_{\rm g}(\xi)+V_{nn}(\xi)]\,\psi_n(\xi)+\sum_{n'\neq n} V_{nn'}(\xi)\,\psi_{n'}(\xi)=\eta_n\psi_n(\xi)-V_{n0}(\xi)\,\psi_0(\xi)\,, \tag{3}$$

where $\eta_n\equiv E-\varepsilon_n$,

$$V_{nn'}(\xi)=\int\limits_{\Omega_q} dq\phi_n^*(q)\,V_{\rm eg}(\xi,q)\,\phi_{n'}(q)\,,$$

equation with $n=0$ is separated from others, so that $n\neq 0$ from now on, and $\eta\equiv\eta_0$. Note that one obtains exactly the same system of equations (3) starting from a general existence equation for arbitrary system configuration and number of components (N) [3,4,6,12–14],

$$\left\{h_0(\xi)+\sum_{k=1}^{N}\left[h_k(q_k)+V_{0k}(\xi,q_k)+\sum_{l>k}^{N}V_{kl}(q_k,q_l)\right]\right\}\Psi(\xi,Q)=E\Psi(\xi,Q)\,, \tag{4}$$

where $Q\equiv\{q_1,...,q_N\}$. This fact should not be surprising, as arbitrary interaction between protofield elements is implied in (1). It demonstrates also the deep underlying *universality* of real world structure emergence at all levels, properly reflected in our unreduced description.

The unreduced interaction complexity emerges if instead of perturbative reduction of "non-integrable" system (3) we try to "solve" it by expressing $\psi_n(\xi)$ through $\psi_0(\xi)$ by the standard Green function technique and inserting the result into the equation for $\psi_0(\xi)$, which gives the *effective existence equation* of the generalised effective (optical) potential method [11,19]:

$$[h_{\rm g}(\xi)+V_{\rm eff}(\xi;\eta)]\,\psi_0(\xi)=\eta\psi_0(\xi)\,, \tag{5}$$

where the *effective potential (EP)*, $V_{\rm eff}(\xi;\eta)$, is given by

$$V_{\rm eff}(\xi;\eta)=V_{00}(\xi)+\hat V(\xi;\eta)\,,\qquad \hat V(\xi;\eta)\,\psi_0(\xi)=\int\limits_{\Omega_\xi} d\xi' V\left(\xi,\xi';\eta\right)\psi_0\left(\xi'\right),$$
$$V\left(\xi,\xi';\eta\right)=\sum_{n,i}\frac{V_{0n}(\xi)\,\psi^0_{ni}(\xi)\,V_{n0}(\xi')\,\psi^{0*}_{ni}(\xi')}{\eta-\eta^0_{ni}-\varepsilon_{n0}}\,,\qquad \varepsilon_{n0}\equiv\varepsilon_n-\varepsilon_0\,, \tag{6}$$

and $\{\psi^0_{ni}(\xi)\}$, $\{\eta^0_{ni}\}$ are the complete sets of eigenfunctions and eigenvalues for an auxiliary, truncated system of equations:

$$[h_{\rm g}(\xi)+V_{nn}(\xi)]\,\psi_n(\xi)+\sum_{n'\neq n}V_{nn'}(\xi)\psi_{n'}(\xi)=\eta_n\psi_n(\xi)\,. \tag{7}$$

The state function (2) of the initial existence equation (1) is then obtained as [1,4,10,11]:

$$\Psi(\xi,q)=\sum_i c_i\left[\phi_0(q)+\sum_n\phi_n(q)\,\hat g_{ni}(\xi)\right]\psi_{0i}(\xi)\,,$$
$$\psi_{ni}(\xi)=\hat g_{ni}(\xi)\,\psi_{0i}(\xi)\equiv\int\limits_{\Omega_\xi} d\xi' g_{ni}\left(\xi,\xi'\right)\psi_{0i}\left(\xi'\right),$$
$$g_{ni}\left(\xi,\xi'\right)=V_{n0}\left(\xi'\right)\sum_{i'}\frac{\psi^0_{ni'}(\xi)\,\psi^{0*}_{ni'}(\xi')}{\eta_i-\eta^0_{ni'}-\varepsilon_{n0}}\,, \tag{8}$$

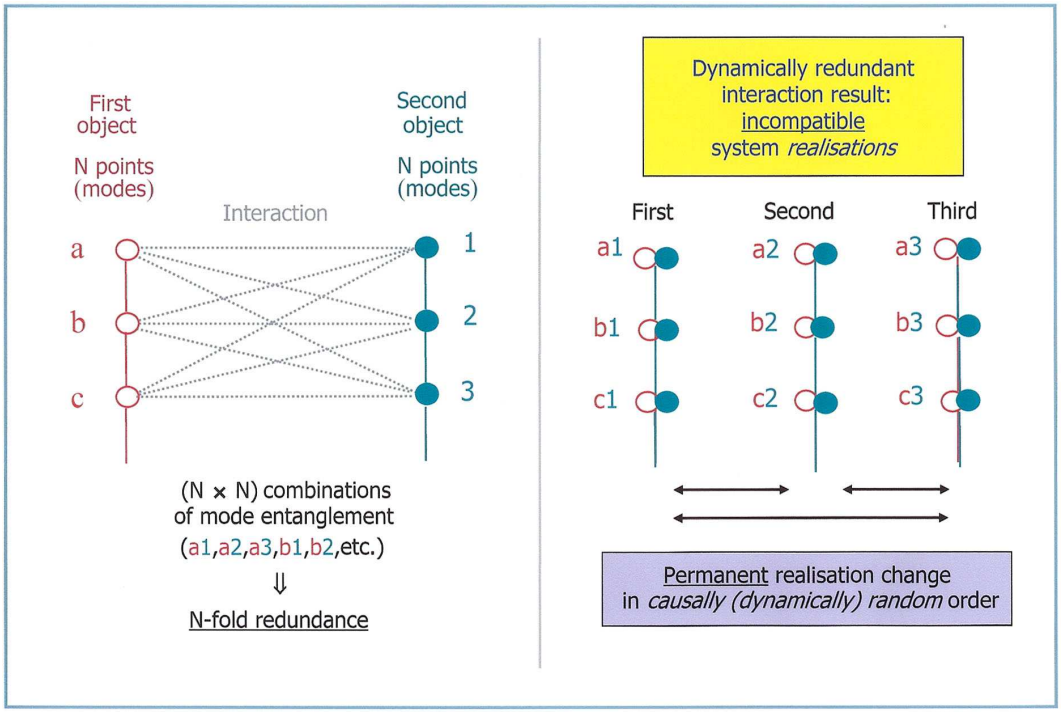

Figure 2. Dynamic multivaluedness emergence in any real interaction process. Unreduced interaction between two objects (e. g. protofields) with N interacting points or modes each (left) includes N^2 mode combinations, leading to N-fold *redundance* of *incompatible* system realisations thus formed (in agreement with equations (6), (11)). It is related to the *symmetry of complexity*, as the "number of places" for interaction components and products, determined by the total system complexity, *cannot change* in the course of interaction. Therefore all $N_{\Re} = N$ equally real system realisations are forced, by the same driving interaction, to *permanently replace* each other in a *dynamically random* order thus defined (right).

where $\{\psi_{0i}(\xi)\}$ are eigenfunctions and $\{\eta_i\}$ eigenvalues found from equation (5), while the coefficients c_i should be determined by state-function matching on the boundary where the effective interaction vanishes. The observed system density, $\rho(\xi, q)$, is given by the squared modulus of the state-function, $\rho(\xi, q) = |\Psi(\xi, q)|^2$ (for "quantum" and other "wave-like" levels of complexity), or by the state-function itself, $\rho(\xi, q) = \Psi(\xi, q)$ (for "particle-like" levels) [1].

The unreduced EP problem formulation (5) reveals the key property of *dynamic multivaluedness* (or *redundance*) of *any real* interaction process that remains hidden in the formally equivalent initial problem expression (1)–(4) and is artificially reduced in usual, perturbative theories (including conventional EP applications [19]). It is due to the self-consistent, *dynamically* nonlinear dependence of the unreduced EP (6) on eigen-solutions to be found that leads to dramatic increase of the maximum eigenvalue power in the characteristic equation and corresponding growth of the number of unreduced problem eigen-solutions with respect to their usual, "unique-solution" set [1–11]. The unique, incomplete solution of perturbative interpretations is replaced by *many* equally real, physically "complete" and therefore *mutually incompatible* solutions of the unreduced problem called (system) *realisations*, which are forced to *permanently replace each other* in a *dynamically random*, or *chaotic*, order thus defined. In addition to the above algebraic derivation of dynamic multivaluedness (confirmed by geometric analysis [1,10]), it can also be understood in terms of *transparent physical picture*, Figure 2, directly reflecting the key features of the unreduced EP expression (6). Measured system density $\rho(\xi, q) = |\Psi(\xi, q)|^2$ is obtained then as a *dynamically probabilistic* sum of all realisation densities, $\{\rho_r(\xi, q)\}$, where each r-th realisation is provided by the *dynamically derived, a priori* value of its emergence

probability α_r:

$$\rho\left(\xi,q\right)=\sum_{r=1}^{N_{\Re}}{}^{\oplus}\rho_r\left(\xi,q\right),\qquad \rho_r(\xi,q)=\left|\Psi_r(\xi,q)\right|^{\,2}\,, \tag{9}$$

$$\alpha_r\left(N_r\right)=\frac{N_r}{N_{\Re}}\quad\left(N_r=1,\ldots,N_{\Re};\ \sum_r N_r=N_{\Re}\right),\qquad \sum_r\alpha_r=1\ . \tag{10}$$

where $N_{\Re}$ is the total number of elementary realisations (equal to the number N of interacting protofield modes, $N_{\Re}=N$, see Figure 2), N_r is the number of elementary realisations within actually observed, "compound" r-th realisation, and the sign $\oplus$ serves to designate the special, dynamically probabilistic meaning of the sum derived above.

The dynamically probabilistic sum (9) over system realisations provides (together with its fractal extension (17)) a universal expression of the *complete general solution* to a problem, as opposed to its usual version of *compatible* eigenfunction *superposition* similar to (2) that does not contain any intrinsic, dynamically probabilistic change and is obtained as solution to a perturbative, "mean-field" problem approximation of the form

$$\left[h_0\left(\xi\right)+V_{nn}\left(\xi\right)+\tilde{V}_n\left(\xi\right)\right]\psi_n\left(\xi\right)=\eta_n\psi_n\left(\xi\right)\ ,$$

where $\left|V_0\left(\xi\right)\right|\leq\left|\tilde{V}_n\left(\xi\right)\right|\leq\left|\sum_{n'}V_{nn'}\left(\xi\right)\right|$. We deal here with the *dynamically single-valued*, or *unitary*, approximation or model of the *whole* conventional science that retains *only one*, averaged system realisation of their really existing multitude. The real complexity of the unreduced problem solution becomes evident by comparison of this kind of oversimplified unitary model with the corresponding unreduced EP and state-function expressions obtained by explicit substitution of the EP equation eigenvalues (equation (5)) into equations (6) and (8):

$$V_{\text{eff}}\left(\xi;\eta_i^r\right)\psi_{0i}^r\left(\xi\right)=V_{00}\left(\xi\right)\psi_{0i}^r\left(\xi\right)+\sum_{n,i'}\frac{V_{0n}\left(\xi\right)\psi_{ni'}^0\left(\xi\right)\int\limits_{\Omega_\xi}d\xi'\psi_{ni'}^{0*}\left(\xi'\right)V_{n0}\left(\xi'\right)\psi_{0i}^r\left(\xi'\right)}{\eta_i^r-\eta_{ni'}^0-\varepsilon_{n0}}\ , \tag{11}$$

$$\Psi_r\left(\xi,q\right)=\sum_i c_i^r\left[\psi_{0i}^r\left(\xi\right)\phi_0\left(q\right)+\sum_{n,i'}\frac{\psi_{ni'}^0\left(\xi\right)\phi_n\left(q\right)\int\limits_{\Omega_\xi}d\xi'\psi_{ni'}^{0*}\left(\xi'\right)V_{n0}\left(\xi'\right)\psi_{0i}^r\left(\xi'\right)}{\eta_i^r-\eta_{ni'}^0-\varepsilon_{n0}}\right]\ , \tag{12}$$

where the last state-function expression should be used in the probabilistic general solution (9).

The expressions for r-th realisation EP (11) and state-function (12) reveal the emerging realisation configuration characterised by autonomous *dynamical squeeze* of the protofield system. It is determined by the resonant denominators in combination with the cutting numerator integrals of the unreduced EP formalism, leading to r-th realisation "concentration" around a particular eigenvalue η_i^r, which can be interpreted as *dynamically* emerging *space point* and elementary particle core [1, 4, 7–9]. The eigenvalue separation $\Delta x=\Delta_r\eta_i^r$ for different r provides the elementary space distance between "point"-particles appearing to be close to the "barred" Compton wavelength $\lambda\!\!\!^{-}_{\mathrm{C}}=\lambda_{\mathrm{C}}/2\pi$, $\Delta x=\Delta_r\eta_i^r=\lambda\!\!\!^{-}_{\mathrm{C}}$, while eigenvalue separation for different i gives the size of the squeezed state determined, for the electron, by the "classical electron radius" r_e, $\Delta_i\eta_i^r=r_e$ (see section 1.3.4 for more details). As follows from equations (11)–(12), the dynamical squeeze has a self-consistent character demonstrating real "self-organisation" (structure formation) process and mechanism, where the more is state-function localisation in the emerging EP well, the deeper is that well around the state-function localisation centre. This rigorously derived property has a clear physical interpretation: a local density increase of

(sufficiently strongly) attracting protofields will grow until saturation, since the more is local protofield density the stronger is their local attraction and vice versa.

Dynamical protofield squeeze saturates at the point where protofield attraction is compensated by internal repulsion forces between the protofield elements (underlying final compressibility of every real medium). After that the self-amplifying system collapse, or "reduction", loses its force and the opposite protofield extension develops due to the same kind of instability related to protofield interaction at neighbouring locations. The system thus transiently returns to its initial, quasi-free state before falling into the next reduction phase involving another, randomly chosen realisation (physical "point"). We obtain thus the unceasing process of *quantum beat*, consisting of repeating cycles of reduction and extension around different, chaotically changing centres, which is equivalent to a dynamically random walk of the squeezed, corpuscular state called *virtual soliton* (as opposed to usual, *permanently* localised and regular solitons). Quantum beat process in the coupled protofield system thus obtained constitutes the *physically real structure* of any (massive) elementary particle called also *field-particle* in view of its permanent *dualistic* change between corpuscular (local) and undular (extended) system states [1, 4, 7, 8]. Note that a big change of configuration involves mainly e/m protofield due to its much larger compressibility (smaller effective density), whereas the relatively dense and (almost) incompressible gravitational medium-matrix shows much smaller external change of properties (similar to a liquid), which leads to essentially e/m origin of directly observed structures and properties.

The transient extended state of the field-particle provides the causal, physically real interpretation of the quantum-mechanical *wavefunction*, remaining otherwise completely mysterious and abstract in the unitary theory framework. The realistic wavefunction thus revealed constitutes a separate, specific system realisation called *intermediate, or main, realisation* and differing essentially from all other, localised, "regular" realisations. It is *explicitly obtained* within the unreduced EP formalism as a special solution with effectively weak, perturbative ("mean-field") interaction where essentially nonlinear additions to V_{00} in the general EP expression (11) are self-consistently small (contrary to the case of regular, localised realisations) [1,4,7]. That's why it is only the main, effectively linear and weak-interaction realisation that remains in the usual, dynamically single-valued theory, in quantum mechanics and beyond, whereas all regular, essentially nonlinear and strong-interaction realisations are neglected, which leads to the well-known "mysteries" and unsolved problems.

The *dynamically discrete*, or *quantised*, structure of the field-particle realisation change within the quantum beat process results from the *holistic*, self-consistent character of *unreduced* interaction, where any local component displacement entrains neighbouring component shifts and propagates thus to the whole system, including the initial perturbation point. The system can have therefore only a limited number of discrete, more stable, structure-forming configurations, while the "continuum" of other possible configurations plays the role of quickly changing intermediate phases during system transitions between those regular realisations (and the main realisation of the wavefunction). When the system is measured at the lowest, "quantum" complexity level, it can only be "caught" in one of its realisations, but not "between" them. Because of that quantum beat pulsation cannot be traced in detail, but it can be registered as a whole using e. g. a resonance effect, and recent electron channeling experiment [20] provides a clear evidence of that kind, confirming *quantum beat reality* (see also section 1.3.2).

Thus *dynamically derived* discreteness of the quantum beat process constitutes *causal, physically real* basis for all "quantisation"/"uncertainty" effects and properties (including Planck's constant origin and universality) [1, 4, 7, 8], which are postulated as unprovable "mysteries" in the usual theory (see also sections 1.3.4, 1.3.7). Dynamic discreteness should be distinguished from mechanistic, non-dynamical discreteness used in unitary simulation of quantised behaviour: the "steps" of dynamically discrete realisation change are *causally determined* by the *unreduced interaction* process and *cannot* be replaced by *arbitrary* values. At the lowest complexity level,

dynamic discreteness is represented by physically real *quantum jumps* of virtual soliton through a distance of $\Delta x = \Delta_r \eta_i^r = \lambda\!\!\!^{-}_{\rm C}$ for a field-particle globally at rest.

One obtains also causally specified *events* of protofield reduction and extension (realisation change) and with them the *emerging change* and *time*, although none of these were present in or inserted into initial system configuration and problem formulation (see equations (1)–(4)). Once the reduction-extension events are obtained in the unreduced EP formalism, time becomes dynamically determined as *intensity* (represented by *frequency*) of those structure formation processes. Specifically, quantum beat frequency is directly related to the above quantum jump length, $\Delta t = \Delta x/c = \lambda\!\!\!^{-}_{\rm C}/c = \tau = 1/\nu$, where c is the velocity of perturbation propagation in a *physically real* medium of e/m protofield coupled to the gravitational protofield, or the *speed of light* thus *causally* introduced, $\Delta t = \tau$ is the quantum beat period, and ν is its frequency. Quantum beat processes *within* each (massive) elementary particle represent thus the fundamental physical *clock* of the universe [1] whose "mechanism" is driven by unreduced interaction of two initially homogeneous protofields (where the interaction magnitude determines $\Delta x = \Delta_r \eta_i^r$ and thus $\Delta t = \Delta x/c$ according to equations (5)–(6)).

Note that we reveal here the fundamental, universal and physically real *origin of time* as such, constituting a stagnating problem of unitary science, despite a lot of most ambitious efforts. Physically real time we obtain has the main property of *unceasing* and *intrinsically irreversible* flow due to *permanent*, interaction-driven change of *multiple* realisations (absent in principle in any unitary theory) and *dynamically random* order of realisation emergence respectively. It is dynamically related to naturally quantised space structure described above. Both quantised space and irreversibly flowing time (see also section 1.3.1) have eventually emerging *multi-level* structure following that of the unreduced dynamic complexity (section 1.3.7).

The key property of dynamic multivaluedness of the unreduced interaction process is completed by equally important *dynamic entanglement* of interacting components (here protofields) within each emerging system realisation. It is described mathematically by dynamically weighted, "inseparable" products of functions depending on interacting degrees of freedom ξ and q in the total state-function expressions (8), (12). Taking into account realisation plurality, one obtains *dynamically multivalued entanglement* as the unreduced interaction content and meaning. Physically real protofield entanglement (whose magnitude varies for different particle species) constitutes tangible, "material" filling, or "texture", of the emerging field-particles determining their perceived material *quality*, which obtains thus its *rigorous* expression (contrary to purely *abstract*, "immaterial" quantities of unitary models).

Dynamically multivalued entanglement is further amplified by the *dynamically probabilistic fractality* of the unreduced problem solution [1, 4–6, 13] that extends essentially usual, dynamically single-valued fractality and gives rise to important system properties, such as *dynamic adaptability*. The unreduced fractality, specifying also the notions of *nonseparability* and *non-integrability* of any real interaction, originates from the truncated system (7) whose solutions enter the unreduced EP expressions (6), (8), (11, (12) of the first level. Applying *universal* EP method to the truncated system (7), one obtains its effective, externally "separated" version:

$$\left[h_{\rm g}\left(\xi\right) + V_{\rm eff}^{n}\left(\xi;\eta_n\right)\right]\psi_n\left(\xi\right) = \eta_n \psi_n\left(\xi\right) \ , \tag{13}$$

where the second-level EP $V_{\rm eff}^{n}\left(\xi;\eta_n\right)$ is similar to its first-level version (6):

$$V_{\rm eff}^{n}\left(\xi;\eta_n\right)\psi_n\left(\xi\right) = V_{nn}\left(\xi\right)\psi_n\left(\xi\right) + \sum_{n'\neq n,i} \frac{V_{nn'}\left(\xi\right)\psi_{n'i}^{0n}\left(\xi\right)\int\limits_{\Omega_\xi} d\xi' \psi_{n'i}^{0n*}\left(\xi'\right) V_{n'n}\left(\xi'\right)\psi_n\left(\xi'\right)}{\eta_n - \eta_{n'i}^{0n} + \varepsilon_{n0} - \varepsilon_{n'0}} \ , \tag{14}$$

and $\left\{\psi_{n'i}^{0n}\left(\xi\right), \eta_{n'i}^{0n}\right\}$ is the complete eigen-solution set of a second-level truncated system:

$$h_{\rm g}\left(\xi\right)\psi_{n'}\left(\xi\right) + \sum_{n''\neq n'} V_{n'n''}\left(\xi\right)\psi_{n''}\left(\xi\right) = \eta_{n'}\psi_{n'}\left(\xi\right) \ , \quad n' \neq n \ , \quad n, n' \neq 0 \ . \tag{15}$$

Similar to dynamic multivaluedness of the first-level EP, its second-level version is split into many incompatible realisations (numbered by index r') due to the self-consistent dependence on the eigen-solutions to be found, leading to corresponding splitting of system (7) solutions:

$$\left\{ \psi_{ni}^{0}\left(\xi \right) ,\eta_{ni}^{0}\right\} \rightarrow \left\{ \psi_{ni}^{0r'}\left(\xi \right) ,\eta_{ni}^{0r'}\right\} \ . \tag{16}$$

Substituting now those dynamically split solutions of truncated system (7) into the first-level EP expressions (6), (8), (11, (12), one gets a two-level structure with dynamic multivaluedness, and thus randomness, at *each* level. As the process of finding the truly complete problem solution continues, one obtains further splitting of solutions of the second-level truncated system (15) that gives the third level of emerging probabilistic fractal and so on, until one gets all N levels of dynamically probabilistic fractality ($N \gg 1$ is the number of interacting e/m protofield modes). The *complete general solution* of the unreduced interaction problem (9) can now be further specified in the form of *dynamically probabilistic fractal*:

$$\rho \left(\xi ,q\right) = \sum_{r,r',r''...}^{N_{\Re }} {}^{\oplus }\rho_{rr'r''...}\left(\xi ,q\right) \ , \tag{17}$$

where indexes $r,r',r'',\ldots$ enumerate obtained realisations at consecutive levels of dynamically probabilistic fractality. The average, *expectation* value of the dynamically probabilistic fractal density (valid for long enough observation time) is obtained as

$$\rho \left(\xi ,q\right) = \sum_{r,r',r''...}^{N_{\Re }} \alpha_{rr'r''...}\rho_{rr'r''...}\left(\xi ,q\right) \ , \tag{18}$$

where $\{\alpha_{rr'r''...}\}$ are *dynamically determined probabilities* for the respective levels of dynamical fractal (cf. equation (10)):

$$\alpha_{rr'r''...} = \frac{N_{rr'r''...}}{N_{\Re }} \ , \quad \sum_{rr'r''...} \alpha_{rr'r''...} = 1 \ . \tag{19}$$

The obtained dynamically probabilistic fractal of the unreduced general solution (17) is essentially different from any unitary "perturbative expansion series", since any term and level of the dynamically probabilistic sum (17) expresses the exact, really existing object structure. The whole unitary solution approximately corresponds, in the best case, to a single term of the dynamically probabilistic sum. Major physical consequence of the obtained multivalued extension of usual, dynamically single-valued fractality is the property of *interactive dynamic adaptability* of the unreduced system structure which can *autonomously* adapt to the changing interaction configuration and efficiently find its "way" for the most complete interaction process development due to *permanent* chaotic, "searching" motion of multivalued fractal branches on all scales (giving a "living arborescence" kind of structure). The multi-level, multivalued fractal structure of dynamic entanglement of interacting entities provides a *physically real* version and true meaning of mathematical "nonseparability" of a real (generic) interaction process, while *transient* component separation (disentanglement) happens locally all the time, during system transition between realisations (in the phase of thus *quasi-linear* wavefunction).

Finally, we can now provide the *causally complete* and *universally applicable* definition of the main physical quantity of *(dynamic) complexity*, C, as a growing function of the total number, $N_{\Re }$, of (explicitly obtained) system realisations, or rate of their change, equal to zero for the (unrealistic) case of only one system realisation:

$$C = C(N_{\Re }) \ , \quad dC/dN_{\Re } > 0 \ , \quad C(1) = 0 \ . \tag{20}$$

Suitable examples are provided by $C\left(N_{\Re}\right) = C_0 \ln N_{\Re}$, $C\left(N_{\Re}\right) = C_0\left(N_{\Re} - 1\right)$, generalised action and entropy, generalised energy/mass (temporal rate of realisation change), and momentum (spatial rate of realisation emergence) [1,4,7,13] (see also sections 1.2, 1.3). As any real system, object, or phenomenon results from an interaction process with at least few components and interacting modes, it becomes clear that *any real entity*, starting from (massive) elementary particle like the electron, has a strictly *positive* dynamic complexity (and actually a great realisation number, $N_{\Re} \gg 1$). Since dynamic multivaluedness ($N_{\Re} > 1$) constitutes the basis of genuine, intrinsic *chaoticity* (dynamic randomness), it is evident that dynamic complexity thus defined *includes* chaoticity as its major content and aspect (we shall see in the next section that chaoticity is represented directly by one of the two complexity forms, *dynamic entropy*). It is evident also that the whole unitary, dynamically single-valued science and paradigm ($N_{\Re} = 1,\ C = 0$), including its versions of "complexity" and "chaoticity", consider exclusively over-simplified, zero-complexity, zero-chaoticity (regular) models of real world dynamics equivalent to its effectively zero-dimensional (point-like) projection (which is sometimes mechanistically extended to one-dimensional projection, using a formally imposed time variable). Therefore unitary definitions of e. g. "chaoticity" by exponential divergence of close trajectories or infinitely long motion period (let alone the totally lost case of quantum chaos) describe at best "sophisticated", "chaotically looking" regularity cases devoid of any genuine, dynamic randomness and complexity (internal inconsistency of those unitary definitions using e. g. incorrect extension of perturbative approximation is a separate issue considered elsewhere [1]).

1.2 Universal symmetry and transformation of complexity

As the full number of system realisations $N_{\Re}$ determining its total complexity $C(N_{\Re})$ (see equation (20)) depends only on the initial system configuration (e. g. the number N of interacting protofield modes, $N_{\Re} = N$, see Figure 2), the *total system complexity remains unchanged* during interaction development, $C = \text{const},\ \Delta C = 0$ [1, 2, 4–9, 13]. This *universal complexity conservation law* constitutes both the result and the origin of unreduced interaction, underlying thus any real structure emergence and existence. In this sense it is equivalent to a universal symmetry of nature called the *symmetry of complexity*: contrary to unitary conservation laws, in the universal science of complexity, describing *explicit* (and unceasing) *structure emergence*, there is no difference between complexity *conservation law* and resulting structure *symmetry*.

A straightforward, "horizontal" manifestation of the universal symmetry of complexity is the symmetry between all (elementary) system realisations at a given complexity level: they are equal by their origin and therefore taken by the system in a *causally random* order (section 1.1), so that (true) randomness *results* from the symmetry of complexity. The latter is uniquely and completely realised by the system *motion dynamics* (realisation change process), rather than any formal "operators" transforming one abstract structure into another (unitary symmetry concept). Always *exact* (unbroken) symmetry between *irregularly structured* and *chaotically* changing elementary realisations leads, in particular, to unequal but *well-defined* probabilities of compound realisations (10) containing different numbers of elementary realisations.

There is a more involved, "vertical" manifestation of complexity symmetry concerning interaction process development with multiple *levels of complexity*. Indeed, emerging system structures (grouped realisations) start interacting among them and produce multivalued structure of the next level, and so on. Every such *qualitative* change of system configuration (also in each transition between realisations) corresponds to *complexity transformation*, or development, or unfolding, from the *permanently decreasing* potential, latent form of *dynamic information* I to the *always increasing* realised, explicit form of *dynamic entropy* S, whereas their sum, the *total dynamic complexity* $C = I + S$, remains unchanged: $\Delta C = 0,\ \Delta I = -\Delta S < 0$ [1,2,4–7,9,13]. This permanent complexity transformation from dynamic information to entropy underlies any inter-

action process and therefore complexity *symmetry (conservation)* can be realised only through a *qualitative change* of its form, determining system dynamics.

In order to derive a unified expression of this relation, we first specify a *universal integral measure of dynamic complexity* in the form of (generalised) *action* $\mathcal{A}$ as the simplest function, whose increment $\Delta\mathcal{A}$ is simultaneously and independently proportional to both emerging elements of space Δx and time Δt obtained above (section 1.1) as universal manifestations of realisation change process (= unreduced interaction development): $\Delta\mathcal{A} = -E\Delta t + p\Delta x$, where E and p are coefficients immediately recognised, however, as *energy* and *momentum* by comparison to classical mechanics. Their generalised, universal definitions in terms of complexity-action are obtained in their *dynamically discrete* (quantised) form:

$$E = -\frac{\Delta\mathcal{A}}{\Delta t}\,|_{x=\text{const}} \ , \tag{21}$$

$$p = \frac{\Delta\mathcal{A}}{\Delta x}\,|_{t=\text{const}} \ , \tag{22}$$

where energy and momentum acquire the new, *universal* meaning of differential *complexity measures* (energy is the temporal and momentum spatial rate of complexity transformation from dynamic information to entropy). Dynamic discreteness of system jumps between realisations is eventually due to the *holistic* character of *real*, unreduced interaction process and leads to the causal (dynamic) and universal version of "(quantum) *uncertainty relations*", if we just rewrite the above energy and momentum definitions as $p\Delta x = |\Delta\mathcal{A}|$ and $E\Delta t = |\Delta\mathcal{A}|$ [1].

As both dynamic information and complexity-action can only *decrease* in any interaction development (cf. equation (21)), generalised action expresses more directly just informational, potential form of complexity, $I = \mathcal{A}$, whereas its dual form of dynamic entropy is measured in the same units but expresses the opposite in sign, always positive, complexity increment:

$$\Delta S = -\Delta I > 0 \ , \quad \Delta\mathcal{A} = -\Delta S \ . \tag{23}$$

The last unified expression of conservation and transformation of complexity leads to the universal dynamic equation if we divide it by $\Delta t\,|_{x=\text{const}}$ [1, 2, 4, 7, 9, 13]:

$$\frac{\Delta\mathcal{A}}{\Delta t}\,|_{x=\text{const}} + H\left(x, \frac{\Delta\mathcal{A}}{\Delta x}\,|_{t=\text{const}}, t\right) = 0 \ , \tag{24}$$

where the *Hamiltonian*, $H = H(x, p, t)$, considered as a function of emerging space-structure coordinate x, momentum $p = (\Delta\mathcal{A}/\Delta x)\,|_{t=\text{const}}$ (see equation (22)), and time t, expresses the implemented, entropy-like form of differential complexity, $H = (\Delta S/\Delta t)\,|_{x=\text{const}}$. The obtained generalised, *universal Hamilton-Jacobi equation* (24) realises the desired dynamic expression of the symmetry of complexity and takes a yet simpler form for conservative systems where the generalised Hamiltonian does not depend explicitly on time:

$$H\left(x, \frac{\Delta\mathcal{A}}{\Delta x}\,|_{t=\text{const}}\right) = E \ , \tag{25}$$

with the generalised energy E defined by equation (21). Note that action distribution $\mathcal{A}(x, t)$ corresponds to the above state-function $\Psi(x, t)$ (see equations (8), (12)) for regular, localised realisations.

The unified differential expression of the symmetry of complexity by equations (24)–(25) would be incomplete without explicit expression of the related complexity *transformation* and its *direction* (from dynamic information to entropy). Due to *unceasing* realisation emergence in a *causally random* order, system information-complexity $I = \mathcal{A}$ can only *decrease*, which means

that not only its partial (discrete) derivative $(-E)$, but also total derivative, or (generalised) *Lagrangian* L, is negative:

$$L = \frac{\Delta \mathcal{A}}{\Delta t} = \frac{\Delta \mathcal{A}}{\Delta t} \mid_{x=\text{const}} + \frac{\Delta \mathcal{A}}{\Delta x} \mid_{t=\text{const}} \frac{\Delta x}{\Delta t} = pv - H < 0 \ , \tag{26}$$

$$E, H \left(x, \frac{\Delta \mathcal{A}}{\Delta x} \mid_{t=\text{const}}, t \right) > pv \geq 0 \ , \tag{27}$$

where $v = \Delta x / \Delta t$ is the velocity of global, averaged system motion (i.e. its motion as a whole). In agreement with the above dynamic origin of time, this dynamic expression of complexity transformation (within its symmetry), or *dynamically generalised second law* ("energy degradation"), equation (27), provides also a rigorous, fundamentally derived expression of the *arrow of time* [2, 4, 7, 9]: since $\Delta \mathcal{A} < 0$, time advances, $\Delta t > 0$, in the direction of growing (dynamic) entropy S and decreasing information $\mathcal{A}$ (i.e. $L < 0$). We see that our dynamically based symmetry of complexity includes the origin of time and causally derived direction of its unceasing flow in the form of interaction complexity development. In fact, dynamic *time origin* and irreversible flow, permanent *growth* of unreduced dynamic complexity-entropy (at the expense of decreasing dynamic complexity-information), and *conservation* of the total dynamic complexity are obtained as *closely unified* manifestations of the *single*, holistic symmetry of complexity.

The universal Hamilton-Jacobi equation (24)–(25) remains naturally valid for the case of elementary field-particle dynamics (section 1.1), but takes into account its unreduced complexity (multivaluedness). The latter includes causally explained *quantum duality*, where the localised, corpuscular states of quantum beat process alternate with extended, undular protofield configuration in the phase of *wavefunction* (intermediate realisation). Correspondingly, the above "classical", corpuscular expression of the Hamilton-Jacobi formalism should have its dual counterpart in the form of explicit undular equation for the wavefunction. It can be obtained with the help of *causal quantisation* procedure that describes just those spatially chaotic transitions between regular (localised) realisations through the extended wavefunction realisation and involves dynamic complexity conservation [1, 2, 4, 7–9, 13]. Hierarchical structure of multilevel complexity development implies that the total complexity of several neighbouring levels is equal to the product of individual level complexities. Since quantum beat process can be considered as cyclic transitions between neighbouring complexity sublevels of localised realisations and wavefunction, its total complexity C is given by the product of localised realisation complexity $\mathcal{A}$ and that of the intermediate realisation expressed by the wavefunction Ψ, $C = \mathcal{A}\Psi$. According to complexity conservation, $\Delta C = \Delta(\mathcal{A}\Psi) = \mathcal{A}\Delta\Psi + \Psi\Delta\mathcal{A} = 0$, or

$$\Delta \mathcal{A} = -\mathcal{A}_0 \frac{\Delta \Psi}{\Psi} = -i\hbar \frac{\Delta \Psi}{\Psi} \ , \tag{28}$$

where $\mathcal{A}_0 = i\hbar$ is a characteristic complexity-action value that may contain also a numerical constant reflecting specific features of the two considered complexity sublevels (imaginary unit i in this case) and $\hbar = h/2\pi$ is Planck's constant.

Note that the above complexity conservation of the quantum beat process reflects the physically transparent fact of system return to the *same* wavefunction state after each beat cycle. Causal quantisation (28) expresses thus the detailed complex-dynamic realisation change, or causally specified "quantum jumps", of the quantum beat process within the elementary field-particle accounting also for its intrinsic "quantum uncertainty" (the corresponding uncertainty and quantisation relations are only formally postulated in the conventional quantum mechanics and its unitary modifications describing physically real particles by purely abstract "state vectors"). Using relation (28) in the Hamilton-Jacobi equation (24), we obtain the *causally derived Schrödinger equation* for the *realistically interpreted* wavefunction:

$$i\hbar \frac{\partial \Psi}{\partial t} = \hat{H} \left(x, \frac{\partial}{\partial x}, t \right) \Psi (x, t) \ , \tag{29}$$

where the Hamiltonian operator, $\hat{H}\left(x, \frac{\partial}{\partial x}, t\right)$, is obtained from the Hamiltonian function $H = H(x, p, t)$ of equation (24) by the same causal quantization (28) and we have used the continuous derivative notations for brevity. The famous Schrödinger equation containing, in usual theory, the whole series of inexplicable "quantum mysteries" excluding any realistic physics is obtained now as a *totally causal* consequence of the universal symmetry of complexity [1, 4, 7, 8].

The *universal* version of Schrödinger equation applicable at *any* complexity level is obtained by the same causal quantisation of the Hamilton-Jacobi equation:

$$\mathcal{A}_0 \frac{\Delta\Psi}{\Delta t} \mid_{x=\text{const}} = \hat{H}\left(x, \frac{\Delta}{\Delta x} \mid_{t=\text{const}}, t\right) \Psi(x,t) \ , \tag{30}$$

where x designates the corresponding dynamically derived system configuration (section 1.1) and the generalised wavefunction, or distribution function, $\Psi(x,t)$ describes intermediate realisation state. The dynamically derived Schrödinger equation (29)–(30) is accompanied by the generalised, *causally obtained Born rule* for realisation probabilities $\{\alpha_r\}$ in terms of the wavefunction, completing the dynamic origin of probabilities in terms of regular (localised) realisations (10):

$$\alpha_r = |\Psi(x_r)|^2 \ , \tag{31}$$

where x_r is the r-th realisation configuration and one may have the value of the generalised distribution function itself at the right-hand side for higher, particle-like complexity levels. The generalised Born rule, extending the corresponding formal postulate of usual quantum mechanics, is valid for any interaction dynamics at any level of complexity and results from the dynamic matching conditions between regular realisations and intermediate realisation of the wavefunction, giving the values of coefficients c_i^r in the state-function expression (8), (12) [1, 4]. This mathematical procedure has a transparent physical origin in the quantum beat dynamics and the underlying symmetry of complexity: as the localised, "corpuscular" realisations emerge by a direct, interaction-driven dynamical squeeze of the extended wavefunction realisation to one of redundant reduction centres, the probability of centre selection will be proportional to the *physically real* wavefunction magnitude at the corresponding location. The symmetry of complexity underlies here the matching condition itself by the evident demand of *continuity* of complexity transformation in the realisation change process.

Note that the *dynamic* rules for realisation probabilities (10), (19), (31) accompanied by their *dynamically fractal* structure (section 1.1) describe their "spontaneous", unreduced, but *interaction-driven, purposeful, "reasonable"* emergence, which underlies the important property of *dynamic (probabilistic) adaptability* of real interaction processes [1, 4]: the system "automatically" goes everywhere it can and chooses the best possible way for its complexity development by a natural "competition" of dynamically produced possibilities. That *dynamically probabilistic* complexity development from dynamic information to entropy constitutes thus the rigorously defined system *purpose* and *teleological* power/property of universal symmetry of complexity.

Equations (24)–(31) form the basis of the *universal Hamilton-Schrödinger formalism* that unifies extended versions of *all* particular (correct) dynamic equations postulated in various fields of unitary theory (whereas the underlying symmetry of complexity unifies causally extended versions of all usual, postulated laws and "principles" [1]). It can be demonstrated by Hamiltonian expansion in a power series of momentum and action, which leads to the following form of universal Schrödinger equation (30) [1, 2, 4, 13]

$$\frac{\Delta\Psi}{\Delta t} \mid_{x=\text{const}} + \sum_{\substack{m=0 \\ n=1}}^{\infty} h_{mn}(x,t) \left[\Psi(x,t)\right]^m \frac{\Delta^n \Psi}{\Delta x^n} \mid_{t=\text{const}} = 0 \ , \tag{32}$$

where the expansion coefficients $h_{mn}(x,t)$ can be arbitrary functions and we have taken into account additional Hamiltonian dependence on action (or wavefunction) through the "potential

energy" and more generally due to the dynamically nonlinear EP dependence on the problem solutions (see equations (6), (11), (14) in section 1.1). It is important that all dynamic equations should be provided, within the universal science of complexity, with the unreduced, *dynamically multivalued* and probabilistic general solution (17)–(19), as opposed to dynamically single-valued solutions of usual theory. The causally derived Hamiltonian form of the universal formalism provides also decisive confirmation of the starting existence equations (1), (4), thus closing the underlying self-consistent cycle of the symmetry of complexity.

We see that various linear and "nonlinear" models and equations, which are often just semi-empirically "guessed" and postulated in the unitary theory, are obtained in reality as truncated versions of a general power series of equation (32) (or a similar expansion for the Hamilton-Jacobi equation (24)) and can therefore be considered as (reduced) consequences of the single, *unified* law, the symmetry of complexity. We can also clearly see the difference between the imitative unitary "nonlinearity" due to formal higher powers of a truncated expansion series and the genuine, *dynamically* emerging, *essential nonlinearity* due to the unreduced EP dependence of the solutions to be found. Contrary to popular confusion of usual "science of complexity", the former, imitative "nonlinearity" *cannot* provide any true complexity and chaoticity by itself, without the proper, unreduced analysis of a real interaction process revealing the dynamically probabilistic fractal of the complete general solution. That usual nonlinearity resembles an artificially, trickily entangled one-dimensional thread that can, however, be completely disentangled and does not change its basic properties upon any smooth change of configuration. Since, on the other hand, essential nonlinearity emerges even for formally "linear" initial problem formulation (section 1.1), one can assume that *any* usual, formal "nonlinearity" is but a reduced representation of genuine, dynamic nonlinearity of real interaction process.

As noted above, the symmetry of complexity unifies *causally extended*, universally applicable versions of various *separated*, individually *postulated* laws and "principles" of usual fundamental science, such as conservation of energy (or "first law of thermodynamics"), entropy growth ("second law of thermodynamics"), all "quantum" and "relativistic" postulates and principles (see section 1.3.7). Many of them are related to the corresponding unitary, abstract symmetries which, besides being separated among them, appear to be practically always "broken" by the full-scale, real-world dynamics reducing them to a status of unrealistic, "approximate", and therefore *false* symmetry that can be "more or less" valid only within a limited, ambiguously defined parameter range. Indeed, the evident irregularity of real-world structures and dynamics is basically different from the "too symmetric", regular and smooth structures of the unitary, abstract science paradigm. The universal symmetry of complexity solves the problems of separation, violation and excessive regularity of usual symmetries by proposing not only *intrinsically unified*, but also *always exact, unbroken* symmetry describing real-world irregularity by its own, *dynamic randomness* (due to chaotic transitions between asymmetric realisations). Therefore now *all* real-world structures (described by essentially random general solution of probabilistic dynamical fractal (17)–(19)) are explicitly obtained as *absolutely symmetric* results of complexity conservation and development supported by the *totality of existing observations*.

An important general manifestation of the universal symmetry of complexity takes the form of *complexity correspondence principle* that can have various particular formulations, but always emphasises the fact that any interaction result depends critically and totally upon relative complexities of interacting entities [1, 4, 13]. Specifically, interaction between several (complex) systems can be "efficient" (induce essential changes) only for interacting systems of comparable complexity. Moreover, the system with higher complexity tends to "control", or "enslave", less complex interaction partners, which gives rise to *complex-dynamic control theory* that unifies and extends essentially usual, unitary control concepts by showing, in particular, that any real control result and mechanism are *basically chaotic* and can never be absolute. If interacting system complexities are very close to each other, a strong, "global" chaos regime can result.

All particular cases of real (complex) interaction dynamics can be conveniently classified and unified in a single scheme and criterion of unreduced interaction results [1, 3, 4, 10, 11, 13]. If the key interaction parameters (properly represented by characteristic frequencies) are close enough to each other, one obtains the limiting case of *uniform, or global, chaos* with rapidly changing, essentially different system realisations and homogeneous distribution of their probabilities. If the characteristic system parameters are essentially different, one gets the opposite limiting case of generalised, *dynamically multivalued self-organisation, or self-organised criticality (SOC)*, that unifies, besides those two concepts, the extended versions of other cases, such as synchronisation, control of chaos, mode locking, and fractality (they remain separated in their unitary, dynamically single-valued versions). It contains a small number of rarely changing "compound" realisations that confine, however, a multitude of rapidly and chaotically changing but externally similar "elementary" realisations within them. The almost total *external* regularity of ultimate SOC cases passes gradually (though unevenly) to the maximum irregularity of global chaos with the corresponding change of characteristic frequency ratio, so that one can describe and classify, in principle, *all* possible dynamic regimes in any kind of system.

Specifically, the point of transition to the strong, uniform chaos is expressed by the *universal criterion of global chaos onset*:

$$\kappa \equiv \frac{\Delta\eta_i}{\Delta\eta_n} = \frac{\omega_\xi}{\omega_q} \cong 1 \ , \tag{33}$$

where κ is the introduced *chaoticity* parameter, while $\Delta\eta_i$, ω_ξ and $\Delta\eta_n \sim \Delta\varepsilon$, ω_q are energy-level separations and frequencies for inter-component and intra-component motions, respectively. At $\kappa \ll 1$ one has an externally regular multivalued SOC regime, which degenerates into global chaos as κ grows from 0 to 1, and maximum irregularity at $\kappa \approx 1$ is again transformed into a SOC kind of structure (but with a "reversed" configuration) at $\kappa \gg 1$.

Using this universal chaos criterion, it is easy to see, in particular, the dynamic origin of *fundamental quantum randomness*, or "indeterminacy", appearing in the form of *inevitably* strong (global) chaoticity of protofield interaction process at those *lowest*, "quantum" levels of the world structure complexity. Indeed, the characteristic frequencies, or eigenvalue separations, at the lowest complexity sublevels containing only elementary structures (field-particles) coincide par excellence as other, essentially different system parameters "have not yet appeared" in that *essentially quantum* reality (their definite appearance marks the emergence of the next complexity level of elementary *classical, permanently localised* structures with a much more regular, SOC kind of dynamics [1, 4, 7–9], see also section 1.3.8). Specifically, the quantum beat frequency determines both internal field-particle dynamics and its "external" motion and interactions. A higher sublevel of quantum complexity, that of *(true) quantum chaos* and *(causal) quantum measurement* (section 1.3.8) [1, 4, 10], already contains a possibility of somewhat more regular, SOC kind of dynamics that further passes to a yet more regular case of classical behaviour.

1.3 Universe and particle properties by the symmetry of complexity

Using *only* the unreduced, universally nonperturbative analysis of sufficiently strong attractive interaction of two physically real, initially homogeneous protofields, we have shown above, in section 1.1, that the elementary field-particle will generically emerge from that interaction (for suitably chosen but non-exotic protofield "material"), in the form of *spatially chaotic* process of *quantum beat* that can be described as *unceasing* cycles of protofield reduction-extension or, alternatively, as *chaotic wandering* of the transient corpuscular state of *virtual soliton*. The resulting, dynamically multivalued, intrinsically *unified* and totally *causal* (realistic) picture of microworld dynamics is called *quantum field mechanics* [1, 4, 7–9], as opposed to various irreducibly *separated* branches of *unrealistic (abstract)* and largely *postulated* (formally imposed)

unitary, dynamically single-valued theory, such as quantum mechanics, field theory, particle (high-energy) physics, special and general relativity, and cosmology, including their recent, "advanced" versions that always remain, however, within the same, effectively *zero-dimensional projection* of reality (e. g. "many-world", "histories", and other abstract "interpretations" of quantum mechanics, string and spin-network schemes of modern field theory, brane-world imitations, innumerable "cosmological" tricks with "hidden" material species, dimensions and whole "multi-verses", etc.). The *universal symmetry of complexity* (section 1.2) totally determines the unreduced interaction development, and we shall continue to derive further emerging world structures and their properties, demonstrating the power of the symmetry of complexity to avoid and solve the accumulating problems of unitary theory and its simplified, regular symmetries.

1.3.1 Dynamic origin of 3D space, time, and elementary particles: Occam's razor

We begin our analysis of the causal, physically real, explicitly emerging, and *always exactly symmetric* world structure with recalling the dynamic origin of the naturally quantised, *tangible space structure* and *irreversibly flowing but immaterial time* obtained above (section 1.1) from the protofield interaction description as, respectively, *eigenvalue separation*, $\Delta x = \Delta_r \eta_i^r = \lambda\!\!\!^{-}_{\rm C}$, of effective existence equation (5) and *intensity* (specified as *frequency*, ν) of quantum beat realisation emergence/change, $\Delta t = \Delta x/c = \lambda\!\!\!^{-}_{\rm C}/c = \tau = 1/\nu$. The space "coordinate" x expresses, in general, *configuration* of *explicitly emerging* system realisation (in the form of localised virtual soliton), while "time flow" (permanently growing t) reflects inevitable *change* of *multiple* and *incompatible* realisations. Space and time appear thus as universal, *basic manifestations* of unreduced interaction complexity and its symmetry/transformation, *together* with the *system structure and dynamics* itself (represented here by an elementary field-particle, such as the electron, with the *dynamically determined size* $\Delta_i \eta_i^r = r_e$, performing its *quantum jumps* to the distance $\Delta x = \Delta_r \eta_i^r = \lambda\!\!\!^{-}_{\rm C}$ with the period of $\Delta t = \Delta x/c$, see sections 1.1 and 1.3.4).

Unitary space-time symmetries are strongly *broken* (and therefore *illusive*) by *dynamic discreteness* (quantisation) of space and irreversible, *oriented flow* (increase) of time variable in a well-defined direction of growing complexity-entropy (see equation (27)), whereas the symmetry of complexity just underlies and *gives rise* to those properties of space and time, remaining absolutely *exact* symmetry. That fundamental violation of irreducible "smoothness" (regularity) of unitary projections will continue and involve higher complexity levels and symmetries, e. g. those from theories of relativity, gravity, and cosmology (see sections 1.3.5, 1.3.7, 2). In particular, any *direct mixture* between space and time entities within a single symmetry (constituting the basis of conventional relativity) is physically *senseless*, already because of tangible, material structure of real space and immaterial time origin: real space and time are related *by and only by the system dynamics*, which is none other than *direct realisation* of the *symmetry of complexity*.

The same interaction-based origin of physically real space and time shows that time cannot be "curved", or deformed, in any sense at all, while space emerges as a globally (in average) flat and homogeneous structure, in agreement with observations and contrary to the corresponding unitary theories (general relativity and cosmology). Moreover, any space inhomogeneity emerging at a higher complexity level is an average density/tension modification of protofields (see also section 1.3.7) that can only formally (and very approximately) be described "geometrically", similar to any other long-range interaction through a (dense enough) continuous medium.

The symmetry of complexity directly determines also the observed *number (three) of space dimensions* and establishes its *universal physical origin* and link to the *interactive* base of *any* real world. Indeed, the initial interaction configuration includes *three* and only three *global* entities, the two protofields and their physically real coupling (interaction) itself (Figure 1). The symmetry of complexity tells us that the number of equally global entities resulting from that interaction should be the same, i.e. equal to three. But the only resulting entity of the

truly *global* scale is the fundamental *space* structure itself, which *should* therefore have *three and only three modes, or "dimensions"*, according to complexity conservation law rigorously substantiated and supported by the totality of all experimental observations [1]. We obtain thus also the genuine, *physical origin* of those space "dimensions" as such, remaining only empirically and formally defined in usual science. As the tangible space "material" is obtained by dynamically multivalued *entanglement* of global interaction partners, the protofields (see section 1.1), its *global degrees of freedom*, or "dimensions", are none other than *physically real*, equivalent "modes", or realisations, of that *complex-dynamic mixture* of interacting e/m and gravitational protofields (including the coupling interaction itself).

The obtained rule for the number of space dimensions and their physical origin is valid for any other system, including higher levels of universe space structure and other possible universes. In particular, the number of (global) space dimensions of arbitrary universe is equal to the number of initial interaction components (including coupling entities). Depending on the driving interaction details, further split into inhomogeneously structured "compound" dimensions is possible, with a three-dimensional space "unity" remaining the "minimal", most stable combination (because one *cannot* have less than two interaction components). Although various complicated cases are possible, the symmetry of complexity provides a realistic and efficient ordering and understanding principle, as opposed to arbitrary unitary guesses on the subject based on the "demands" of a purely abstract, *postulated* formalism that eventually appears to be but an effectively zero-dimensional projection of any real-world structure. Thus, according to the symmetry of complexity, higher-dimensional universes appear from *higher-complexity interactions* as a sort of "excited states" over the exceptionally stable (and therefore most common, if not unique) "ground state" of three-dimensional world. The latter may have *only one* irreversibly flowing *time*, which may also be true for any *unified* higher-dimensional world. But a more complicated substructure of global space dimensions can give rise to multiple time flows in a higher-dimensional world that would realise a much higher, "excited-state" complexity of such "multi-time" world [1]. Despite "purely theoretical" character of those possibilities, one can easily have "higher-dimensional" and "multi-time" situations with *local* realisation structure at *higher levels* of complexity, space and time of the present, *globally* three-dimensional world.

We shall see below (section 1.3.3) that the number of fundamental interaction forces (and particle species) enters into the same physically transparent manifestation of the symmetry of complexity, leading to considerable reduction of the (practically unlimited) number of *formal* possibilities of unitary theory, such as "hidden" dimensions and other strangely "invisible" entities. It becomes clear that space and its dimensions have a *physically real* origin in a global *interaction process* and therefore should *not* be introduced artificially, by *ad hoc* assumptions in order to save a contradictory imitation of reality, as it is done in the unitary theory. The symmetry of complexity provides, in this sense, the *rigorous* and *practically efficient* extension of the well-known *Occam's razor, or principle of parsimony*, as it specifies *how exactly* each real, observed entity emerges in an *interaction process* from other, equally real entities, which provides a reliable way of their specification [1]. One obtains also a *realistic* extension of *Gödel incompleteness* theory, where any interaction result "incompleteness" is due to its intrinsic uncertainty (multivaluedness) and (partially unknown) interaction components.

1.3.2 Universal dynamic origin of particle mass, charge, and spin

Since the first-level world structures, elementary field-particles, emerge together with physically real space and time (see Figure 1), the same complex-dynamic process of quantum beat should give rise to the "intrinsic" particle properties, such as mass, electric charge, spin, and their observed features. We start with the major property of *mass* and can state that its key feature of *inertia* is universally and consistently explained by the *dynamically chaotic* character of the

spatial wandering of virtual soliton within any (massive) field-particle (quantum beat process), *rigorously* obtained above (section 1.1). Indeed, it is this *already existing*, never vanishing *internal* motion of the particle "matter" that determines its "resistance" to any external *force* (attempt to *change* it) and ensures *finite* values of acquired *acceleration*. It is evident that anything different from *purely dynamic, internal* chaoticity *cannot* solve the problem of *intrinsic* inertia in principle, including any external influence (e. g. of "zero-point field" fluctuations) often arbitrarily assumed in the unitary theory. Moreover, we show that inertial mass thus *dynamically emerging* in the unreduced protofield interaction is synonymous, or "equivalent" (up to a coefficient or measurement unit), to the total, "relativistic" *energy* and expresses therefore a differential form of system *complexity* (see equation (21)) [1, 4, 7–9]. Following universal definitions of complexity-action, energy and momentum (21), (22) in section 1.2, we obtain for the field-particle *at rest* ($p = 0$): $\Delta\mathcal{A} = -E_0\Delta t$ and

$$E_0 = -\frac{\Delta\mathcal{A}}{\Delta t} = \frac{h}{\tau_0} = h\nu_0 = m_0c^2 \ , \tag{34}$$

where E_0 is the particle *rest energy*, $\Delta\mathcal{A} = -h$ is the *dynamically discrete* complexity-action increment equal at this *first* complexity level to *universal* Planck's constant h with the negative sign (since $E_0, \Delta t > 0$), τ_0 is the quantum beat period and ν_0 frequency for the field-particle at rest, m_0 is the particle *rest mass* introduced above, and c^2 is a coefficient for the moment, but later rigorously shown to be equal indeed to the square of light velocity. One also obtains here the explicit expression of the elementary dynamical *clock of the universe* within each (massive) particle (section 1.1) that has a sufficiently high frequency ($\nu_0 \sim 10^{20}$ Hz for the electron) and provides the causal, physically real basis for the famous relation $h\nu_0 = m_0c^2$ used by Louis de Broglie in his original derivation of particle ("de Broglie") wavelength [21, 22] and confirmed recently by an electron channeling experiment [20]. We develop below this unified causal interpretation of mass, energy, and time to the case of moving particles and obtain the *dynamically* derived effects of (special) relativity (section 1.3.7).

The *multitude* of particle species, reflected by their observed *mass spectrum*, is obtained as a consequence of fundamental *dynamic multivaluedness* of the protofield interaction process, where the light family of *leptons* represented by the absolutely stable electron is obtained as a compound realisation with a relatively small quantum beat amplitude, so that e/m protofield pulsation remains rather "close" to the unperturbed protofield state in Figure 1. The opposite case of strongest effective protofield interaction is obtained for the compound realisation of heavy particles, *hadrons*, represented by the stable species of proton. Their composition of explicitly nonseparable quarks corresponds to a compound structure of quantum beat process that cannot be split, however, into separate interacting beats for individual quarks. This involvement of quarks, their unique role in strong interaction force, and the absence of strong interaction for leptons can be uniquely explained by the fact that the gravitational protofield, or medium, is represented by a dense *quark condensate* (probably with "quantum" properties like superfluidity and with unknown degree of separate quark individuality as localised, corpuscular states). Recent experimental evidence in favour of *quark-gluon liquid* [23] (*rather than* expected *plasma* of usual theory) confirms this conclusion and the whole picture of quantum field mechanics.

The compound realisations of leptons and hadrons are further split into three canonical "generations" closely resembling "excited states" of their stable, weakest-interaction species, which corresponds very well to our interpretation in terms of different, progressively growing quantum beat (or protofield EP) amplitude. As for the main *massless* species of *photon*, it is represented by a basically *regular*, non-chaotic oscillation process with relatively very small amplitude, which is additionally stabilised by permanent attraction to the gravitational protofield and resembles thus *ordinary, regular solitons* (the tiny remaining dissipation of such photon energy provides just the necessary features for the consistent explanation for the *cosmological red shift* phe-

nomenon, *without* the contradictory Big Bang hypothesis, see [9] and section 2.2). The case of massless photons emphasizes once more the role of *truly chaotic*, multivalued *internal* dynamics, and the associated *symmetry of complexity*, in the emerging property of particle mass. It also avoids artificial introduction of *additional* entities giving rise to mass, such as hypothetical but never found Higgs particles and field from the unitary theory (contradicting the above causally extended Occam's razor, see section 1.3.1). One can see here that our interacting protofield construction is indeed explicitly "economical" as it gives rise, within the *same* quantum beat process, to *both* elementary field-particles and their intrinsic properties (as well as to all other, dynamic properties, as we shall see below, in section 1.3.7).

Since all massive particles live within the same, *physically unified* protofield volume (mainly perceptible from the e/m protofield side), their respective quantum beat processes should be *synchronised* in time, which is necessary for both *coherent particle interaction* (especially evident for the case of *attraction*) and *unified time flow* for the whole universe. Such complex-dynamic synchronisation is a subject of separate study, but irrespective of its details one knows the final result: temporal pulsation phases of all quantum beat processes *coincide* up to phase inversion (i.e. one may have either the same or opposite pulsation phases).[1] This important feature leads, in addition, to dynamic interpretation of the next major intrinsic property of *electric charge* that emerges now as *phase-related measure* of the same *quantum beat complexity*. Indeed, the synchronised field-particles are naturally subdivided into *two and only two* "opposite" species according to their quantum beat phase, which explains the existence of two "opposite" charges. Like charges represented by quantum beat processes with the same phases will naturally *repulse* each other because of their direct, "mechanical" competition for the common e/m protofield material, while unlike charges will naturally *attract* each other due to a mutual "help" of their reduction-extension processes with opposite phases [1]. The famous "quantisation" of elementary charge (its fixed observed value), remaining unexplained in the unitary theory, is due to the same global *phase synchronisation* of all quantum beat processes (most probably at the frequency of *electronic* quantum beat) and thus eventually due to *quantisation* of their complex dynamics (i.e. dynamically discrete structure of the symmetry of complexity).

The described direct link between elementary electric charge e and quantised complexity of the quantum beat process (expressed according to equation (34) by the complexity-action quantum $\hbar = h/2\pi$) constitutes the genuine, causal content of the well-known relation between e and $\hbar$, $e^2 = \alpha c\hbar$, where α is the fine structure constant. We shall see below (section 1.3.4) that it leads also to the new interpretation of the latter (together with Planck's constant universality). Needless to say, the *electric charge conservation law*, appearing as a *separate* and *postulated* (empirical) law in the conventional theory, obtains now causal and universal extension as a particular case of *dynamically substantiated* symmetry (conservation) of complexity.

It is easy to see that dynamic reduction (squeeze) of the *physically real* e/m protofield within each quantum beat cycle of an elementary field-particle should involve a strong vortical *twirl* of the squeezing protofield matter, simply due to its *finite compressibility*. The phenomenon can be described as a highly nonlinear (self-amplified) version of a liquid whirlpool appearing when a liquid is forced, usually by gravitational field, to pass through a small hole. The *unique* feature of *unreduced* quantum beat interaction and in particular self-amplifying *dynamic entanglement* (section 1.1) is that it produces, in a *purely dynamic*, "spontaneous" way, a never-ending series of such "holes", or protofield reduction centres. The detailed mechanism of protofield vortex

[1] Such synchronisation provides, in particular, a candidate *dynamic* origin of the observed *particle-antiparticle asymmetry*, in contradiction with formal symmetry between particle and antiparticle properties. The propagating "wave" of *inevitable* complex-dynamic synchronisation of quantum beat processes will automatically leave only same-phase/antiphase particle species coupled also to their related spin vorticity (see below in this section). This necessary dynamic "ordering" phase of material universe content implies also essential modification in the related problems of universe age, dimension, isotropy, etc. (see also section 2.3).

emergence itself is similar to usual instability against local shift deformation of the liquid/gas flow, where more rapidly moving parts (closer to the "hole") experience sideways "twisting" deviations due to simultaneously emerging pressure differences in the inhomogeneously moving matter. The emerging twirl continues in the extension phase, and one obtains in the whole the *physically real*, dynamic and *essentially nonlinear* origin of the universal intrinsic property of elementary particle *spin*. The complex, multivalued dynamics of protofield interaction provides just a *unique* combination of properties for this consistent causal interpretation of spin, as opposed to any unitary "rotating ball" models.

Moreover, the quantitative expression of spin, s (and any other angular momentum I), in terms of angular momentum quantum $\hbar$ ($s = \hbar/2$ for the electron) presents it as *another form* of (naturally quantised) quantum beat *complexity* and reveals the origin of the deep dynamical connection between complexity-action quantum h for quantum beat *pulsation* and angular momentum quantum $\hbar$ for spin *rotation* within *the same* quantum beat process [1]. Universal expression for complexity-action increment will, in general, contain a "rotational" term, $\Delta\mathcal{A} = -E\Delta t + p\Delta x + I\Delta\phi$, where $\Delta\phi$ is the angle variable increment, so that the rest energy ($p = 0$) of (for example) the electron will contain a contribution from the spin rotation energy:

$$E_0 = \frac{h\nu_0}{2} + s\omega_0 = \frac{h\nu_0 + \hbar\omega_0}{2} = h\nu_0 = \hbar\omega_0 \ ,$$

where the circular frequency of spin *rotation* ω_0 should coincide with the circular frequency of quantum beat *pulsation*, $\omega_0 = 2\pi\nu_0$, as it is *one and the same process*, so that its energy partition into contributions from "pulsation" and "spin rotation" can have only conventional meaning, as shown above. The "anomalous" values of electron spin and gyromagnetic ratio obtain now a *causal* interpretation in terms of two-phase structure of the electronic quantum beat process [1]. The spin-induced rotation of the e/m protofield matter can now be seen also as fundamental *physical origin* of *magnetic field and effects* [1]. And similar to the above case of electric charge, all conservation laws involving angular (spin and orbital) momentum are universally extended now to causally substantiated, unified symmetry of complexity. We can clearly, directly see how all the diverse quantities conserved according to *formally imposed (empirical)* conservation laws of the unitary science are obtained and conserved as *measures* of only *externally* different manifestations (or levels) of the same *dynamic complexity of unreduced interaction process*, which specifies the *physically real, unified origin* of both conserved quantities and their conservation.

1.3.3 Dynamically unified fundamental interactions, their number and properties

The above intrinsic particle properties are related to fundamental interactions between particles, which naturally emerge in quantum field mechanics in their *dynamically unified* state and observed properties [1, 4, 7, 8]. The unified dynamic origin of all particle interactions is the underlying protofield attraction, in its "implemented" form of quantum beat processes within each field-particle. As every such particle-process changes the surrounding protofield properties (because of protofield deformation), it will influence the quantum beat parameters of any other particle (by certain analogy to "deformation interaction" between solid state defects and excitations). As a result, one obtains two such long-range fundamental interactions through e/m and gravitational media, the e/m and gravitational interactions, which explains now the respective protofield names. The e/m interaction forces are introduced in the previous section, while the dynamic gravitation mechanism thus obtained provides the causal, *physically real* basis for *universal gravitation* (absent in any its unitary description), which possesses all its observed classical properties, *intrinsically quantum* origin (due to quantum beat discreteness) avoiding usual quantum gravity problems (cf. [24]), and *relativistic* effects without any artificial "geometrisation" of physically real space and flowing time (see section 1.3.7 for more details). The other two, short-range interaction forces, known as "weak" and "strong" interactions, are

simply due to close-contact forces between constituent elements (remaining basically unresolved) of e/m and gravitational media respectively. We obtain thus *exactly the observed number (four)* of fundamental interactions with their *observed properties* (including two short-range and two long-range interactions for two protofields).

Moreover, all the four interactions are *naturally unified* from the beginning within every quantum beat process (the total unity is obtained in the maximum reduction phase for the heaviest hadronic particles), which resolves the notorious "grand unification" problem (also known as the "theory of everything"), or even *avoids* any "big problem" around such unification that *seems* a kind of "magic dream" and desired "super-goal" in the *unitary* theory just because of *its specific*, effectively zero-dimensional, *intrinsically split* and postulated, abstract *imitation (projection)* of reality. We demonstrate below a rigorously specified expression of dynamic interaction unification that provides a practically important solution of a series of problems related to Planckian unit values and interpretation (section 1.3.4). We can also confirm and understand the *causal*, physical origin of "partial" unification of *e/m and weak interactions* by their common material, transmitting basis of e/m protofield and can *predict* a similar (though maybe different in details) unification of *gravitational and strong interactions* by the *common gravitational medium* actually represented, as mentioned in the previous section, by a dense quark condensate. The *forces* of particle interaction as such emerge as a general consequence of the symmetry of complexity, in the form of *complexity development from dynamic information to entropy*, i.e. particles are forced to move so as to preserve the total system complexity by an optimal *increase of its dynamic entropy* (through structure creation) at the expense of dynamic information (or "generalised potential energy"). Rigorous expression of this law is provided by the universal Hamilton-Schrödinger formalism (24)–(32), which can be further specified to reveal unified relativistic, gravitational, and quantum effects (section 1.3.7).

The dynamic structure of fundamental particle interactions thus causally derived can be further specified, including e. g. physically real extension of photon exchange processes for e/m interactions [1], which are described by purely abstract means as unreal ("virtual") processes in usual theory. However, we shall concentrate here on important general relation between *numbers* of most *fundamental entities* (dimensions, forces, and particles) valid for *any real* universe and following from the symmetry of complexity and its causal manifestations. According to the dynamic origin of real space dimensions (section 1.3.1), a world emerging from interaction of n initial entities (protofields) will have $N_{\rm dim} = n + 1$ *global* space dimensions (and one irreversibly flowing time), which is a direct consequence of the symmetry of complexity. As shown above in this section, the same world will have $N_{\rm F} = 2n$ "fundamental" interaction forces between its (dynamically emerging) particles, physically transmitted through those n protofields and subdivided into n short-range and n long-range forces (within protofield configuration). One obtains thus the following relation between the numbers of (any) world forces and (space) dimensions:

$$N_{\rm F} = 2\,(N_{\rm dim} - 1)\,, \quad N_{\rm dim} = \frac{N_{\rm F}}{2} + 1\ , \tag{35}$$

where $N_{\rm dim}-1$ interaction forces (one half of their total number) have long-range character, while other $N_{\rm dim} - 1$ forces are short-range, "contact" ones. This relation can be more general than the underlying dependencies of $N_{\rm F}$ and $N_{\rm dim}$ on the protofield number n. Indeed, possible more complicated, "non-global" structure of protofield interactions can give rise to various "partial", (half-) hidden dimensions and "rare" forces, but relation (35) between numbers of those *emerging* entities will remain valid due to its well-specified *physical* basis and related *absolutely universal* symmetry of complexity. As any starting protofield entity may have, in principle, more than one short-, middle-, or long-range kind of excitations and interaction transmission ways, one should also envisage a yet more general form of relation (35), in the form of *lower limit* to the number of

forces, $N_{\rm F} \geq 2\,(N_{\rm dim} - 1)$, even though the strict inequality here should be considered as a more exotic possibility. The latter is hardly realised in our world, where we have $n = 2$, $N_{\rm dim} = 3$, and $N_{\rm F} = 4$, according to equation (35). Next higher-dimensional universes should have $\{n = 3,\ N_{\rm dim} \geq 4,\ N_{\rm F} \geq 6\}$, $\{n = 4,\ N_{\rm dim} \geq 5,\ N_{\rm F} \geq 8\}$, and so on. Another relation following from (35) may be its yet more universal consequence: $N_{\rm F} - N_{\rm dim} = N_{\rm dim} - 2 \geq 1\,(= n - 1)$, or $N_{\rm F} \geq N_{\rm dim} + 1$, where the universal inequality follows from the fact that $N_{\rm dim} \geq 3$ (or $n \geq 2$) for any real, *interaction-based* world and shows that *any additional, real dimension brings about additional interaction forces* (and related particles).

The latter statement introduces important application of equation (35) and similar relations. As the number of interaction forces can be experimentally checked, it *strongly limits* the number of *any real* ("large", "small", or "hidden") dimensions ($N_{\rm dim} \leq \frac{N_{\rm F}}{2} + 1$) and gives rise to additional doubts in various popular violations, in the usual theory, of Occam's razor principle (*following* from the symmetry of complexity) by introduction of additional dimensions á la carte, according to *internal*, "mathematical" needs of an *abstract* "model" (e. g. in string theory, quantum gravity, brane world models, etc.). Those doubts are yet more amplified if we take into account that each new force implies new (observable) particles (or excitations), so that the number of particles $N_{\rm part}$ will in any case be greater than the number of short-range forces (or protofields), or $N_{\rm part} \geq N_{\rm F}/2 = N_{\rm dim} - 1$ (which corresponds to unrealistic, absolute minimum of exchange particles). Thus, in our world with *four* interaction forces and *three* dimensions we have indeed *two* such "really irreducible" (and *therefore* stable) particles in the form of electron and proton originating from the respective protofields (without counting more ephemeral photon and all the unstable and "excited-state" species). A world obtained by n protofield interaction will have at least $N_{\rm F} = 2n$ fundamental interaction forces, $N_{\rm dim} = n + 1$ space dimensions, and $N_{\rm part} = n$ "irreducible" (i.e. rather stable and "strongly" observable) particles. Needless to say, all the unitary, "anti-Occamian", entity-producing theories directly and strongly violate even least restrictive, unrealistic versions of those relations between the numbers of dimensions, basic forces and particles. Instead of incorrect imposition of arbitrary fantasies from a purely abstract "reality", one can use the above *causally substantiated* consequences of the universal symmetry of complexity for *deduction* of the total number of (any) world dimensions from the number of its observed fundamental forces and "basic" elementary particles (as opposed to any "intuitive" or formal way of definition of space dimensions and their number).

1.3.4 Complex-dynamic origin of universal constants and realistic Planckian units

Due to the intrinsically creative, structure-forming character of the symmetry of complexity (section 1.2), *all* the fundamental world structures and properties have explicitly *causal, dynamic* origin in quantum field mechanics, including such "intrinsically abstract" features of usual theory as universal (physical) constants [7,9]. Thus, the *speed of light* c is introduced as *physically real velocity* of perturbation propagation in e/m protofield coupled to gravitational medium (see also section 1.1), rather than "logical" consequence of the *postulated, abstract* "principle of relativity" of the unitary theory, after which we *rigorously derive* major "relativistic" effects as causal manifestations of the underlying *complex interaction* dynamics (section 1.3.7). Another universal constant, *Planck's constant* h, appears in our approach as a *dynamically discrete* portion, or "quantum", of the universal complexity measure, complexity-action $\mathcal{A}$ (sections 1.2, 1.3.2). Its universality follows from the *common, physically unified* structure of the underlying system of coupled protofields and the fact that complexity-action quantum h appears at the very first, *least structured* level of world complexity. However, the truly unlimited, astonishingly large universality of h, from photon energy to nuclear, subnuclear, and even intra-particle properties, has a more detailed explanation within that general interpretation, involving also the complex-dynamic origin of the *fine structure constant* α and *elementary charge* e (see also section 1.3.2).

The well-known relation between h, e, and α, $e^2 = \alpha ch/2\pi$, can be written as

$$m_0c^2 = \frac{2\pi}{\alpha}\,\frac{e^2}{\lambda_{\rm C}} = N^e_{\Re}\,\frac{e^2}{\lambda\!\!\!^{-}_{\rm C}}\ ,\ N^e_{\Re} = \frac{1}{\alpha}\ ,\ \lambda\!\!\!^{-}_{\rm C} = \frac{\lambda_{\rm C}}{2\pi}\ , \tag{36}$$

where m_0 is the electron rest mass and $\lambda_{\rm C} = h/m_0c$ is the Compton wavelength. As $E_0 = m_0c^2$ is the causally defined electron rest energy (see equation (34)), equation (36) *means* that $\Delta x = \lambda\!\!\!^{-}_{\rm C}$ can be interpreted as the *length of virtual soliton jump* within the quantum beat process (in relation to elementary space length Δx introduced in section 1.3.1), $N^e_{\Re} = 1/\alpha \approx 137$ as *the electron (quantum beat) realisation number*, and α as *realisation emergence probability* (in agreement with the general dynamic definition of the latter, equation (10)). The canonical h–e relation can now be written also as

$$\hbar = N^e_{\Re}\,\frac{e^2}{c} = \lambda\!\!\!^{-}_{\rm C}p_0\ ,\quad \lambda\!\!\!^{-}_{\rm C} = N^e_{\Re}r_e\ , \tag{37}$$

where $p_0 = m_0c = E_0/c$ and $r_e = e^2/m_0c^2$ is the usual "classical radius" of the electron. Equation (37) provides then a transparent physical interpretation of Planck's constant and its universality: $\hbar$ (or h) measures the "volume" (in units of action-*complexity*) of the quantum beat EP well that *remains the same* for *any* particle species (including massless excitations like photons) and their coherent-beat combinations, due to both complexity conservation and permanence of the coupled protofield properties, whereas the *EP width*, $\lambda\!\!\!^{-}_{\rm C}$ ($\lambda_{\rm C}$) or $N^e_{\Re}$ (up to 2π), and *depth*, p_0 or e^2/c, *vary* for different species, but with the permanent value of their complexity-based product, the EP well volume. Since all equal quantum beat realisations should occupy the closest two-dimensional vicinity of a current reduction centre, i.e. a two-dimensional circle with the radius $\lambda\!\!\!^{-}_{\rm C}$, one obtains an estimate for the virtual soliton size (in the state of maximum dynamical squeeze), $D_e = 2\pi r_e = \pi d_e$, which coincides, up to coefficient π, with the classical electron diameter, $d_e = 2r_e$ (we have used this result in elementary space and field-particle size specification, section 1.3.1).[2] Equation (37) provides also another, particle-dependent unit of quantum action-complexity, $\hbar_e = \hbar/N^e_{\Re} = e^2/c$, that corresponds to *one* realisation (reduction-extension cycle).

It is essential that the above relations, written formally for the electron, are directly extendible to arbitrary spatially coherent (or *quantum*) particles, their systems and excitations. The electron corresponds to a rather shallow and large EP well, admitting "horizontally" as much as $N^e_{\Re} \gg 1$ "corpuscular" (localised) particle states, as should be expected for that *light* particle with weak involvement of gravitational (quark) medium. In the opposite case of heaviest hadronic species with the effective charge q, mass $M_{\rm P}$, and "classical" radius $r_{\rm P}$, one will have a very narrow EP well with the width $\sim r_{\rm P}$ (or $N_{\Re} \sim 1$) and depth $P_{\rm P} = M_{\rm P}c$ (or q^2/c) that corresponds to the highest protofield deformation/interaction amplitude and $\hbar_{\rm P} \sim \hbar$. In that way one obtains the causally complete, complex-dynamic explanation for the remarkable universality (and physical origin) of Planck's constant that finds its additional confirmation in the case of *many-particle* quantum system of atomic nucleus, by the fact that largest *nuclear* masses are close to the heaviest *elementary particle* mass, $M_{\rm P} \sim 200$ GeV [7–9].

[2]Note that similar result for the virtual soliton size follows directly from equation (36), since the total particle energy should be equal to Coulomb "self-interaction" within the squeezed field-particle state (as an alternative to its equally valid expression as "dynamic" interaction energy through extended field-particle state during $N^e_{\Re}$ jumps of the virtual soliton). We obtain thus the direct extension of the usual, formal definition of the classical electron radius, where we specify the *causal, physical origin* of the "compressed" electron state (as well as its dynamic instability and permanent reappearance). One should also take into account that the above interpretation will remain valid if we change $N^e_{\Re}$, $\Delta x = \lambda\!\!\!^{-}_{\rm C}$, and r_e correspondingly, according to their relations (36)–(37). It means that the exact number of field-particle realisations and its virtual soliton size can, in principle, be somewhat different from the above values. However, the latter should be valid at least approximately, up to numerical factor like 2π, as otherwise it would be difficult to explain the essential difference of the virtual soliton size from the physically reasonable (and now causally justified) classical radius (for the electron).

This heaviest species case brings us to the causally complete interpretation of the third universal constant, the *gravitational constant* γ from classical Newton's law, and related *realistic, modified* values of *Planckian units*. Since any unitary theory does *not* provide the real, physical mechanism of gravity, the classical gravitational constant has *purely formal* origin in the usual theory, as a simple coefficient in Newton's gravity law and its equally formal extension to relativistic and quantum applications. In quantum field mechanics gravitational interaction is causally derived as a deformation influence of one quantum beat process on another, transmitted through the physically real matter of gravitational protofield (section 1.3.3), and the gravitational constant represents a "condensed", resulting expression of that complex-dynamic (and basically quantised) transmission process through the gravitational quark condensate. It becomes evident that this *indirectly transmitted* interaction is driven by, but remains very *different* from, the underlying *direct attraction* between the two protofields that gives rise to the quantum beat processes *within* each particle. It means that formal combinations of the three universal constants in Planckian units describe actually the *internal* quantum beat parameters, i.e. *direct* protofield attraction, and therefore should contain another, modified value of "gravitational" constant, γ_0, whose usual value γ refers to *much weaker, indirect* interaction between *different* particles. We obtain thus the new, modified (or "renormalised") values of the Planckian units of length $L_{\rm P}$ $(= r_{\rm P})$, time $T_{\rm P}$, and mass $M_{\rm P}$ that just coincide (approximately) with the *experimentally observed* extreme values of the corresponding quantities l_{exp}, t_{exp}, and m_{exp}:

$$\begin{aligned} L_{\rm P} &= \left(\frac{\gamma_0\hbar}{c^3}\right)^{\frac{1}{2}} \approx 10^{-17} - 10^{-16}\ {\rm cm} \approx l_{\rm exp}\ , \\ T_{\rm P} &= \left(\frac{\gamma_0\hbar}{c^5}\right)^{\frac{1}{2}} \approx 10^{-27} - 10^{-26}\ {\rm s} \approx t_{\rm exp}\ , \\ M_{\rm P} &= \left(\frac{\hbar c}{\gamma_0}\right)^{\frac{1}{2}} \approx 10^{-22} - 10^{-21}\ {\rm g}\ \left(10^2 - 10^3\ {\rm GeV}\right) \approx m_{\rm exp}\ , \end{aligned} \tag{38}$$

where the relation between γ_0 and γ can be specified, for example, using the values of *ordinary* Planckian unit of length $l_{\rm P}$ and measured length l_{exp}: $\gamma_0 = (l_{\rm exp}/l_{\rm P})^2\gamma \approx (10^{33} - 10^{34})\gamma$.

Such *essential*, causally derived (i.e. *inevitable*) modification of Planckian units and their new, *realistic* meaning lead to consistent solution of various stagnating problems. One of the most remarkable of them is the so-called *hierarchy problem*, i.e. the problem of huge gap between the values of usual Planckian values and observed quantities, especially evident for particle mass spectrum. We see that the hierarchy gap completely disappears for the modified, *causally substantiated* Planckian units, which shows that the *whole* particle spectrum is *already basically covered* by the existing experimental data and facilities, with evident and important practical implications for *high-energy physics strategy* [7–9]. Note the difference of our *intrinsically parsimonious* solution of the hierarchy problem from anti-Occamian, unitary imitations of "brane-world" models [25–27] arbitrarily postulating additional (and totally *abstract*), but strangely "hidden" dimensions that would inevitably give rise to additional, experimentally observed forces and particle species (section 1.3.3). It is easy to see that such artificial, unreal entities in this and many other models of unitary science appear as *unavoidable* replacement for *incorrectly* rejected *real*, naturally plural entities and (dynamic) "dimensions".

Other applications of the modified Planckian units include major and *fatal* consequences for standard theory concepts essentially relying upon usual Planckian units, such as *cosmological inflation* and *quantum gravity* theories. One obtains also consistent, physically transparent explanation for relative *weakness of gravity* (as being due to the small ratio γ/γ_0), dynamic *unification of all fundamental forces*, and *causal* theory of "black holes" and other dense "quantum condensates" [1] (see also below, section 1.3.5). In particular, the above causal difference between γ and γ_0 effectively disappears in the *dynamic unification phase* of (hadronic) virtual

soliton (section 1.3.3) and at corresponding distances of the order of $L_{\rm P}$ ($= r_{\rm P}$), where one deals with the ultimately dense state of original quark matter of the gravitational protofield (so that $r_{\rm P} = L_{\rm P}$ should be close to the "quark classical radius"). It becomes clear also that modified Planckian units and their practical realisation within quantum beat processes for heavier particle species represent the real, causally complete version of various "microscopic/quantum black holes" ("Kerr-Newman" solutions, etc.), often formally introduced in the unitary theory as particular, exotic possibilities and models whose zero dynamic complexity is often accompanied by additional, "inexplicably plural" dimensions (see e. g. [28, 29] and further references therein).

1.3.5 Self-tuning, adaptable universe from the creative symmetry of complexity

We can summarise now those first "material", structure-formation results of complexity symmetry unfolding on the "cosmological" scale of the *whole* universe by noting that due to the *intrinsically creative* character of the unreduced interaction process and resulting symmetry of complexity, the emerging universe will automatically have *self-tuning*, internally consistent structure and properties, as opposed to intrinsically "anthropic", as if very specially "designed" properties of any unitary universe picture. That dynamic consistency of the real, complex-dynamic universe structure is expressed by general property of *dynamic adaptability* of unreduced interaction process (section 1.1), which is due to the *self-consistent dependence* of the *unreduced* EP formalism on the solutions to be found (equations (5)–(12)) amplified by the *probabilistic dynamic fractality* of interaction-driven structure formation (equations (13)–(19)). It is important that such "self-tuned" unfolding of the symmetry of complexity includes even *most fundamental*, "intrinsic" structures and properties (such as universal constants and internal particle properties), which are obtained now as *dynamically emerging*, *globally unified* and *physically real* entities (sections 1.3.1–1.3.4), contrary to their unconditionally *imposed*, postulated, and *abstract* status in any unitary theory version.

The differential form of "potential" complexity at the beginning of interaction process, alias dynamic information, is given by generalised, *positively* defined *potential energy* $V_{\rm init} = -\left(\Delta\mathcal{A}/\Delta t\right)|_{x=\rm const}$ and enters the initial existence equation (1) through the interaction potential $V_{\rm eg}\left(\xi, q\right)$. Emergence of system realisations in the form of spatially chaotic quantum beat processes within elementary particles transforms potential energy into the total universe mass-energy-complexity $M_{\rm univ}c^2$, with the basic equality between the two due to the symmetry (conservation and transformation) of complexity:

$$V_{\rm init} = M_{\rm univ}c^2 \ . \tag{39}$$

It means that, in accord with the underlying EP formalism (equations (5)–(19)), elementary field-particle emergence leads to increase of internal e/m protofield tension until it becomes greater than (sufficient) attraction between protofields, so that new particles cannot emerge any more and further complexity development proceeds to its higher levels driven by interaction between particles (first-level structures) thus formed (see also Figure 1). That multi-level, fractally structured universe complexity development, always preserving its major self-tuning property, can be schematically presented as

$$M_{\rm univ} \to \sum_{\rm part} N_{\rm part} m_{\rm part} + \frac{V_{\rm fund}}{c^2} \to \sum_{\rm atom} N_{\rm atom} m_{\rm atom} + \frac{V_{\rm chem}}{c^2} \to \dots \ , \tag{40}$$

where"part" and "atom" designate progressively emerging species of elementary particles (and their interactions $V_{\rm fund}$), atoms (and their interactions $V_{\rm chem}$), and so on.

Equations (39), (40) show that the more is the initial protofield interaction magnitude, the more matter will emerge in the universe thus obtained, which is a major manifestation of the

self-tuning property of interaction-driven universe structure formation. Note that impossibility to satisfy equations (39), (40) immediately at *all* universe locations and for those intrinsically *chaotic* interaction processes provides a causal explanation for existence of seemingly "redundant" species and generations of *unstable* elementary particles that can efficiently "fill in the (small) gaps" in the symmetry of complexity, in agreement with its *dynamically fractal* structure.

The "anthropic" universe image of the unitary theory with the *inexplicably unique* choice of parameters is thus replaced, in both reality and its causally complete picture of the universal science of complexity, by the *generically successful* universe emergence and development, but with naturally, *consistently variable* quantity and specific features of its material content.[3] Those *generic* cases of unreduced protofield interaction can be yet better understood by their *causally* specified *non-generic limits* at the ultimately strong and weak interaction sides.

The excessively *strong* protofield attraction would create a *macroscopically large* protofield collapse region (as opposed to transient *microscopic* collapse within any quantum beat process). Although such peculiar state differs qualitatively from any "ordinary" matter, it can be causally understood as *partially coherent, dense condensate* of quantum beat pulsations with many discrete states ("phases") of different density providing causally complete, *physically specified* versions of such "contradictory" stellar objects as black holes and neutron stars [1], which are only "phenomenologically" (macroscopically) introduced and *formally* described in usual theory, leaving too much place for ambiguity and related (often justified) doubts.

The ultimately *weak* protofield attraction is insufficient for appearance of a genuine, chaotic quantum beat and can give rise only to small, quasi-linear protofield fluctuations. This is the "primordial ether" state of the coupled protofield system that can have its modern realisation far enough from massive particles, in the (physically real) "vacuum", where it can account for the realistic, fundamentally substantiated version of "microwave radiation background". The latter appears thus not as a "definite" sign of the past Big Bang event and related hot universe state, but as a *generic vacuum state* of *any real* universe, where those photonic "vacuum fluctuations" are driven by *weak protofield interaction* and configured in detail by their multiple interactions *within* the e/m protofield, tending to *equilibrium, thermodynamically determined* state in an old enough universe (like ours) with basically created massive particle content.[4] It is interesting to note that *both* these cases of ultimately strong and weak protofield interaction are realised also within *each* massive field-particle (quantum beat process), but remain limited there to very small volumes and short (permanently alternating) time periods.

Describing cosmological results of dynamic adaptability of the unreduced interaction process, we should finally mention its causally specified, *exponentially huge efficiency* [4,6,12–14], which is due to *autonomous dynamic branching* processes of the *fractal realisation hierarchy* and leads to extremely efficient, *intrinsically complete* structure creation by complex-dynamic search and invasion processes. They give rise to the observed "unlimited" diversity and complexity of structures that demonstrates *creation efficiency* of the underlying *symmetry of complexity* and inevitably seems "miraculous" (inexplicable) within *any* dynamically single-valued description.

[3]Note, however, that a viable universe with *any* protofield interaction parameters needs certain "mechanical" properties of the protofield material and in particular sufficient e/m protofield "elasticity". Such demands do not seem exotic at that "subquantum" level of reality (internal protofield mechanics) and in any case are fundamentally different from dynamic or conceptual restrictions of "anthropic" origin. The necessary mechanical properties of the protofield material constitute the *inevitable minimum* of purely *physical* and *realistic* "postulates" of our theory, as opposed to *numerous conceptual* and *"mysterious" (contradictory)* assumptions of the unitary theory.

[4]This interpretation of microwave background radiation as protofield fluctuations shows also why much *larger* fluctuations, in the form of "virtual" *massive* particles, are actually *impossible*, contrary to their formal introduction in the unitary theory. Such greater, massive fluctuations cannot emerge already because of direct, mechanical impossibility of sufficient protofield deformation in a "mature" universe, but also because their existence would contradict to the symmetry of complexity (contrary to the case of effectively zero-complexity photons). We obtain thus consistent solution of another group of stagnating unitary problems (in particle physics and cosmology) related to improper, diverging energy contributions from such "strong" vacuum fluctuations.

1.3.6 Positive energy-complexity of the universe and cosmological time arrow

As shown in section 1.2, the universal symmetry of complexity of any real interaction *necessarily implies* the *irreversible* time flow in the direction of growing dynamic entropy, which is equivalent to strictly negative sign of generalised Lagrangian L and *positive sign of total energy* E (see equations (26)–(27)), $L = \Delta\mathcal{A}/\Delta t = pv - H < 0$, $E = H > pv \geq 0$. Being applied to the whole universe (interacting protofield system), the last inequality imposes strictly positive total energy of the universe, in contrast with the dominating unitary assumption about its zero value, obtained as a result of compensation between positive "kinetic" (motion) energy and negative energy of gravitational attraction. The latter statement is widely used, often under the reference of "Hamiltonian constraint", in various cosmological models (such as the famous Wheeler-DeWitt equation in quantum cosmology) and justifies the possibility of universe emergence "from nothing", by self-amplified "tunneling" starting from a (genuine) vacuum "fluctuation".

We can see now that the real basis of the zero-energy assumption of scholar cosmology is the unitary-science "approximation" reducing the strictly positive (and *large*) dynamic complexity of the real world to the *zero complexity value* of its *dynamically single-valued projection*. The mechanism that ensures impossibility of any zero-complexity (totally *regular*) universe is the fundamental dynamic multivaluedness of any real interaction (section 1.1) implying that any imaginary zero-complexity world configuration would immediately change to a positive-complexity case once all its interactions are turned on in their unreduced, *dynamically chaotic* (multivalued) version providing *permanently growing* entropy and *positive* total energy.

It follows that *no* zero-energy "Hamiltonian constraint" or other "nothingness-based" model can be valid in principle, irrespective of details, which provides an important restriction on acceptable cosmological theories. Moreover, even when a positive energy value is formally inserted in a unitary theory, it can hardly lead to a correct description, as the dynamically single-valued world projection in such theories *cannot* reveal the genuine, complex-dynamical content and meaning of energy-mass, in *direct relation* to the increasingly acute, "unsolvable" problems of *dark mass* and *dark energy* (see section 2). Due to the high degree of randomness in mass-energy universe content, the positive total energy of the universe is as big as its total material content (and thus cannot be a relatively small "unbalanced residue").

As noted above, the positive energy-mass (or dynamic complexity) content of the universe is *equivalent* to the *real time arrow*: since for the (closed) universe $E = -\Delta\mathcal{A}/\Delta t$ (global motion velocity $v = 0$) and $\Delta\mathcal{A} < 0$ (chaos-induced loss of dynamic information), time can *advance* in a real universe, $\Delta t > 0$ (and thus the universe *can exist*), if and only if $E > 0$. The obtained time arrow orientation to *always growing* complexity-entropy (or decreasing complexity-information) solves also all entropy-related problems by implying that entropy grows in *all* kind of processes, including an *externally* "ordered" structure formation (in this latter case one deals with the SOC regime of multivalued dynamics, see section 1.2). Thus rigorously specified *asymmetry* of time flow and entropy growth constitutes, however, an integral part and *inevitable result* of the global *symmetry* of complexity (whereas unitary symmetry is *opposed* to its asymmetric "breaking").

It is remarkable that the "old" problem of universe time arrow (and the origin of time) is causally solved *together* with the energy-mass and entropy-information problems, without play on "quantum" or other "mysteries" and related ambiguous speculations, but simply due to the *unreduced* interaction problem solution, revealing the key, *qualitatively* new phenomenon of *dynamic multivaluedness* and related universal *symmetry* of complexity.

Note also the causally derived *direct link* between *the real time flow* and *genuine dynamic randomness*: the basically *regular*, though arbitrarily involved, "Laplacian" world of the unitary science cannot exist already because it is devoid of any real, advancing time flow (that's why this direct and fundamental relation between time and randomness remains "hidden" in the conventional, dynamically single-valued science framework).

1.3.7 Unified complex-dynamic origin of relativistic and quantum properties

We have seen in previous sections 1.3.1–1.3.6 how the global universe structure and properties (space, time, energy), its universal constants, elementary field-particles, their intrinsic properties (mass-energy, charge, spin) and interaction forces causally emerge as *unified manifestations of the symmetry of complexity* of the underlying protofield interaction process with generic parameters and simplest possible initial configuration. We now continue to follow the natural complexity development of the *same* interaction towards the basic external, *dynamical* features of the field-particles thus obtained, in the form of their *unified relativistic and quantum properties* that will be derived as *totally causal, realistic* manifestations of the same unreduced *dynamic complexity* and its symmetry. Moreover, it is the rough *rejection* of the underlying complex interaction dynamics in the standard, unitary theory that accounts for the "inexplicable mystery" status of official quantum and relativistic postulates. All "relativistic" and "quantum" effects emerge as *inevitable, standard, and totally causal* manifestations of real, unreduced interaction dynamics and therefore can be generalised to higher complexity levels [1, 2, 4, 6, 13] (see also section 1.2 and below in this section).

We start from the causally derived intrinsic property of inertial particle *rest mass* m_0 defined by equation (34) (section 1.3.2) that contains already natural, *dynamic* unification of causal *quantisation* of the underlying quantum beat process and complex-dynamic origin of *relativistic "equivalence"* between mass/inertia and its energetic content.[5] If the field-particle is not isolated and interacts with other particles by the causally emerging interaction forces (section 1.3.3), it leads to (further) *growth* of complexity-entropy appearing as particle *motion*. In other words, we can now *rigorously* and *universally* define the system *state of motion* itself as any state with (generalised) energy-complexity *exceeding* its *minimum* value in the *state of rest* (also provided thus with absolutely universal and fundamental definition). As energy-complexity is a positively defined quantity (see equation (27)), such minimum always exists.

Because of the maximum homogeneity of initial (protofield) system configuration giving rise to the emerging system (particle) at rest, the latter state corresponds to *maximum homogeneity* of realisation probability distribution (cf. the generalised Born rule (31)). On the other hand, as realisation number is fixed, growth of energy-complexity in a state of motion is possible only due to appearing (or growing) *inhomogeneity* of realisation probability distribution (and thus moving system structure). It means that action-complexity function $\mathcal{A}$ of a *moving system* acquires dependence on coordinate x (emerging space configuration, see section 1.3.1), *in addition* to its dependence on time t in the state of rest, and ordinary (discrete) time derivative of action in equation (34) for the state of rest should be replaced by the total (discrete) time derivative of action for a moving particle:

$$\frac{\Delta\mathcal{A}}{\Delta t} = \frac{\Delta\mathcal{A}}{\Delta t}\,|_{x=\text{const}} + \frac{\Delta\mathcal{A}}{\Delta x}\,|_{t=\text{const}}\,\frac{\Delta x}{\Delta t}\,, \quad E = -\frac{\Delta\mathcal{A}}{\Delta t} + \frac{\Delta\mathcal{A}}{\lambda}\frac{\Delta x}{\Delta t} = \frac{h}{\mathcal{T}} + \frac{h}{\lambda}\,v = h\mathcal{N} + pv\,, \quad (41)$$

where

$$E = -\frac{\Delta\mathcal{A}}{\Delta t}\,|_{x=\text{const}} = \frac{h}{\tau} = h\nu \quad (42)$$

is the *total energy* of a moving system (in accord with its previous definition (21)) specified for the moving field-particle,[6]

$$p = \frac{\Delta\mathcal{A}}{\Delta x}\,|_{t=\text{const}} = \frac{|\Delta\mathcal{A}|}{\lambda} = \frac{h}{\lambda} \quad (43)$$

[5] It is not a coincidence that a heuristically postulated version of this relation was used by Louis de Broglie in his original, realistically based derivation of his famous formula for the particle wavelength [21, 22].

[6] Expressions containing momentum-complexity can generally be understood in the sense of corresponding *vector* definitions and operations. However, in the considered simplest case of single particle motion, one can interpret p and v as respective vector moduli.

is the universally defined system momentum (see equation (22)) specified now for the moving field-particle,

$$v = \frac{\Delta x}{\Delta t} \equiv \frac{\Lambda}{\mathcal{T}}$$

is the *global motion velocity*, $\tau \equiv (\Delta t)\,|_{x=\mathrm{const}}$ is the quantum beat period at a fixed space point, $\nu = 1/\tau$, $\lambda \equiv (\Delta x)\,|_{t=\mathrm{const}} = \lambda_{\mathrm{B}} = h/p$ is the space element (inhomogeneity) related to the global field-particle motion and known as *de Broglie wavelength* λ_{B}, $\mathcal{T} = \Delta t$ is the "total" quantum beat period ($\mathcal{T} \neq \tau$), $\mathcal{N} = 1/\mathcal{T}$, and $\Lambda = \Delta x$.

Equation (41) describes the total energy partition for the globally moving field-particle (quantum beat process) reflecting its real, complex-dynamical structure that remains hidden in the unitary theory. It is easy to see that the second term, pv, accounts for the *global*, averaged, and therefore *regular* motion of the quantum beat process (virtual soliton wandering), while the first summand, the negative-sign Lagrangian $-L = -\Delta\mathcal{A}/\Delta t = h/\mathcal{T}$, describes contribution to the total energy from the *purely random* deviations of virtual soliton wandering from that average, global motion tendency (it is the energy of complex system dynamics in its *moving reference frame*). We see that any global motion emerges only as an *average tendency* of internal *chaotic* (dynamically multivalued) process of structure formation, where the above dynamically derived de Broglie wave of a moving particle is the corresponding (regular) space structure of that global motion tendency. However, every single jump of the virtual soliton within the quantum beat process is characterised by the *intrinsic uncertainty* of *dynamically redundant* choice of the next reduction centre, and therefore the *whole* content of the total energy E possesses the key property of *inertia*, $E = mc^2$, where m is the total ("relativistic") mass and c^2 is a coefficient to be rigorously specified below.

According to our *causal* definition of the speed of light c (section 1.1), every virtual soliton jump within the globally moving field-particle proceeds with the speed c. It becomes clear now that the global motion velocity v is (usually essentially) different from c just because of the (usually dominating) tendency of purely random wandering of the virtual soliton "around" global motion tendency, so that only some (usually very small) part of chaotic quantum jumps falls within that global, "systematic" tendency that forms *explicitly observed* structure. Specifically, the field-particle moving as a whole with the velocity v performs (in average) a quantised global-tendency jump of $\Delta x = \lambda = \lambda_{\mathrm{B}}$ during the *same* time period $\tau_v = \lambda/c$ that includes $n_v = c/v$ purely random jumps around global tendency. As any such jump duration is τ, we have $\tau_v = n_v\tau$, or $\lambda = V_{\mathrm{ph}}\tau$, where $V_{\mathrm{ph}} = c^2/v$ is the fictitious, apparently faster-than-light "phase velocity" of "matter wave" propagation, appearing if one does *not* take into account the irregular, "multivalued" part of the field-particle dynamics [21]. Energy and momentum definitions (42), (43) transform this relation between λ and τ into the famous *relativistic dispersion relation* (which is now obtained as a *causal result* of underlying *complex* interaction dynamics):

$$p = E\,\frac{v}{c^2} = mv\ , \tag{44}$$

where $m = E/c^2$, now by *rigorously obtained* definition containing the *physically real* speed of light c (we thus also justify, of course, the corresponding mass-energy equivalence for the rest mass, equation (34)). The *genuine* meaning of the famous equivalence of mass and energy, $E = mc^2$, becomes now clear due to its *causal, dynamic derivation* in quantum field mechanics (whereas it is actually only postulated in the standard theory): particle energy has the property of enertia due to its well-specified, *complex-dynamic* quantum beat *content*.

Combining equations (44) and (43), we obtain the standard expression for the de Broglie wavelength of a moving particle:

$$\lambda = \lambda_{\mathrm{B}} = \frac{h}{mv}\ . \tag{45}$$

Now, however, this famous relation, constituting the basis of the whole quantum physics, is not formally postulated (as in the standard, unitary theory), or "phenomenologically" explained (as in the original de Broglie approach [21]), but *rigorously derived* as a totally *consistent* consequence of the underlying *complex, multivalued interaction dynamics* within every massive elementary particle. This result and its derivation include, in particular, remarkable, *intrinsic unification* of "relativistic" and "quantum" particle properties remaining irreducibly split in the unitary theory but in reality resulting, as we can clearly see now, from the same complex dynamics of quantum beat process [1,4,7,8]. This omnipresent unification appears, for example, as otherwise "strange" combination of *classical* quantity v, *quantum* Planck's constant h, and *relativistic* total mass m in the same relation (45), or as the above complex-dynamical origin of inertial property of the total energy E due to its internal quantisation.

One can also conclude that the basic dispersion relation (44) results from the *symmetry of complexity* as the latter determines the underlying major *equivalence* between multiple realisations, including those of both global-motion tendency and irregular deviations from it. This very familiar and apparently "simple" relation, $p = mv$, includes, as we have seen, the whole complexity of the unreduced interaction dynamics and has further fundamental and *universally* valid consequences. In particular, by taking its time derivative, one obtains *rigorously derived*, *causally relativistic* and universally extended version of Newton's laws of "classical" dynamics (usually postulated), without any specially introduced classicality or empirically determined quantities (mass, energy, momentum, etc.):

$$\frac{\partial\,(mv)}{\partial t} = \mathcal{F}\,(x,t)\ , \quad \mathcal{F}\,(x,t) = \frac{\partial p}{\partial t} = \frac{\partial \mathcal{A}}{\partial x \partial t} = -\frac{\partial \mathcal{U}}{\partial x}\ , \quad \mathcal{U}\,(x,t) = -\frac{\partial \mathcal{A}}{\partial t}\ ,$$

where *force* $\mathcal{F}\,(x,t)$ and *potential energy-complexity* $\mathcal{U}\,(x,t)$ are thus *causally* defined, and continuous derivative notations are used for brevity, with the general meaning of *dynamically discrete* derivatives. Therefore Newton's laws also *result from the symmetry of complexity* (and underlying *multivalued* dynamics) if one asks for their *consistent derivation*. Such causally extended Newton's laws are *universally* applicable to *any* system and complexity level, although they may be more suitable and efficient in cases of homogeneous enough, *pseudo*-unitary dynamics.

Inserting now the obtained relativistic dispersion relation (44) into the complex-dynamic particle energy partition (41) and using energy definition (42), we get the explicit expression of *dynamically* derived *time relativity*:

$$\tau = \mathcal{T}\left(1 - \frac{v^2}{c^2}\right)\ . \tag{46}$$

As the period $\mathcal{T}$ provides the real (dynamic) time period for the *intrinsic* clock of the moving particle (system), we conclude that time slows down *within* the moving field-particle ($\mathcal{T} > \tau$) because time flow is explicitly *produced* by the *same*, complex-dynamic (multivalued) interaction process that gives rise to *global motion*. Combining equation (46) with a relation involving the quantum beat frequency ν_0 and period τ_0 at rest [1,7],

$$\mathcal{N}\nu = (\nu_0)^2 \quad \text{or} \quad \mathcal{T}\tau = (\tau_0)^2\ , \tag{47}$$

we get the canonical expression of time relativity (but now *causally derived* from the underlying *complex* dynamics):

$$\mathcal{N} = \nu_0\sqrt{1 - \frac{v^2}{c^2}} \quad \text{or} \quad \mathcal{T} = \frac{\tau_0}{\sqrt{1 - \dfrac{v^2}{c^2}}}\ . \tag{48}$$

Note that equation (47) also follows from the symmetry (conservation) of complexity: it means that the system realisation number filling the rectilinear $\mathcal{N} \times \nu$ area remains unchanged. The

complex-dynamic time relativity thus rigorously derived from the symmetry of complexity is easily extended to other effects of special relativity.

The obtained *intrinsic unification* of causally derived versions of *relativistic* and *quantum* dynamics in a single, *complex-dynamical* quantum beat process for a moving field-particle can be summarised by insertion of the time relativity expression (48), dispersion relation (44) and de Broglie wavelength formula (45) into the total energy partition (41):

$$E = h\nu_0\sqrt{1-\frac{v^2}{c^2}} + \frac{h}{\lambda_{\rm B}}\,v = h\nu_0\sqrt{1-\frac{v^2}{c^2}} + h\nu_{\rm B} = m_0c^2\sqrt{1-\frac{v^2}{c^2}} + \frac{m_0v^2}{\sqrt{1-\dfrac{v^2}{c^2}}}\ , \tag{49}$$

where $h\nu_0 = m_0c^2$ according to equation (34) and *de Broglie frequency* $\nu_{\rm B}$ is defined as

$$\nu_{\rm B} = \frac{v}{\lambda_{\rm B}} = \frac{pv}{h} = \frac{\nu_{\rm B0}}{\sqrt{1-\dfrac{v^2}{c^2}}} = \nu\,\frac{v^2}{c^2}\ ,\quad \nu_{\rm B0} = \frac{m_0v^2}{h} = \nu_0\,\frac{v^2}{c^2} = \frac{v}{\lambda_{\rm B0}}\ ,\quad \lambda_{\rm B0} = \frac{h}{m_0v}\ . \tag{50}$$

The physical *reality* of de Broglie wave (emerging as a *complex-dynamic field-particle structure*) is confirmed now by the standard relation between its length, frequency, and velocity, $\lambda_{\rm B}\nu_{\rm B} = v$, which describes *occasional quantum jumps* of the moving particle wave field to the distance $\lambda_{\rm B}$, occurring with the *average* frequency $\nu_{\rm B}$ and accompanied by extended *chaotic wandering* of the particle reduction centre (virtual soliton) around global motion, reducing its velocity from c (for any single jump) to v. As the frequencies in equation (49) refer to quantised, *causally random* field-particle jumps, it follows that the quantities $\alpha_1 = v^2/c^2$ and $\alpha_2 = 1-\alpha_1 = 1-v^2/c^2$ are none other than *dynamically* obtained *(compound) realisation probabilities* of, respectively, global (average) and totally random tendencies of the moving field-particle dynamics, in agreement with their general definition (10), which confirms once again the *intrinsic unity* of "quantum" and "relativistic" manifestations of the *unreduced interaction complexity*.

Equation (49) provides also *relativistic transformation of (total) mass* and thus de Broglie wavelength (45), the latter demonstrating dynamic and "quantum" origin of *relativistic contraction of length* of a globally moving body (it can also be derived from relativistic time retardation):

$$m = \frac{E}{c^2} = m_0\left(\sqrt{1-\frac{v^2}{c^2}} + \frac{\dfrac{v^2}{c^2}}{\sqrt{1-\dfrac{v^2}{c^2}}}\right) = \frac{m_0}{\sqrt{1-\dfrac{v^2}{c^2}}}\ ,\quad \lambda_{\rm B} = \frac{h\sqrt{1-\dfrac{v^2}{c^2}}}{m_0v} = \lambda_{\rm B0}\sqrt{1-\frac{v^2}{c^2}}\ . \tag{51}$$

The first term of the final complex-dynamic energy partition (49) taken with the negative sign provides the *causally derived* expression for *relativistic particle Lagrangian*, $\Delta\mathcal{A}/\Delta t = pv - E \equiv L$ (see also equation (26) and above in this and the previous sections), that remains valid, of course, for any macroscopic body (agglomerate of particles):

$$L = -h\mathcal{N} = -h\nu_0\sqrt{1-\frac{v^2}{c^2}} = -m_0c^2\sqrt{1-\frac{v^2}{c^2}}\ . \tag{52}$$

We obtain also the causal, complex-dynamic interpretation of Lagrangian as the energy of the *totally random* part of a system (field-particle) dynamics, or its "(internal) heat energy", specifying the corresponding heuristically introduced ideas of Louis de Broglie about "hidden thermodynamics" of a single particle [30], as well as his anticipation of *realistic extension* of usual "least action principle", describing now the *real*, dynamically chaotic system wandering around the average (global) motion tendency, rather than formal "variations" of action functional [1, 7]. Minimisation of action corresponds in our description to action-complexity transformation into

entropy-complexity, within *conservation* (symmetry) of the total complexity. Recalling that relativistic Lagrangian (52) is only mechanistically guessed and postulated in the standard special relativity and then used, together with artificially imposed "principle of relativity" and other postulates, for "derivation" of time relativity and other related effects, we can state now that the symmetry of complexity provides the *unified causal extension* of *all* those abstract and separated principles of the unitary theory, including least action and relativity principles, quantum postulates (see also below), first and second laws of thermodynamics.

It is clear that the obtained *dynamic* unity of physically real space (*structure*) and time (*events* of its explicit emergence) excludes their mechanistic unification in the same, "geometric" construction. Correspondingly, the symmetry of complexity underlying real world dynamics is much richer ("less symmetric") than unitary symmetries of standard relativity, which allows for a natural solution of all problems of their "violation" (including quantisation, irregularities, etc.), so that the symmetry of complexity remains always exact and gives the real, somewhat limited and irregular "relativity" that can also be directly extended to arbitrary levels of physically real space and time (see below) [1]. These general conclusions concern also the naturally emerging, *dynamically* based effects of *general relativity.*

Indeed, we have seen in section 1.3.3 that gravitational interaction between any material particles (protofield perturbations) emerges inevitably and universally due to their "deformation interaction" through the gravitational medium coupled everywhere to the equally omnipresent e/m protofield. This physically real gravity has therefore intrinsically *dynamic* and *quantised*, but not "geometric" origin (even though a formal geometric *description* can be applied and give correct results within its validity domain, similar to other cases of deformation interaction through a quasi-continuous medium). It is evident that gravitational medium perturbation and interaction magnitude will grow with the above causally specified inertial mass of interacting body, which gives the generalised, *causally substantiated* "principle of equivalence", as opposed to its formally postulated version of the conventional general relativity. In a usual case of not very dense interaction configurations, essentially beyond the (modified) Planckian unit situation (section 1.3.4), the same quantity of *inertial* mass (temporal rate of action-complexity change, section 1.3.2) will also play the role of *gravitational* mass (i.e. "gravitational charge"). Those gravitational mass-charges and their interaction through gravitational medium are produced by the *same, complex-dynamic* quantum beat processes that give rise to electric charges and their interaction through the e/m protofield, which is another manifestation of the universal symmetry of complexity and its "naturally broken" character. The latter is due here to *different physical properties* of e/m and gravitational protofields (sections 1.1, 1.3.3) and appears e. g. in the fact that there is no "sign" of gravitational mass-charges and they always attract to each other (beyond the Planckian-scale situation of unified interactions) [1].

The intrinsically *quantised* dynamic origin of mass determining the local *flow of time* (see also sections 1.3.1, 1.3.2) naturally leads to *causally explained, dynamic* effects of general relativity, demonstrating once more *inseparable unification of quantum and relativistic manifestations* of dynamic complexity in quantum field mechanics [1, 7, 8]. In particular, the quantum beat frequency ν (see equations (34), (42)) directly depends on the local gravitational protofield tension/density created by other material objects and described as "gravitational (field) potential":

$$M(x)\,c^2 \equiv h\nu(x) = mc^2\sqrt{g_{00}(x)}\,, \tag{53}$$

where $\nu(x)$ is the local quantum beat frequency for a "test" particle, while "metric" $g_{00}(x)$ describes in reality the gravitational protofield tension, $g_{00}(x) = 1 + 2\phi_{\rm g}(x)/c^2$, $\phi_{\rm g}(x)$ being the classical gravitational potential (we use the standard relation for the weak field case [31]). Since $\nu(x)$ determines the causally derived time flow and $\phi_{\rm g}(x) < 0$ ($g_{00}(x) < 1$) for *attractive* gravitational interaction, equation (53) provides the causal, dynamically derived version of "relativistic time retardation" in the gravitational field.

The unified complex-dynamic origin of both relativistic and quantum effects becomes yet more complete when we provide the explicit causal derivation of major quantum mechanical wave equations, as they are associated most closely with the specific "quantum" (undular) kind of behaviour. Such complex-dynamic origin and causal derivation of the Schrödinger equation from the underlying symmetry of complexity are provided in section 1.2, together with the related causal solution of the unitary "quantum mysteries" and Schrödinger formalism generalisation to any higher complexity levels (see equations (23)–(32)).

The key condition of causal quantisation (28) reflecting quantum beat dynamics gives rise to the "Dirac quantisation" rules, which are now dynamically explained [1, 7, 8], but only formally postulated in the unitary theory:

$$p = \frac{\Delta\mathcal{A}}{\Delta x} = -\frac{1}{\Psi}\, i\hbar\, \frac{\partial\Psi}{\partial x} \ , \quad p^2 = -\frac{1}{\Psi}\, \hbar^2 \frac{\partial^2\Psi}{\partial x^2} \ , \tag{54}$$

$$E = -\frac{\Delta\mathcal{A}}{\Delta t} = \frac{1}{\Psi}\, i\hbar\, \frac{\partial\Psi}{\partial t} \ , \quad E^2 = -\frac{1}{\Psi}\, \hbar^2 \frac{\partial^2\Psi}{\partial t^2} \ . \tag{55}$$

Inserting these causally obtained rules into relativistic equations of the same complex-dynamic origin, we can obtain various relativistic wave equations. Thus, complex-dynamic energy partition for a moving particle (49) can be written as

$$E = m_0c^2\sqrt{1 - \frac{v^2}{c^2}} + \frac{p^2}{m} \quad \text{or} \quad mE = m_0c^2 + p^2 \ . \tag{56}$$

Combining equations (54)–(56), we get the Klein-Gordon or Dirac equation for a free particle:

$$\frac{\partial^2\Psi}{\partial t^2} - c^2\frac{\partial^2\Psi}{\partial x^2} + \omega_0^2\Psi = 0 \ ,$$

where $\omega_0 \equiv m_0c^2/\hbar = 2\pi\nu_0$ is the "circular" frequency of quantum beat pulsation at rest (see equation (34)), which actually accounts for the spin vorticity twirl (see section 1.3). More complicated versions of relativistic wave equations for interacting field-particles can be obtained in the same way as causal consequences of the underlying symmetry of complexity, whereas their nonrelativistic limit leads again to the causally substantiated Schrödinger equation [1].

A straightforward analysis shows also that the Schrödinger equation (29) with the Hamiltonian $H(x, p, t) = p^2/2m + V(x, t)$, where $V(x, t)$ is a *binding* potential well, can be satisfied only for a *discrete* set of configurations of the wavefunction $\Psi(x, t)$ determined by *integer* numbers of the *same* action-complexity quantum, h, that describes *quantum-beat cycle*, or "system realisation change" (see section 1.3.4), which explains the famous quantum-mechanical *energy-level discreteness* (e. g. in atoms) by *complex-dynamical discreteness (or causal quantisation)* of the underlying protofield interaction process [1] and shows why the same Planck's constant appears also at this *higher sublevel* of quantum dynamics.

Another "postulated mystery" of the unitary quantum-mechanics, *linear superposition* of various *probabilistically* emerging states, including the particular case of *quantum entanglement* for a many-body system, reflects the *real* but *multivalued* dynamics of *underlying interaction*, where the system performs unceasing series of reduction-extension cycles, or *real quantum jumps*, between the corresponding *realisations* with the now *dynamically* determined probabilities (see equations (9)–(12), (31)). The *quasi*-linearity of wavefunction behaviour is due to the *transiently* weak, perturbative interaction character *only* within the intermediate (main) system realisation that constitutes the *physically real* version of the wavefunction, whereas the actually *measured* eigenvalue *emergence* from the wavefunction realisation, obscured by the "inexplicable" conventional postulates, is due to its *essentially nonlinear* and *physically real* reduction to respective regular, localised realisations (section 1.1). The symmetry of complexity between *all* system realisations naturally provides thus the necessary *dynamic unification* of those "opposite", linear

and nonlinear, undular and corpuscular, distributed and localised, types of behaviour within the single, holistic interaction process.

The revealed unified, causal origin of quantum, special-relativistic and general-relativistic effects in the underlying complex (multivalued) interaction dynamics finds further confirmation in its straightforward *generalisation to (arbitrary) higher complexity levels*, where one can also observe dynamic discreteness (quantisation) and "relativistic" modification of the respective time flow rates and length scales [1]. Rigorous derivation of unified quantum and relativistic behaviour for arbitrary (many-body) interaction process starts from the existence equation for such a process, equation (4), that generalises all (correct) "model" equations (see also section 1.2) and leads to the same basic system of equations (3) as the protofield existence equation (1) at the first complexity level (section 1.1) [1, 2, 4, 6, 13, 14]. We follow then the standard complexity development analysis by the unreduced EP method, sections 1.1–1.2, and obtain *universal dynamic discreteness (quantisation)* of unreduced, complex interaction dynamics and its detailed description by the *unified Hamilton-Schrödinger formalism* (24)–(32).

The universal physical origin of *discrete* structure of *unreduced* interaction dynamics accounts for the basic phenomenon of *dynamic multivaluedness* itself and takes the form of omnipresent *dynamic instability* by interaction feedback loops (section 1.1), where the self-consistent EP dependence on the solution to be found (equations (5)–(6)) makes impossible an evolutionary, smooth change of system configuration that follows instead a series of highly *inhomogeneous, "quantum" jumps* between its incompatible realisations. Major expression of unreduced interaction quantisation at any level of complexity is provided by quantised elements of emerging space structure Δx (distance between neighbouring realisation configurations) and related time increments Δt (duration of transitions between realisation, or realisation change events), which are determined according to universal energy-complexity and momentum-complexity definitions (21), (22) (see also equations (42), (43) for the quantum complexity level):

$$\Delta x = \frac{\mathcal{A}_0}{p} \ , \quad \Delta t = \frac{\mathcal{A}_0}{E} \ ,$$

where $\mathcal{A}_0 \gg h$ is a characteristic action value, which is not as unique/universal, however, as its value h at the lowest, quantum complexity level. The dynamically determined time increment $\Delta t = \tau$ is a period of "generalised quantum beat", and for the system globally at rest, it is directly related to the generalised inertial (rest) mass m_0 and energy E_0 (cf. equation (34)):

$$E_0 = m_0 v_0^2 = -\frac{\Delta \mathcal{A}}{\Delta t} = \frac{\mathcal{A}_0}{\tau_0} = \mathcal{A}_0 \nu_0 \ , \tag{57}$$

where v_0 is the perturbation propagation speed in a lower-level structure (analogous to the speed of light at the first complexity level), and $\nu_0 = 1/\tau_0$ is the generalised quantum beat (realisation change) frequency determining the corresponding *level* of *causal, irreversible time flow.*

Generalised (special) relativity of this *higher-level time* (and space) for a *globally moving system* follows from the universal symmetry of complexity in the same way as the corresponding relativistic effects at the first complexity level (see above in this section). Universal definitions of the *states of rest and motion* by, respectively, minimum and greater than minimum values of differential complexity (energy) remain directly applicable at any complexity level. The related *chaotic wandering* of the globally moving system around its average motion tendency leads to *essential difference* between its *total* differential complexity (total energy E) and *pseudo-regular, averaged* motion part (determined by momentum p) expressed by the (generalised) "relativistic dispersion relation" between E and p (cf. equation (44)):

$$E = pV\,(v) \ , \tag{58}$$

where $V(v) > v, v_0$ is the generalised, "faster-than-light" (and actually fictitious) "phase velocity" function; for example, in the simplest case of homogeneous chaotic wandering one has $V(v) = (v_0)^2/v$ (this is the case of dynamic relativity at the first complexity level with $v_0 = c$).

Using now the generalised dispersion relation (58) in combination with universally applicable equations (41), (42), and (47), one obtains the *universal, dynamically derived time relativity* (retardation) for a globally moving system of *any* complexity (and time) level (cf. equations (46), (48) for the first complexity level):

$$\tau = \mathcal{T}\left(1 - \frac{v}{V(v)}\right) \ , \quad \mathcal{T} = \frac{\tau_0}{\sqrt{1 - \dfrac{v}{V(v)}}} \ , \quad \mathcal{N} = \nu_0 \sqrt{1 - \frac{v}{V(v)}} \ .$$

As $\mathcal{N} < \nu_0$, objective, real time *goes relatively slower* within a *globally moving*, or in general *developing*, system due to investment of a larger part of the whole energy-complexity to that global motion tendency and corresponding decrease of the "time-producing" energy of purely random wandering around that average tendency. Similar to the fundamental, first-level relativity, the key point here is the *complex-dynamic origin* of *real physical time* itself.

System interaction with omnipresent environment, or (generalised) "field", gives rise to universal effects of general relativity. Using generalised mass-energy definition (57) we can directly extend the first-level expression of complex-dynamical time retardation in the field of gravity (53) to arbitrary complexity level:

$$M(x)\, v_0^2 \equiv \mathcal{A}_0 \nu(x) = m v_0^2 \sqrt{1 + \Phi(x)} \ , \tag{59}$$

where x is the generalised coordinate of the "test" system, $\nu(x)$ is its generalised quantum beat (realisation change) frequency, determining flow rate of the corresponding level of its internal, physically real time, and $\Phi(x)$ is the (dimensionless) potential of environmental field ($|\Phi(x)| < 1$). Contrary to attractive gravity field, one may have both $\Phi < 0$ and $\Phi > 0$ at arbitrary complexity levels, and therefore "internal" system time can either slow down or accelerate depending on the properties of the environment and its interaction with the "test" system.

Universal relativistic modifications of length (spatial dimension) and generalised mass are obtained in a straightforward way together with respective time relativity. By analogy to equation (51), the "generalised de Broglie wavelength" $\Lambda_{\rm B}$, or characteristic size of a globally moving system (at arbitrary complexity level), and its generalised mass transform as:

$$m = \frac{m_0}{\sqrt{1 - \dfrac{v}{V(v)}}} \ , \quad \Lambda_{\rm B} = \frac{\mathcal{A}_0}{mv} = \frac{\mathcal{A}_0}{m_0 v} \sqrt{1 - \frac{v}{V(v)}} \ .$$

The universal general-relativistic mass and length transformations follow from equation (59):

$$M(x) = m\sqrt{1 + \Phi(x)} = m_0 \sqrt{\frac{1 + \Phi(x)}{1 - \dfrac{v}{V(v)}}} \ , \quad \Lambda_{\rm B}(x) = \frac{\mathcal{A}_0}{mv\sqrt{1 + \Phi(x)}} = \frac{\mathcal{A}_0}{m_0 v} \sqrt{\frac{1 - \dfrac{v}{V(v)}}{1 + \Phi(x)}} \ .$$

The unified quantum and relativistic manifestations of the symmetry of complexity at the first and higher complexity levels provide the causally complete, realistic and demystified understanding of the respective types of behaviour that look irreducibly "weird" and only formally postulated in the traditional, unitary description. Thus, one can now provide an exact, *physically realistic* answer to the question why a moving clock mechanism goes slower with respect

to the one at rest: it happens because a growing proportion of total moving system dynamics (measured by its energy-complexity) goes to this global motion tendency from the internal motion that just determines the "proper" time flow rate, for *any* its measurement mechanism and *in the same way* at *any level* of that mechanism. Moreover, the obtained extension of causal relativity effects to *any* system dynamics provides a *rigorously specified* explanation even for such traditionally "subjective" effects as personal, "psychological" time flow change with the environment ("general relativity") and internal development ("special relativity") of a conscious subject [1]. The practically unlimited *power* of the universal symmetry of complexity to *solve real-world problems* is thus convincingly demonstrated, in addition to various other examples described in this paper.

1.3.8 Genuine quantum chaos, causal quantum measurement, and complex-dynamic classicality emergence in closed systems

We have rigorously derived, in previous sections 1.3.1–1.3.7, the lowest, "quantum" sublevels of world structure and complexity, in the form of physically real space and time, elementary particles, their intrinsic and dynamical properties, and fundamental interaction forces, all of them emerging as a result of the unified symmetry (conservation and transformation) of complexity of the underlying interaction between two initially homogeneous protofields. The next sublevels of world complexity naturally emerge by the same kind of unreduced interaction between those elementary structures, appearing thus as further, dynamically continuous development of the same, unified protofield interaction (next sublevel of its *dynamically fractal* hierarchy). They contain the elements of *both quantum* (undular, nonlocal) *and emerging classical* (corpuscular, localised) behaviour and can take the form of *(genuine) quantum chaos* for *essentially non-dissipative* (Hamiltonian) interaction cases, or *causal quantum measurement* for *slightly dissipative* systems, or complex-dynamic *classicality emergence* in elementary (closed) *bound systems* (like atoms) [1, 4, 7, 8, 10, 11, 32].

The situation of *quantum chaos* [1, 4, 10, 11] is described by a particular case of general existence equation (4), the Schrödinger equation (now causally derived) for many (in general) particles interacting among them and with external, time-dependent field(s), for example:

$$i\hbar\frac{\partial\Psi}{\partial t} = \left[\sum_{\substack{i,j=1\\ i\neq j}}^{N} -\frac{\hbar^2}{2m_i}\frac{\partial^2}{\partial x_i^2} + V_{ij}(x_i, x_j) + U_i(x_i, t)\right]\Psi(X, t) \ ,$$

where $X = (x_1, x_2, \ldots, x_N)$ is the vector of all particle coordinates (x_i are also vectors, in general), $U_i(x_i, t)$ is the time-dependent external field potential acting on i-th particle with the mass m_i, $V_{ij}(x_i, x_j)$ are potentials of interaction between i-th and j-th particles, and N is the number of particles. Time-periodic external fields $U_i(x_i, t)$ are of special practical and fundamental interest for Hamiltonian chaos problem (where periodic dependence on time is generally equivalent to periodic dependence of external interaction on one of space coordinates). In that "canonical" case external field can be presented as a Fourier series:

$$U_i(x_i, t) = \sum_{n=-\infty}^{n=\infty} U_{in}(x_i)\exp(i\omega_\pi nt) = U_{i0}(x_i) + \sum_{n\neq 0} U_{in}(x_i)\exp(i\omega_\pi nt) \ ,$$

where ω_π is the perturbation frequency, n takes only integer values, and we can consider, without limitation of generality, that $U_{i0}(x_i)$ constitute integrable, binding potentials of "free" particle motion (i.e. their motion in the absence of essential, chaos-bringing interaction).

Our general analysis (section 1.1) shows that both inter-particle interactions and their interaction with the external field will lead to dynamic multivaluedness and related intrinsic randomness

in a quantum system with interaction. However, Hamiltonian chaos emerging due to integrable system interaction with time- or space-periodic field constitutes a major, most transparent case, especially for the quantum chaos problem. Application of the unreduced EP analysis and results to that situation reveals indeed the *genuine, dynamic randomness* in a *purely quantum* system (that can be *far* from the semi-classical limit), in the same, universal form of multiple, incompatible realisations forced to permanently replace each other in a causally random (probabilistic) order thus defined [1, 4, 10, 11]. The problem of *genuine* quantum chaoticity, persisting in the usual theory, acquires thus the direct, universal and transparent solution.

The universal criterion of global chaos onset (33) remains valid for quantum chaos, but the characteristic frequency ω_q and energy-level separation $\Delta\eta_n$ of intra-component motion are replaced, respectively, by the perturbation frequency ω_π and "quantum energy" $\hbar\omega_\pi$:

$$\kappa \equiv \frac{\Delta\varepsilon}{\hbar\omega_\pi} = \frac{\omega_0}{\omega_\pi} \cong 1 \ , \tag{60}$$

where $\Delta\varepsilon$ is energy-level separation in the non-perturbed Hamiltonian system (with the above integrable potential $U_{i0}(x_i)$) and $\omega_0 = \Delta\varepsilon/\hbar$ is its characteristic frequency. It is important, in particular, that the global Hamiltonian chaos criterion (60) obtained by purely *quantum-mechanical* analysis has a classical form (frequency ratio) that coincides (in the limit $\hbar \to 0$) with the respective chaos criterion obtained within *classical mechanics* [1, 10, 11] and thus confirms the usual *correspondence principle* for *real, chaotic* systems, which constitutes the well-known unsolved problem of the unitary quantum chaos description. We can conclude that the symmetry of complexity (here between *all* realisations of a Hamiltonian quantum system) provides solution to a practically important and otherwise "unsolvable" problem.

The problem of quantum measurement is different from the Hamiltonian quantum chaos situation by a local, small but finite energy *dissipation* towards the measurement device that has *no* special "classical" or "macroscopic" character in our analysis, but needs that initial dissipation as a source of *real change* of its state. The unreduced EP analysis and results remain basically the same, but local dissipation violates equality between system realisations and creates a transient compound, SOC-type realisation (section 1.2) accompanied by spatial system reduction (dynamical squeeze) towards the centre of dissipation (cf. section 1.1) that explains all quantum measurement properties by *causal, but complex (multivalued) interaction dynamics* [1, 32]. It is important that *before* (as well as after) the *dynamically random* emergence of quantum measurement event, the measured quantum system performs *unceasing transitions*, i.e. *physically real "quantum jumps"*, between *all its eigenstates* (with the corresponding, *now dynamically determined* probabilities), which provides *causal, dynamic* explanation for the *formal* quantum postulates about "linear superposition" of eigenstates (see also section 1.3.7). Self-amplifying complex-dynamic transformation of *externally* "linear" combination into "classical", incoherent sum of probabilities provides consistent solution to the famous "Schrödinger cat" paradox [4].

Classical, permanently localised kind of dynamics emerges *dynamically* as a natural "advanced" case of quantum measurement, where transient SOC state during measurement event becomes *permanent*, actually giving rise to the *next, higher level of dynamic complexity.* Specifically, such elementary classical states emerge as *bound states of elementary particles* (such as atoms), which have a classical behaviour tendency in a totally *closed* system configuration, *without* any "environmental decoherence" effects necessarily evoked in the standard quantum mechanics and its unitary modifications. The role of unreduced interaction complexity is essential in understanding of that *qualitative* transition ("generalised phase transition" [1]) to a higher complexity level: it is the *dynamically random*, "quantum" wandering processes of virtual solitons of *each* of the *bound* system components that determine *vanishingly small probability* of longer-distance jump series of *all* components in the *same* direction (which would determine "quantum", delocalised system behaviour) [1, 4, 7, 8]. The same *internal dynamic complexity*

of a classical system (in the form of a SOC kind of state) explains the "asymptotic", fractal boundary between quantum and classical behaviour and occasional *dynamic* revivals of quantum behaviour for classical, sometimes macroscopic systems under the influence of their suitable interactions (in direct contradiction to all "decoherence" theories).

In terms of our rigorous criterion of chaoticity (33), a classical, bound-SOC state is described by the chaoticity parameter $\kappa = \omega_\xi/\omega_q \approx U_\xi/m_q c^2$, where ω_ξ is the bound motion frequency, ω_q is the component quantum beat frequency, $U_\xi = \hbar\omega_\xi$ is the binding energy, and $m_q c^2 = \hbar\omega_q$ is the total component mass-energy. In all "usual" bound systems with well-defined components, including atoms, binding energy is much smaller than mass-energy, $U_\xi \ll m_q c^2$, or $\omega_\xi \ll \omega_q$, which determines the *complex-dynamic origin* of the "classical", *localised* and *externally* quasi-regular, SOC type of system configuration, $\kappa \ll 1$ (section 1.2) [4]. It is interesting to note that in "ultra-relativistic" elementary systems where binding energy can attain the rest energy, $U_\xi \sim m_q c^2$ (so that individual component structure cannot be ensured), the chaoticity parameter is not small, $\kappa \sim 1$, and thus classicality does *not* appear, which provides a nontrivial explanation for globally *quantum* behaviour of hadrons as "ultra-relativistic" bound systems of quarks.

In the simplest case of hydrogen atom ω_ξ coincides with the Bohr frequency and $U_\xi = \hbar\omega_\xi$ with the atomic energy unit $\varepsilon_0 = m_e e^4/\hbar^2$, while $m_q = m_e$ is the electron mass, and we have $\kappa = U_\xi/m_q c^2 = \varepsilon_0/m_e c^2 = e^4/\hbar^2 c^2 = \alpha^2 \ll 1$, where $\alpha = e^2/\hbar c \approx 1/137$ is the fine structure constant. In that way we confirm the complex-dynamic origin of hydrogen atom classicality and develop the above interpretation of fine structure constant in terms of electron realisation number $N^e_\Re$, $\alpha = 1/N^e_\Re$ (section 1.3.4). Indeed, if the electron quantum beat frequency is the synchronised frequency of virtual soliton wandering for both electron and proton in the hydrogen atom (cf. section 1.3.2), then the probability of their *correlated* quantum jump in the *same direction* will be of the order of $(N^e_\Re)^{-2} = \alpha^2 = \kappa$, thus confirming the above classicality interpretation in terms of *multivalued* SOC dynamics. The probability $\alpha(x)$ of correlated quantum wandering of two virtual solitons in a bound system to a distance x from their "equilibrium", global-motion separation is determined by $(N_\Re)^{-2x/\Delta x}$, where Δx is the quantum jump length ($\Delta x \simeq \lambda\!\!\!^{-}_{\rm C}$ for the electron, see section 1.3.4), so that $\alpha(x)$ drops exponentially with x. The pronounced classical, localised behaviour of a bound system is obtained if $N_\Re \gg 1$ and interaction is not so strong as to destroy component individuality (these two conditions should largely coincide for our unified world construction, see Figure 1).

We obtain here a causal, realistic explanation for the "fuzzy" atom structure, with "electron clouds", etc. that can have only inexact, figurative meaning in usual theory. In reality, all the regular electron "orbits" (Schrödinger wavefunction configurations) represent but the *average, global-motion* (and relatively weak) tendency of permanent *chaotic wandering* of a corpuscular electron state, or virtual soliton (cf. section 1.3.7). As we have seen above, larger deviations from a global motion "orbit" are exponentially suppressed, which explains orbit reality and well defined shape (especially for the ground state), but the relative *number* of (small) deviations is *large*. The above expression for the bound system chaoticity κ defines it also as a measure of global motion "relativity", and a comparison with the complex-dynamic interpretation of relativistic factor v^2/c^2 in section 1.3.7 shows that $\alpha = 1/N_\Re$ is also the *probability (proportion)* of quantum jumps *within* the global motion tendency (which should be expected in view of multivalued dynamics structure). It is easy to verify that for the electron $\Delta x = \lambda\!\!\!^{-}_{\rm C} = \alpha a_{\rm B}$, or $a_{\rm B} = N^e_\Re \lambda\!\!\!^{-}_{\rm C}$, where $a_{\rm B} = \hbar^2/m_e e^2$ is the Bohr radius and "average" radius of the ground-state orbit of the hydrogen atom. This well-known relation acquires now a new meaning as it shows that the size of the main electron orbit is intimately adjusted to the complex-dynamical "cycle" of $N^e_\Re$ (chaotic) quantum jumps around it. The whole internal dynamics of an atom appears now as a chaotic, *complex-dynamical engine* causally driven by the underlying *protofield interaction*, instead of fixed, abstract "state-vector" configurations, related formal "exact solutions", and underlying *irreducible* quantum mysteries of unitary atomic physics.

2 Complex-dynamic solution of major cosmological problems

2.1 Dark mass effects: Unitary projection of multivalued dynamics

In previous sections we have specified the first, most fundamental levels of explicit universe structure emergence in the process of complex-dynamic, unreduced interaction between two protofields governed by the universal symmetry of complexity. We have shown, in particular, that this unified symmetry determines self-tuning, dynamically adaptable universe structure creation without "anthropic" problems (section 1.3.5) and ensures strict positivity (and large value) of the total universe energy determining also the physically real, dynamically irreversible time flow (section 1.3.6). We shall continue now to study *cosmological manifestations* of the symmetry of complexity at its higher, *macroscopic* levels confirming its status of the unified Order of the World. In this section we show that the *same* unreduced dynamic complexity that determines non-zero material content of the universe (its positive mass-energy) provides also a natural and universal solution to multiple problems of apparently strongly excessive, hidden, or "dark" mass content of major cosmological objects (galaxies, clusters, etc.).

The dark mass problem involves various observations showing that universe structure dynamics, mostly on the scale of galaxies and related structures, would need larger, and often much larger, quantities of massive matter, than those that can actually be perceived (see e. g. [33–36]). Great *variability* of the missing mass effect is a serious additional complication of a problem. We show that these difficulties of the *unitary interpretation* are actually spurious and originate from the same incorrect *neglect* of the *main, chaotic* part of *real* system dynamics, now occurring at the level of cosmic object dynamics. If one considers the unreduced, *dynamically multivalued* system behaviour, the problem will not even appear and the truly chaotic dynamics of real objects will account for observed dynamical features with the "visible", normal mass values. It is important that one should take into account the *genuine*, dynamically multivalued chaos, rather than one of its unitary imitations by "involved" but basically regular behaviour.

The main idea is straightforward: because of *artificial* cut of all system realisations but one in the unitary theory (this is an *exponentially big* reduction for a many-body system, see section 1.3.5), one inevitably obtains a *missing motion* problem, which is interpreted as inexplicably "missing mass". One can specify this result in various ways, and we start with a demonstration of incompleteness of the standard virial theorem application to the real, multivalued dynamics of a many-body system, since it shows how the key balance between potential and kinetic energy can be modified by the true chaos.

If system components move under the influence of gravitational attraction, e. g. in a galaxy, then the ordinary virial theorem gives the following relation between the time-averaged values of kinetic $\bar{T}$ and potential $\bar{U}$ energy of a system or any its subsystem (see e. g. [37]):

$$2\bar{T} = -\bar{U} \ , \tag{61}$$

whereas in reality this *regular*-motion kinetic energy, $\bar{T} = \bar{T}_{\rm reg}$, is a *small* part of its true, *chaotic* content $\bar{T}_{\rm real}$:

$$\bar{T}_{\rm real} = \bar{T}_{\rm reg} N_{\Re} \ ,$$

where $N_{\Re}$ is an *effective* realisation number for a given kind of observation and averaging (usually $N_{\Re} \gg 1$, while $N_{\Re} = 1$ for unitary models of the standard theory).

The *observed* potential energy, $\bar{U}_{\rm obs}$, gives *real* kinetic energy:

$$2\bar{T}_{\rm real} = -\bar{U}_{\rm obs} \ . \tag{62}$$

However, if observations are interpreted within a unitary, *deficient* version of dynamics (61) implying that

$$2\bar{T}_{\rm reg} = -\bar{U}_{\rm obs} \ , \tag{63}$$

one obtains a "mysterious" *discrepancy*, δ, between (62) and (63):

$$\delta = \frac{\bar{T}_{\text{real}}}{\bar{T}_{\text{reg}}} = N_{\Re} \ .$$

It is explained *within the unitary model* as being due to "invisible", but actually present, or "dark" mass, $M_{\text{dark}} = M_{\text{real}} - M_{\text{reg}}$, whose relative value can be estimated as

$$\frac{M_{\text{real}}}{M_{\text{reg}}} = \frac{\bar{T}_{\text{real}}}{\bar{T}_{\text{reg}}} = \delta = N_{\Re} \ .$$

According to the unreduced, *complex-dynamic interpretation*, the observed discrepancy δ can be used for estimation of effective $N_{\Re}$ values. Since $\bar{T} \propto \overline{Mv^2}$, one can say that in reality there is *too much motion*, or (deviating) *velocity*, in a system with respect to unitary expectations, so that one has rather a "dark velocity (or kinetic energy)" effect:

$$(\overline{v^2})_{\text{real}} = N_{\Re}(\overline{v^2})_{\text{reg}} \ .$$

One can easily refine this result for a *distance-dependent case*, $N_{\Re} = N_{\Re}(r)$ (where r is a coordinate within the system), in terms of velocity-distance dependence curves, or "rotation curves", for galaxies. In that case an "anomalous" $v(r)$ dependence is *not* due to anomalies of mass distribution, $M(r)$ (attributed to "dark matter halos"), but due to "unexpected" (in the *unitary* model) contribution to average velocity from *chaotic* motion parts, so that $v(r)$ is proportional not to $\sqrt{M_{\text{reg}}(r) + M_{\text{dark}}(r)}$, but to $\sqrt{N_{\Re}(r)}$. In a general case,

$$v\,(r) = \sqrt{\frac{\gamma N_{\Re}\,(r)\, M_{\text{obs}}\,(r)}{r}} \quad \text{or} \quad N_{\Re}\,(r) = \frac{r v^2\,(r)}{\gamma M_{\text{obs}}\,(r)} \ , \tag{64}$$

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 $v(r)$ and $M_{\text{obs}}(r)$ dependences for perceivable, "normal" object components.

As should be expected, $N_{\Re}(r)$, and thus chaoticity, will typically have a wide, often irregular maximum in "looser" system parts, such as galactic halos and central, inter-component regions of a cluster. This result correlates with the *empirically based* MOND hypothesis interpreting "unusual" motion in those weak-interaction regions in terms of modification of Newtonian gravitational attraction itself (see e. g. [35, 36, 38–40]). There is even a deeper link between MOND hypothesis and our unreduced EP approach: in a real many-body system one always deals with an *effective*, rather than direct, interaction that bears the self-consistent influence of *all* system components, *differs* essentially from the direct interaction, and possesses *many* contributing, chaotically changing realisations. By contrast, if one takes any MOND-like assumption *without* reference to the underlying complex dynamics of the system in question, then any its explanation should still inevitably rely upon additional "dissipation" of unknown origin.

The observed *big variations* of dark mass effects for different objects represent a "heavy" difficulty for any explanation in terms of additional, "invisible" entities, but are, on the contrary, *inevitable* for the above unified explanation in terms of the true (multivalued) chaos effects. Such "unlimited" variability and visible "asymmetry" are just *unique* properties of the symmetry of complexity (section 1.2) appearing at all, but especially higher complexity levels. Moreover, one can trace a definite qualitative correlation between the expected object chaoticity (degree of irregularity), its spatial dependence, and the observed magnitude of "missing mass" effects (further extended verification is certainly necessary). It seems also to be much more consistent to explain an observed, variable system property by a *fundamental* property of its *dynamics*, rather than by a new, strangely escaping, and inevitably *fixed* entity (this situation is quite

similar to interpretation of the *origin of mass* at the *first* level of complexity, see section 1.3.2). One should also take into account the spatial dependence of chaotic mass distribution effects (or "structural" chaos) that tend to accumulate just outside of the main mass and interaction concentration in the system, in agreement with data interpretation using equation (64).

Finally, we emphasize once more the discovered *unified solution*, within the *symmetry of complexity*, of the missing mass problems at different levels of world dynamics, including elementary particle mass (section 1.3.2), the (total) mass-energy of the universe (section 1.3.6), and "dark mass" effects at the level of galactic structures (this section), all of them related to consistent solution of the *unreduced interaction problem* (sections 1.1–1.2).

2.2 Complex-dynamic solution of dark energy and Big Bang problems

The origin of *globally* missing, "distributed" universe energy, or "dark energy" [33–35], is directly related to the vicious circle of the *unitary* cosmology scheme centred on the *zero-energy universe assumption* and related *Big Bang hypothesis*, or "exploding vacuum" solution. Indeed, the latter starts from *postulated*, artificially imposed nothingness of the universe mass-energy content (see section 1.3.6), in the form of dynamically single-valued, *zero-complexity* reduction of universe dynamics (irrespective of particular "model" details and including occasional models with formally positive energy, but always zero dynamic complexity). Because of the *intrinsic instability* of that fundamentally *fixed*, static construction, one is forced to impose a mechanistic "general expansion" (or the reverse squeeze) of the universe as a single possible mode of its (totally illusive) "development". The choice for expansion, or Big Bang, is justified by a *particular interpretation* of the observed "red shift" effect (involving a number of *serious contradictions* in itself). However, the conceptual instability of *any* unitary model (absence of evolving, adaptable degrees of freedom, as opposed to abstract "parameters") persists in the form of multiple problems of the Big Bang model whose proposed "solutions" only transform them to other formulations or artificially introduced entities. The dark energy problem represents only the latest in the list, though scandalously big and long hidden, rupture in the *basically frustrated* construction: the discovered *slightly* uneven red-shift dependence on distance leads to a *huge* deficiency in the source of uneven expansion, supposed to be a distributed stock of mysterious, invisible energy that should take very exotic, normally *impossible* forms.

That *final impasse* of missing energy (and mass) content of the universe (see also the previous section) simply takes us back to the beginning of the unitary vicious circle, where such emptiness of the universe content has been *explicitly imposed* by the unitary paradigm itself. In fact we deal here with another, though unrealistically simplified case of the *symmetry (conservation) of complexity*, astonishing in its long-lasting reduction, $0 = 0$, applied here to the *whole universe content*. In other words, the symmetry of complexity provides the rigorous and properly universal substantiation of the fact that *all* the artificially reduced, *dynamically single-valued* universe models with zero value of genuine dynamic complexity will *inevitably* and *essentially* fail in description of *real, dynamically multivalued* universe structure characterised by *positive (and high)* value of unreduced dynamic complexity [1, 2, 9].[7]

By contrast, the unreduced, dynamically multivalued and probabilistically fractal structure of real interaction dynamics leads to *globally stable* concept of universe structure development, just because it is based on the omnipresent and massively adaptable *local, dynamic instability* of *explicit structure creation* (see also section 1.3.5). The explicit universe structure emergence in the *initially homogeneous* system of interacting protofields, starting from the physically real

[7]Note that any usual, zero-complexity cosmology necessarily implies, due to its dynamic single-valuedness, total basic *regularity* and thus zero entropy of the universe and any its quasi-closed subsystem, in contradiction to entropy growth principle. Any observed or described "chaoticity" or randomness of such universe content, on any scale, is inevitably reduced to mere "entangled regularity", in agreement with the old Laplacian vision of totally mechanistic, *basically predictable*, but maybe *practically* noncomputable world.

space, time, and elementary particles, intrinsically unified with their fundamental properties and interactions (section 1.3), can be described as a distributed *implosion* of ubiquitous, fractally structured *creation*, as opposed to mechanistic and intrinsically *destructive explosion* of the unitary Big Bang (and "inflation") schemes.

Therefore the "dark energy" problem *does not even appear* in the complex-dynamic, intrinsically creative cosmology, quite similar to all "anthropic" kind of problems (section 1.3.5). The self-tuning universe structure, liberated from artificial unitary instabilities and related "anthropic" speculations, emerges naturally and self-consistently, simply due to the unreduced, *truly exact* picture of the *underlying interaction* processes.

As for the origin of the observed *red shift effect* in radiation spectra of distant objects, it finds its consistent explanation in terms of *intrinsically nonlinear* radiation propagation properties in the system of coupled protofields (see section 1.3.2 and Figure 1), where some (relatively weak) loss of energy by soliton-like photons, propagating in the e/m protofield medium, is *inevitable* because of their weak, but finite coupling to the gravitational medium. Note the essential difference of this nonlinear energy dissipation from linear scattering effects in any ordinary model. The soliton-like photon, remaining stabilised by interaction with the gravitational protofield, can *slowly* give its *energy* to the gravitational degrees of freedom (most probably quarks) *without* any noticeable change of its direction of propagation (i.e. without any "blur" effects in the distant object images). Characteristic "transpiercing" and "circumventing" modes of soliton interaction with small enough obstacles can explain anomalously small loss and vanishing angular deviation effects for photons and very high-energy particles (see below).

One should also take into account possible contribution from modified protofield parameters around big mass concentration or various "special" objects, as well as "older" photon propagation at earlier stages of universe structure development. Detailed calculations of the effect will inevitably involve many unknown parameters of the system, but *qualitative* properties and *consistency of the whole picture* provide convincing evidence in favour of this kind of *fundamentally new* explanation for the red shift effect (within a broader scope of "tired light" approach) and its expected refinement, including the necessary clarification of the *detailed physical origin of photon* (missing persistently in the unitary theory framework).

The nonlinear red shift dependence on distance that gives rise to *catastrophic* consequences in the unitary cosmology can only be natural in the complex-dynamic, *essentially nonlinear* picture (section 1.1). The nonlinear energy-loss mechanism of soliton-like photons explains why this loss grows more slowly with distance, than any usual mechanism of diffuse scattering would imply (cf. the above note on soliton scattering dynamics). Similar dynamics could solve, by the way, the persisting puzzle of GZK effect for the ultra-relativistic particles, since at those super-high energies the motion of a massive particle approaches that of (a group of) photons, according to the results of quantum field mechanics [1, 7, 8]. Another, though maybe less specific, feature of red-shift data correlating with our explanation is (increased) growth of average scatter of data points with distance.

2.3 Complex-dynamic cosmology: Global universe structure development

Returning to the general picture of emerging universe (section 1), note once more that according to the underlying *symmetry of complexity*, it *cannot* contain "motion-on-circles" dynamics, on *any* scale of structure creation, so that the initial, *positive* amount of *dynamic information*, in the form of protofield interaction, gives rise to generalised, *complex-dynamical system birth*, followed by its uneven, *irreversible*, and global *transformation* into *dynamic entropy* (developed structure) within thus *universally* defined, *finite* system *life*, which ends up in the state of *generalised death, or equilibrium*, around the total transformation of the initial dynamic information into entropy (unless additional dynamic information is introduced into the system) [1].

The generalised "potential energy" of interacting protofields can be introduced e. g. by their explicit separation from the pre-existing state of "totally unified" (mixed) protofields that could have the form of a generally inert quark-gluon condensate in its "absolute" ground state. Although these "prehistoric" assumptions are subject to inevitable and increased uncertainty, they can be estimated rather definitely by general consistency and parsimony principles, now *rigorously specified* by the universal symmetry of complexity (see section 1.3.1). What appears to be much more certain, however, is that one does need an initial form of "potential" interaction energy, positively defined and specified here as "dynamic information", since the birth of a structured, real universe from absolute "nothingness", without genuine interaction development (which is the preferred dogma of the conventional unitarity), contradicts the fundamentally substantiated and *universally* confirmed symmetry (conservation) of complexity (section 1.2).

We can add here other perspectives of our complex-dynamical universe description, whose consistent development within the standard, unitary cosmology paradigm seems much less probable (cf. e. g. [41]). The highly uneven, long-distance concentration of various anomalous, superintense sources of energy, as well as their "peculiar" red-shift tendency, point to a (probably moving) "shape of the world", which looks quite natural in our interacting protofield logic, while it would need additional, "unnatural" assumptions in the Big Bang logic of "exploding emptiness". Growing problems with the *universe age* can be naturally solved in our complex-dynamic cosmology as it traces *explicitly* the *real life-cycle dynamics* of emerging structures, while the unitary theory encounters here another series of its *inbred* "instabilities" (due to the rigidly fixed, imposed "models" and mechanistic data fit). The same refers to structural difficulties of the omnipresent expansion and natural elimination in our approach of this and other "old" difficulties of the unitary cosmology, such as average *space flatness* and *homogeneity* (section 1.3.1), "anthropic" problems (section 1.3.5), causal origin of high-density states, real Planckian units and microwave background radiation (section 1.3.4). Intrinsic inclusion of *realistic, unified* solution of stagnating problems of quantum mechanics, field theory, and relativity (sections 1.1, 1.3) constitutes the *unique feature* of our theory that, being highly desirable, cannot be even expected for any unitary approach. Finally, *irreducibly complex* dynamics of detailed formation and evolution of galaxies, stars, and planetary systems is among further applications of the present theory that will similarly profit from the universal problem-solving power of the symmetry of complexity demonstrated above.

3 New mathematics of complexity and emergence

We have demonstrated, in previous sections, how the *universal symmetry of complexity*, including *conservation* and unceasing *development* of unreduced dynamic complexity describes the *explicit emergence* and *properties* of *real* universe structures, starting from elementary particles, their properties and interactions, and provides thus *consistent* and *unified* solutions to many stagnating problems of usual, zero-complexity models. This problem-solving power of the symmetry of complexity centered on the obtained property of explicit structure emergence necessarily involves a qualitatively new, extended application of familiar mathematical tools and ideas [1, 2, 6]. In this section we summarise the main features of the *new mathematics of emergence* thus obtained (it can also be called *new mathematics of complexity*), with the reference to previous sections presenting its more detailed framework (sections 1.1–1.2) and applications to fundamental world structures and properties (sections 1.3, 2.1–2.3).

The most important, embracing feature of the *new mathematics of emergence and complexity* is that it is represented by the *unified, single structure* of *dynamically probabilistic fractal* obtained as explicit, *causally complete solution* of *real, unreduced interaction problem* (Sect. 1.1). All its properties, describing the *exact* world structure and dynamics as it is, are unified within the single, *absolutely exact* (never broken) *symmetry, or conservation, of complexity* including

its *unceasing transformation* from complexity-information to complexity-entropy (Sect. 1.2). It means, in particular, that *all real-world structures*, and thus the *world/universe as a whole*, are *absolutely symmetric* (and *dynamically complex*) and in this sense *represent* the symmetry of complexity as such, the latter *explicitly producing*, in particular, all the observed *irregularities*. By contrast, omnipresent violations of usual, unitary symmetries result *inevitably* from their *artificially reduced*, dynamically single-valued basis, including all imitative models of usual, unitary "science of complexity" (cf. [43, 44]).

One can emphasize several *specific, but universally appearing features* of this unified structure and law of the new mathematics, distinguishing it essentially from the unitary framework [1, 6]:

(i) *Non*uniqueness of any *real, unreduced* (interaction) problem solution, in the form of its *dynamic multivaluedness (redundance)*; exclusively *complex-dynamic* (multivalued, internally *chaotic*) existence of any real system (cf. usual "existence and uniqueness" theorems).

(ii) Omnipresent, explicit *emergence* of *qualitatively new* structure and *dynamic origin of time* (change) and *events*: $\mathbf{A} \neq \mathbf{A}$ for *any* structure/element $\mathbf{A}$ in the new mathematics *and* reality, while $\mathbf{A} = \mathbf{A}$ (self-identity postulate) in the *whole* usual mathematics, which thus excludes any *real* change in principle.

(iii) Fractally structured *dynamic entanglement* of unreduced problem solution (interaction-driven, *physically real* intertwining between system components *within any realisation*): it is a *rigorous* expression of *material quality* of a real structure in mathematics (as opposed to "immaterial", qualitatively "neutral", "dead" structures of usual mathematics).

(iv) Basic deficiency of perturbation theory and "exact solution" paradigm: the unreduced problem solution is *dynamically random* (permanently, chaotically changing), *dynamically entangled* (internally textured and "living") and *fractal* (hierarchically structured). One obtains *unified dynamic origin* and *causally specified* meaning of such basic properties of unreduced problems and underlying real systems as *nonintegrability*, *nonseparability*, *noncomputability*, *(genuine) randomness*, *uncertainty (indeterminacy)*, *undecidability*, *"broken symmetry"*, etc. Real interaction problem is nonintegrable and nonseparable *but* solvable. Realistic mathematics of complexity is *well defined* (*certain*, *unified* and *complete*, cf. [42]), but its structures are intrinsically "fuzzy" (dynamically *indeterminate* and really *fluctuating*) and properly *diverse* (*not* reduced to numbers or geometry).

(v) *Dynamic discreteness (causal quantisation)* of unreduced interaction products (realisations) resulting simply from the *holistic* character of every unreduced interaction process. It appears as *qualitative* inhomogeneity, or *nonunitarity*, of any system structure and evolution and provides universal *dynamic* origin of (fractally structured) *space*. It demonstrates *qualitative deficiency* of usual unitarity, continuity *and* discontinuity, calculus, and *all* major structures (evolution operators, symmetry operators, *any* unitary operators, Lyapunov exponents, path integrals, etc.).

4 Conclusion: Real problem solution by real-world symmetry

The rigorously derived concept of *universal dynamic complexity* and related *symmetry of complexity* involve qualitatively extended and intrinsically unified properties that allow for the *causally complete*, totally realistic and consistent, description of world structure behaviour at any level of complexity in terms of *unreduced interaction problem solution* (sections 1.1–1.2, 3). However, this rigorously based consistency of the unified symmetry of complexity should also be *confirmed* by various *applications* to particular systems and levels of complexity.

A part of this applied aspect comes already from the *extended, causally complete interpretation* of the well-known (but often unexplained) observation results and related explicit *unification* of traditionally separated phenomena and levels of world dynamics. In that way one obtains, for example, not only *causal, dynamically based* explanation for major *quantum and relativistic effects*, but also their *intrinsic unification* by the symmetry of complexity and *extension* to *any* level of world dynamics (section 1.3.7). All the canonical "mysteries" and "inexplicable", formally imposed "postulates" and "principles" naturally appear now as *inevitable*, totally realistic manifestations of the *genuine, complex-dynamic* (multivalued) content of *any* structure and dynamics. As this content always obeys the exact symmetry of complexity, it turns out that the *whole* real world content, including all changes and structure creation processes, is *absolutely* and *exactly symmetric*, i.e. it is a unified, but properly diverse manifestation of the universal and never broken underlying symmetry, the symmetry of complexity.

The *problem-solving power* of the universal symmetry of complexity is further confirmed by a growing number of its *successful applications* to various particular systems covering the whole hierarchy of world's complexity and involving explicit solutions of both "old" and new, sometimes urgent problems emerging for both old and new kind of systems (and remaining "increasingly" unsolved within the unitary science paradigm) [1, 5–15]. One can briefly summarise such applications to systems from both lowest complexity levels (considered in this paper) and higher complexity levels (considered elsewhere) in the following way:

(1) In *particle and quantum physics* one obtains *causal, unified* origin and structure of *elementary particles*, *all* their *properties* ("intrinsic", quantum, relativistic) and interactions (section 1.3) [1, 4, 7–9, 22]. *Complex-dynamic origin of mass* (section 1.3.2) avoids any additional, abstract entities (Higgs bosons, zero-point field, extra dimensions, etc.). *Renormalised Planckian units* provide consistent *mass spectrum* and other stagnating problem solution, including causally complete explanation for the *physical* origin of *universal constants* and their *universality* (section 1.3.4). *Complex-dynamic cosmology* (including higher complexity levels) resolves the dark mass and energy problems without "invisible" entities (sections 2.1, 2.2), together with other old and new problems of unitary cosmology (sections 1.3.5, 1.3.6, 2.3). The established *fundamental link between the numbers of (realistically specified) space dimensions and interaction forces* (section 1.3.3) leaves no place for arbitrary insertion of "additional" entities (e. g. "hidden dimensions").

(2) At a higher complexity sublevel of *interacting particles* [1, 4, 7, 8, 10, 11, 32] (section 1.3.8) one obtains *genuine, purely dynamic quantum chaos* for Hamiltonian (nondissipative) dynamics and *correct correspondence principle* for (real) *chaotic systems* (natural transition from quantum to classical behaviour as $\hbar \to 0$). A slightly dissipative interaction dynamics leads to the *causally complete* understanding of *quantum measurement* in terms of (causal) *quantum* dynamics *alone*. *Intrinsic classically* emerges as a *higher complexity level* in a *closed*, bound system, like atom, without any ambiguous "decoherence by environment".

(3) *Realistic, causally complete* foundation of *nanobiotechnology* is provided by *rigorous* description of *arbitrary* nanoscale interaction, revealing the *irreducible* role of *genuine chaoticity* just on that smallest scale [4, 12]. *Exponentially huge power* of unreduced, complex nanobiosystem dynamics explains the *essential properties of life* and has direct relation to complex information and communication system development (see item (5) below).

(4) *Causally complete* description of *unreduced genome interactions* leads to *reliable, rigorously substantiated genetics* and consistent understanding of related *evolutionary processes* [6].

(5) Higher-complexity applications include *general many-body problem solution* and related description of "difficult" cases in *solid-state physics*, unreduced dynamics and evolution

of *living organisms* (causally complete understanding of the state of *life* as a high enough level of unreduced dynamic complexity), *integral (causally complete) medicine*, emergent (genuine) *intelligence* and *consciousness*, *complex information and communication system dynamics*, *creative ecology* and practically efficient *sustainable development concept*, *rigorously* specified *ethics* and *aesthetics* [1, 4–6, 13–15].

These results explicitly demonstrate the expected advantages of applying the (exact) *real-world symmetry* to *real problem solution* and outline practically unlimited development perspectives of the universal symmetry complexity and its applications.

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