Article

Scales, Hierarchies and Particles: A Unifying Approach on Quantum Gravity & Quantum Vacuum Model for Physics Beyond Standard Model

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Abstract

In epistemological affinity with the Bohm idea of implicate and explicate orders and with the view of an emergent physics, two different levels of the fundamental background of physics, invoked by the author in several recent papers, are considered for the beyond Standard Model physics: The quantum-gravity space and the three-dimensional dynamic quantum vacuum. The link between these two levels of physical reality is analysed and a unifying mathematical formalism is developed. The interpretation of the baryonic particles of the Standard Model inside this approach is examined. Finally, suggestive perspectives are introduced as regards the issues of generation of scales and hierarchies, which show how the effective theory of the Standard Model, Higgs mechanism, as well as the TeV scale of strong interactions, are emergent processes from this fundamental background.

Keywords: Scale, hierarchy, unified approach, quantum gravity, quantum vacuum, new physics, standard model.

1. Introduction

The developments of XX century theoretical physics suggest that physical reality can be seen as a hierarchical structure at interdependent generation, consisting of various descriptive levels between which precise relationships exist and in which the fundamental law is represented by the principle of collective organization. In this regard, quantum field theory surely plays a crucial role. In particular, the elaboration of QCD allowed the derivation of hadrons properties and interactions starting from the fundamental principles and elementary particles invoked by this theory, namely from the quark and gluon degrees of freedom. In the same way, the formulation of QED lead to find atomic and condensed matter physics and thus the world of our everyday experience as emergent properties.

On the other hand, in epistemological affinity with the foundations and the structure of quantum field theory, Bohm's theory of Implicate/Explicate order can be considered as the first significant attempt to realize the J.A. Wheeler program of *It from Bit* (or *QBit*), the possibility to describe the emergent features of space-time-matter as expressions, constrained and conveyed, of an

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informational matrix "at the bottom of the world" [1]. In this picture, the transition from the ultimate background represented by the implicate order to the explicate level characterized by local and fragmentary manifestations take place as a consequence of a sort of spontaneous symmetry breaking with respect to the laws regarding the undivided pre-space.

Today, it must be emphasized that the view of physical properties of space and particles as emergent properties which derive from a fundamental background is receiving more and more attention. Above all, the vision of quantum gravity as an emergent phenomenon is becoming the core of the theoretical speculations. Well known theories such as loop quantum gravity, group field theories, theories of causal sets as well as other approaches, suggest that space-time emerges from more fundamental structures which are not space-temporal in themselves, namely that fundamental microscopic discrete entities exist which constitute what we call space-time and that geometry and fields that are used to describe space-time are only approximated collective manifestations of these more fundamental microscopic entities. In this modern scenario, an emergent space-time, which is not only quantum, can be considered the object of quantum gravity and, as a consequence, quantum gravity leads to two radical aims: to identify and mathematically describe the atemporal and aspatial quantum entities which constitute the universe at the most fundamental level, and their dynamics; and to show how space-time as we know it and its dynamics in terms of General Relativity and Quantum Field Theory emerge in a peculiar approximation [2, 3].

In particular, in Oriti's Group Field Theory, space-time emerges at the level of collective dynamics from an atomic and quantum description of space-time, whose elementary quanta are the elementary constituents of space-time itself and universe becomes a condensate, a quantum fluid of quanta which allows the conceptual picture of cosmology to be obtained at the level of hydrodynamic approximation [4-7]. Moreover, always as regards current research of an emergent quantum gravity, in [8] a reformulation of gravity is proposed in terms of atoms of space-time-matter (STM), characterized by a classical non-commutative geometry, based on an asymmetric metric, and sourced by a closed string, which interact via entanglement. In this picture, the statistical thermodynamics of a large number of such atoms gives rise, at equilibrium, to a theory of quantum gravity and here, far from equilibrium, where statistical fluctuations are large, the emergent theory reduces to classical general relativity. In a similar way, in [9] it has been suggested that general relativity emerges from an underlying microscopic description, where the metric field and its dynamics are derivable from a type of microstructure constituted by strings, quantum bits or condensed matter fields.

In the spirit of an emergent view of space-time, I have recently developed two complementary descriptive levels of physical reality, with a corresponding appropriate mathematical formalism, which introduce interesting timeless perspectives towards the unification of gravity with quantum theory. These two approaches, known respectively as a-temporal quantum-gravity space theory and model of the three-dimensional dynamic quantum vacuum, suggest that a region of universal space which theoretically is void of all fields, elementary particles and massive objects, still exists on its own and so must have some concrete physical origin, in other words that the so called "empty space" is a type of energy that is "full" of itself, has its independent physical existence. In this way, they introduce new keys of reading as regards the issue of emergence and scales in physics, by considering a new form of " quantum ether" which can open scenarios that are all to be explored.

In the second half of the 19th century, William Clifford discussed the possibility that all matter derives simply by undulations in the fabric of space, that space waves are real, while mass and charge substances exist merely as emerging appearances of the wave structure of space. According to Clifford's view of the geometry of space, "small portions of space can be considered as little hills on a surface which is on the average flat […] and this property of being curved or distorted is continually being passed on from one portion of space to another after the manner of a wave" [10, 11]. By trying inspiration from Clifford's considerations, the a-temporal quantum-gravity space developed by the author of this paper suggests that the gravitational space can receive a wave description in terms of a wave function satisfying appropriate non-linear generalized Klein-Gordon and Dirac equations depending on two fundamental parameters: the density of cosmic space and the quantum number of "rotation-orientation" [12-15].

In the a-temporal quantum-gravity space theory, each region of the gravitational space is described by assigning a specific value of the density of space $D(r)$ which indicates that space is full of itself in the sense that it measures the degree of the fluid features of space. The density of cosmic space can be considered as the physical origin of the appearance of a material object in a given region of space. The mass m of a material object is an emerging entity from the density of space $D(r)$ on the basis of relation

$$m = \frac{D(r)\cdot r^2}{G} \tag{1}$$

Moreover, in this approach, the gravitational space has got a rotational-orientational degree of freedom which is described by the quantum vector

$$\vec{j} = \frac{G\vec{s}}{r^3} \tag{2}$$

(where $\vec{s}$ is the spin of the particle which derives from the density of cosmic space $D(r)$), which is assumed to be given by integer or half-integer multiple values of $\frac{\hbar G}{r^3}$ in order to assure consistency with the results of the standard quantum mechanics. In our theory, the density of cosmic space $D(r)$ and the quantum vector $\vec{j}$ indicating the rotation-orientation are interpreted as the mass and spin of a quasi-particle which may be termed the "Planck-Fiscaletti granule".

In other words, we can say that, at the level of the quantum-gravity space, the gravitational space is full of a sort of fluid energy which is given by the Planck-Fiscaletti granules defined by a density of cosmic space and a rotational-orientational degree of freedom. A crucial aspect of the interaction of the quasi-particles populating the gravitational space, namely the Planck-Fiscaletti granules, lies in its timeless nature, linked to the fact that no movement of particle-wave is needed for the action of gravitational interaction: gravity is transmitted directly by the density of cosmic space corresponding to each Planck-Fiscaletti granule. Two Planck-Fiscaletti granules characterized by different density of cosmic space $D_1(r_1)$ and $D_2(r_2)$), attract each other on the basis of the relation

$$\vec{F}_g = \frac{D_1(r_1)\cdot D_2(r_2)\cdot r_1^{\,2}\cdot r_2^{\,2}}{Gr^2}\hat{r} \qquad (3)$$

which represents the general law of interaction. According to equation (3) the following interpretation of masses' interaction emerges: material objects move in the direction where the density of cosmic space is increasing. On the basis of this approach, objects with lower mass have a tendency to move towards objects with bigger mass as a consequence of the fact that areas of lower density have a tendency to move towards areas of higher density.

On the other hand, in the effort to develop new perspectives as regards the fundamental background of physics, taking account of the current results of several authors, together with A. Sorli, I have recently proposed a model of a three-dimensional (3D) dynamic quantum vacuum (DQV) in which general relativity emerges as the hydrodynamic limit of some underlying theory of a more fundamental microscopic 3D quantum vacuum condensate [15-24]. In this model, which can also be called as "model of the 3D DQV", each elementary particle is determined by elementary reduction-state (RS) processes of virtual particles similar to the transactional processes invoked by Chiatti and Licata in [25, 26] and corresponding to opportune changes of a quantum vacuum energy density. This model implies that the variable energy density of DQV is the fundamental energy which gives origin to the different physical entities existing in the universe. The DQV energy density, as fundamental energy of the universe, cannot be created and cannot be destroyed and here time exists only as a mathematical parameter measuring the numerical order of changes.

The model of the 3D DQV postulates that, in the absence of elementary particles, atoms and massive objects, energy density of quantum vacuum is defined by the following relation:

$$\rho_{pE} = \frac{m_p \cdot c^2}{l_p^3} \qquad (4)$$

where m_p is Planck mass and l_p is Planck length. The quantity (4) is the maximum value of the quantum vacuum energy density and physically corresponds to the total average volumetric energy density, owed to all the frequency modes possible within the visible size of the universe, expressed by

$$\rho_{pE} = \frac{c^7\hbar}{G^2} = 4{,}641266 \cdot 10^{113} J/m^3 \qquad (5)$$

The Planck energy density (5) can be considered as the ground state of the same physical flat-space background: out of this fundamental energy particles and antiparticles continuously appear and disappear.

Moreover, taking account of Rueda's and Haisch's interpretation of the inertial mass as an effect of the electromagnetic quantum vacuum (in which the presence of a particle with a given volume expels from the vacuum energy within this volume exactly the same amount of energy as is the particle's internal energy, equivalent to its rest mass) [27], as well as Santos' explanation for the actual value

$$\rho_{DE} \cong 10^{-26} Kg/m^3 \tag{6}$$

of the dark energy density as the effect of the fluctuations of the quantum vacuum on the curvature of space-time [28-30], in the model of the 3D DQV each elementary particle is associated with fluctuations of the quantum vacuum which determine a diminishing $\Delta\rho_{qvE}$ of the quantum vacuum energy density. The changes $\Delta\rho_{qvE}$ of the quantum vacuum energy density with respect to the Planck energy density (4) represent here the origin of the mass of a material object. In other words, the mass of a material object by a change of the DQV energy density can be here considered as an emergent entity on the basis of equation

$$m = \frac{V \cdot \Delta\rho_{qvE}}{c^2} \tag{7}$$

where

$$\Delta\rho_{qvE} = \rho_{pE} - \rho_{qvE} \tag{8}$$

where V is the volume of the object. The model of the 3D DQV considers the possibility that relations (7)-(8) are valid both in macrophysics and in microphysics, in the sense that they describe baryonic matter both in macrophysics and in microphysics. Moreover, as shown in [17-20], this model has the merit to introduce a unifying treatment of dark energy and dark matter in terms of opportune, specific fluctuations of the quantum vacuum energy density: dark energy is associated with fluctuations of quantum vacuum energy density responsible of the curvature of space-time, dark matter is assimilated to a fundamental polarization of the vacuum characterized by a fluctuating viscosity.

Now, in this paper my aim is to analyse what is the possible link and what are the possible relations between these two different models of the fundamental background of physics, in other words to analyse, inside a unifying scheme, in what sense the a-temporal quantum-gravity space theory and the model of the 3D DQV provide a hierarchical structure at interdependent generation of physical reality, in epistemological affinity with the Bohm picture represented by the implicate/explicate order. This paper is structured in the following way. In chapter 2, I will develop a unifying mathematical formalism which permits to re-read the results of these two different approaches inside a unifying framework. In chapter 3, I will explore how, by following the lesson of condensed matter physics, my unifying approach of the a-temporal quantum-gravity space theory and the model of the 3D DQV, allows us to explain the issues of the generation of scales of the Standard Model, of the Higgs mechanism and of the spontaneous symmetry breaking in the TeV regime of strong interactions.

2. A unifying mathematical formalism for the a-temporal quantum-gravity space theory and the model of the three-dimensional dynamic quantum vacuum

The a-temporal quantum-gravity space approach and the model of the 3D DQV imply that the stage of physics has two levels of description at hierarchical generation in the sense that the a-temporal quantum gravity space can be seen as an emergent manifold from the more fundamental 3D DQV which can be regarded as the fundamental "quantum ether". More precisely, one can say that, in this picture, the gravitational space we perceive can be seen as a projection of the a-temporal quantum-gravity space characterized by Planck-Fiscaletti granules and that the a-temporal quantum-gravity space, in turn, emerges from the more fundamental three-dimensional timeless quantum vacuum. In this chapter we want to explore this relation between the quantum-gravity space and the 3D DQV.

Before all, one starts by defining a background, represented by the 3D quantum vacuum defined by the quantum vacuum energy density fluctuations (6) corresponding to RS processes of creation/annihilation of virtual particles, as the fundamental, deepest level of physical reality. This fundamental background represented by the 3D quantum vacuum is characterized by a ground state defined by the Planck energy density (4) which identifies a 3D Euclid space as a preferred fundamental arena, which is quantitatively defined by Galilean transformations for the three spatial dimensions

$$\begin{aligned} X' &= X - v\cdot\tau \\ Y' &= Y \\ Z' &= Z \end{aligned} \tag{9}$$

and Selleri's transformation

$$\tau' = \sqrt{1-\frac{v^2}{c^2}}\cdot\tau \tag{10}$$

for the rate of clocks. In equations (9) and (10) v is the velocity of the moving observer O' of the inertial frame o' measured by the stationary observer O and τ is the proper time of the observer O of the rest frame o, namely the speed of clock of the observer O (here, as usual, the origin of o', observed from o, is seen to move with velocity v parallel to the X axis). According to the transformations (9) and (10), the temporal coordinate has thus a different ontological status with respect to the spatial coordinates. It is the motion relative to the rest frame of the Euclidean space associated with the quantum vacuum energy density (4) that influences the clocks' running. On the basis of equations (9) and (10), we can conclude therefore that the real ultimate arena of special relativity is a 3D Euclidean space where time does not represent a fourth coordinate of space but must be considered merely as a mathematical quantity measuring the numerical order of material changes. The duration of material changes satisfying the standard Lorentz transformation for the temporal coordinate is a physical scaling function which emerges from the more fundamental numerical order τ defined by equation

$$t=\tau\left(1-\frac{v^2}{c^2}\right)+\frac{vX}{c^2} \tag{11}$$

and determines itself a re-scaling factor of the distance in the first spatial coordinate determined by the material motion of the form

$$\delta=\sqrt{\frac{1}{\tau}\left(t-\frac{vX}{c^2}\right)} \tag{12}$$

which yields just a re-scaling of the position measured by the moving observer expressed by the standard Lorentz transformation for the first spatial coordinate [24].

The RS processes of creation/annihilation of the virtual particles of the vacuum are subjected to evolution that can be described by a wave function $C=\begin{pmatrix}\psi\\ \phi\end{pmatrix}$ at two components satisfying a time-symmetric extension of the Klein-Gordon quantum relativistic equation

$$\begin{pmatrix}H & 0\\ 0 & -H\end{pmatrix}C=0 \tag{13}$$

where $H=\left(-\hbar^2\partial^\mu\partial_\mu+\frac{V^2}{c^2}(\Delta\rho_{qvE})^2\right)$ and $\Delta\rho_{qvE}=(\rho_{PE}-\rho_{qvE})$ is the change of the quantum vacuum energy density [9-18]. Equation (10) corresponds to the following two equations:

$$\left(-\hbar^2\partial^\mu\partial_\mu+\frac{V^2}{c^2}(\Delta\rho_{qvE})^2\right)\psi_{Q,i}(x)=0 \tag{14}$$

for creation events and

$$\left(\hbar^2\partial^\mu\partial_\mu-\frac{V^2}{c^2}(\Delta\rho_{qvE})^2\right)\phi_{Q,i}(x)=0 \tag{15}$$

for destruction events. Moreover, in this scheme, the 3D quantum vacuum characterized by RS processes turns out to be a non-local manifold, as a consequence of the fact that the RS processes are choreographed by a quantum potential of the vacuum

$$Q_{Q,i} = \frac{\hbar^2 c^2}{V^2 \left(\Delta\rho_{qvE}\right)^2} \left(\frac{\left(\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right)\left|\psi_{Q,i}\right|}{\left|\psi_{Q,i}\right|} - \frac{\left(\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right)\left|\phi_{Q,i}\right|}{\left|\phi_{Q,i}\right|} \right) \tag{16}$$

In the light of the quantum potential of the vacuum (16), the 3D quantum vacuum characterized by fluctuations of its energy density can be interpreted as an ultimate immediate medium of quantum entanglement, the fundamental source of non-local phenomena. In other words, the non-locality of the laboratory level may here be seen as a special case of this more fundamental non-locality regarding the 3D quantum vacuum. The degree of non-local correlations characterizing the 3D quantum vacuum can also be described by introducing an appropriate Bell length of the vacuum

$$L_{vacuum} = \sqrt{\frac{\hbar^2 c^2}{2V\Delta\rho_{qvE} Q_{Q,i}}} \tag{17}$$

namely

$$L_{vacuum} = \sqrt{\frac{V\Delta\rho_{qvE}}{2}} \left(\frac{\sqrt{\frac{|\psi_{Q,i}|}{\left(\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right)|\psi_{Q,i}|}}}{\sqrt{-\frac{|\phi_{Q,i}|}{\left(\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right)|\phi_{Q,i}|}}} \right) \tag{18}$$

The advantage to introduce a Bell length in order to describe the quantum world lies in the fact that it allows us to evaluate numerically the real degree of delocalization in a quantum system. The different values that the Bell length can assume correspond to different degrees of non-locality. In particular, in the light of some recent research, the maximum de-localization of a quantum system corresponds to the value 1 of the Bell length [31]. Since the 3D quantum vacuum acts as an immediate information medium between subatomic particles, in this picture, time is not a fundamental reality in which material changes occur but emerges as a mathematical parameter which measures the sequential numerical order of motion of local objects [15-24].

Now, by starting from the 3D DQV defined by energy density fluctuations, one can obtain the behaviour of matter in the gravitational space as an emergent phenomenon, in agreement with an emergent view of physics. In other words, the Planck-Fiscaletti granules defining the a-temporal quantum-gravity space can be seen as collective excitations which emerge from the primordial and most fundamental 3D DQV. The density of cosmic space (1) emerges as a collective excitation from elementary fluctuations of the quantum vacuum energy density on the basis of relation:

$$D(r) = G\,\frac{V\cdot\Delta\rho_{qvE}}{c^2 r^2} \tag{19}$$

In other words, in the gravitational space, the fluctuations of the quantum vacuum energy density, associated to opportune RS processes of creation/annihilation of virtual particles, are the fundamental primary reality, while the density of cosmic space $D(r)$ of the quasi-particles of the a-temporal quantum-gravity space theory, namely the Planck-Fiscaletti granules, can be seen as an emergent property.

In this picture, we propose that the a-temporal quantum-gravity space theory can be interpreted as the hydrodynamic limit of the 3D DQV condensate whose most universal physical property is its energy density and whose quantum evolution can be seen as the coherent superposition of virtual fine–grained histories. In the opportune lower energy and long wavelength with respect to the Planck scale, the a-temporal quantum gravity-space described by the density of cosmic space (16) emerges from the microscopic 3D quantum vacuum, in which the metric and its perturbation correspond to collective variables and collective excitations associated to coarse-grained histories which emerge from more fundamental fine-grained histories of the 3D DQV as a consequence of the action of a filter function which determines a dynamic spontaneous symmetry breaking.

A fine–grained history which describes the 3D quantum vacuum is defined by the value of a field $\Phi(x)$ at the point x and has quantum amplitude $\Psi[\Phi]=e^{iS[\Phi]}$, where S is the classical action corresponding to the considered history, which satisfies the usual generalized Klein-Gordon equation (11) regarding creation events of the RS processes of the virtual particles of the vacuum. The density of cosmic space (16) of the quantum-gravity space is generated by the 3D quantum vacuum under the constraint represented by the selection – performed by an opportune filter function ω – of corresponding coarse-grained histories. The quantum amplitude for a coarse–grained history is defined by:

$$\Psi[\omega]=\int D_F \Phi e^{iS} \omega[\Phi] \tag{20}$$

where

$$D_F[\Phi_A,\Phi_B] \approx \Psi[\Phi_A]\Psi[\Phi_B]^* \approx e^{i(S[\Phi_A]-S[\Phi_B])} \tag{21}$$

is the “decoherence” functional measuring the quantum interference between two virtual histories A and B, ω is the “filter” function that selects which fine–grained histories are associated to the same superposition with their relative phases [17, 20].

By expressing the field (20) associated with a coarse-grained history of the 3D DQV in polar form, and separating the generalized Klein-Gordon equation for the quantum vacuum energy density for events of creation (14) it satisfies, into real and imaginary parts, one obtains a nonlinear quantum Hamilton-Jacoby equation for the field (20)[1] that, by imposing the

[1] In many of the following equations we are going to use the 3+1-dimensional Riemann-Minkowski notation (with implicit Einstein sum convention) in order to characterize the quantum vacuum.

requirement that it be Poincarè invariant and have the correct non-relativistic limit, assumes the following form

$$\partial_\mu S \partial^\mu S = \frac{V^2(\Delta\rho)^2}{c^2\hbar^2}\exp Q \tag{22}$$

and the continuity equation

$$\partial_\mu J^\mu = 0 \tag{23}$$

where

$$Q = \frac{c^2\hbar^2}{V^2(\Delta\rho)^2}\frac{\left(\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right)A}{A} \tag{24}$$

can be interpreted as the quantum potential associated with the field (20),

$$S = \frac{2\pi}{\hbar}\left[\left(H_{eg}\frac{V}{c^2}\Delta\rho\frac{1}{r^2}\hat{r}\cdot\vec{r}_0 - H_{eg}\vec{r}\times\frac{V}{c^2}\Delta\rho\vec{v}\frac{1}{r^3}t + \varphi_0\right)\right] \tag{25}$$

is the phase of this field, A is the amplitude of this wave function, $H_{eg} = \frac{G}{c^2}$ is the basic gravitodynamic constant and

$$J^\mu = -\frac{c^2 r^2 A^2}{H_{eg}V\Delta\rho}\partial^\mu S \tag{26}$$

is the current associated with this field.

Hence, by changing the ordinary differentiating ∂_μ with the covariant derivative ∇_μ and by changing the Lorentz metric with the curved metric $g_{\mu\nu}$, one obtains the following equations of motion for a change of the quantum vacuum energy density (which generates the quasi-particles of the a-temporal quantum-gravity space) in a curved background:

$$\tilde{g}_{\mu\nu}\tilde{\nabla}_\mu S\tilde{\nabla}_\nu S = \frac{V^2(\Delta\rho)^2}{c^2\hbar^2} \tag{27}$$

$$\tilde{g}_{\mu\nu}\tilde{\nabla}_\mu J^\mu = 0 \tag{28}$$

where $\tilde{\nabla}_\mu$ represents the covariant differentiation with respect to the metric

$$\tilde{g}_{\mu\nu} = g_{\mu\nu}\exp Q \tag{29}$$

which is a conformal metric, where

$$Q = \frac{c^2\hbar^2}{V^2(\Delta\rho)^2}\frac{\left(\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right)_g A}{A} \tag{30}$$

is the quantum potential of the vacuum in this regime.

From equations (27)-(30), one can conclude that as a consequence of the action of a filter function which determines a dynamic spontaneous symmetry breaking from the fine-grained histories of the 3D DQV to the coarse-grained histories associated with the generation of the Planck-Fiscaletti granules of the a-temporal quantum-gravity space, the effects of gravity on geometry and the quantum effects on the geometry of space-time are highly coupled and the source of both of them is always the field (20) of the 3D quantum vacuum: the space-time geometry sometimes looks like what we call gravity and sometimes looks like what we understand as quantum behaviours and this derives from the collective excitations of the 3D quantum vacuum.

The presence of the quantum potential associated with the field (20) of the 3D quantum vacuum, when this spontaneous symmetry breaking towards coarse-grained histories occurs, is equivalent to a curved space-time with its metric being given by (29) and thus allows the results of general relativity to be recovered as the hydrodynamic limit of the 3D DQV condensate whose most universal physical property is its energy density and whose quantum evolution can be seen as the coherent superposition of virtual fine–grained histories. The curving of space-time characteristic of general relativity, can be considered a form of collective organization which is associated with the quantum potential (30) of the 3D quantum vacuum in the regime of spontaneous symmetry breaking performed by the filter function towards the coarse-grained histories.

On the basis of this approach, we can say that the fluctuations of the quantum vacuum energy density corresponding to opportune fields of the 3D quantum vacuum, in regime of spontaneous symmetry breaking towards coarse-grained histories, are the fundamental origin of the curvature of space-time and, at the same time, the space-time metric is related with the quantum potential associated with these collective excitations of the 3D quantum vacuum and which influences the behaviour of the particles of the laboratory level determined by these same collective excitations. The collective excitations of the 3D DQV in regime of coarse-grained histories determined by a spontaneous symmetry breaking, imply that space-time geometry sometimes looks like what we call gravity and sometimes look like what we understand as quantum behaviour just as a consequence of the features of the collective excitations of the quantum vacuum.

In this way, the wave nature of the gravitational space, predicted by the a-temporal quantum-gravity space theory, may be seen as something that itself derives from the fundamental fluctuations of the quantum vacuum energy density corresponding to the RS processes of virtual particles of the vacuum, as a consequence of a spontaneous symmetry breaking from the fine-grained histories of the 3D DQV towards the coarse-grained histories. The density of cosmic space of the quantum-gravity space generates wave features of space because it has origin from the primordial quantum vacuum energy density fluctuations corresponding to the elementary RS processes of creation/annihilation of virtual particles of the vacuum whose behavior is described by equations (13)-(16), when a dynamical spontaneous symmetry breaking from the fine-grained histories of the 3D DQV towards coarse-grained histories takes place.

Following the emergence of the quantum-gravity space as a collective excitation of the most fundamental 3D DQV in regime of coarse-grained histories, the Planck-Fiscaletti granules, in the case j=0, are described by the wave function of space

$$\psi_S = A\exp\left[2\pi i\left(\frac{D(r)}{c^2}\hat{r}\cdot\vec{r}_0 - \frac{D(r)\cdot v\cdot sen\vartheta}{c^2}t+\varphi_0\right)\right] \tag{31}$$

where $\vec{v}$ is the speed of the particle generated by the density of cosmic space $D(r)$, ϑ is the angle between $\vec{r}$ and $\vec{v}$ and the amplitude A is a function of the point (x,y,z) of space. The wave function of space (31) is solution of the generalized non-linear Klein-Gordon equation for the density of cosmic space

$$\nabla^2\psi_S - \frac{1}{c^2}\frac{\partial^2\psi_S}{\partial t^2} = \frac{[D(r)]^2}{c^4}\psi_S \tag{32}$$

Instead, in the case $j=\frac{G\hbar}{2r^3}$, in the light of the density of cosmic space (16), the wave function of space can be expressed as

$$\psi_S(x) = \psi_S^{(P)}(x) + \psi_S^{(A)}(x) \tag{33}$$

where $\psi_S^{(P)}(x)$ represents the wave function of quantum-gravity space generating the appearance of particles of spin ½ and $\psi_S^{(A)}(x)$ represents the wave function of quantum- gravity space generating the appearance of the corresponding antiparticles. These two set of wave functions of quantum-gravity space can be expanded as

$$\psi_S^{(P)}(x) = \sum_k b_k u_k(x) \tag{34}$$

$$\psi_S^{(A)}(x) = \sum_k d_k{}^* v_k(x) \tag{35}$$

respectively. Here u_k are positive-frequency 4-spinors of quantum-gravity space while v_k are negative frequency 4-spinors of quantum-gravity space; they together constitute a complete set of orthonormal solutions to the non-linear generalized Dirac equation for the density of cosmic space

$$\left(i\gamma^{\mu}\partial_{\mu}-\frac{D(r)}{c^{2}}\right)\psi_{S}=0 \tag{36}$$

where $x=\left(x^{0},x^{1},x^{2},x^{3}\right)=\left(t,\vec{x}\right)$ and γ_{μ} are the well-known relativistic matrices $\gamma^{0}=1\otimes\begin{pmatrix}1 & 0\\ 0 & -1\end{pmatrix}$, $\gamma^{i}=\sigma_{i}\otimes\begin{pmatrix}0 & 1\\ -1 & 0\end{pmatrix}$ (and $\vec{\sigma}$ are the Pauli matrices which are linked with $\vec{j}$ through the relation $\vec{j}=\frac{1}{2}G\hbar\frac{\vec{\sigma}}{r^{3}}$). In equations (34) and (35), the label k is an abbreviation for the set $(\vec{k},j)$ where $\vec{k}$ is the 3-momentum $\vec{k}=(p_{1},p_{2},p_{3})$ and $j=\frac{Gs}{r^{3}}$ with $s=\frac{1}{2}\hbar$, is the label of the rotation-orientation of the generic Planck-Fiscaletti granule of cosmic space. As regards the expressions of u_{k} and v_{k}, equation (36) leads to the following results:

$$u=W^{z}(\vec{k})\exp\left[-\frac{i}{\hbar}p_{\mu}x^{\mu}\right] \tag{37}$$

with z=1,2 and

$$v=W^{z}(\vec{k})\exp\left[\frac{i}{\hbar}p_{\mu}x^{\mu}\right] \tag{38}$$

with z=3,4, where $p_{0}=\frac{\hbar D(r)}{c}$ and

$$W^{1}=\sqrt{\frac{cE+\hbar D(r)}{2\hbar D(r)}}\begin{bmatrix}1\\ 0\\ \dfrac{p_{3}c^{2}}{cE+\hbar D(r)}\\ \dfrac{(p_{1}+ip_{2})c^{2}}{cE+\hbar D(r)}\end{bmatrix} \tag{39}$$

$$W^{2}=\sqrt{\frac{cE+\hbar D(r)}{2\hbar D(r)}}\begin{bmatrix}0\\ 1\\ \dfrac{(p_{1}-ip_{2})c^{2}}{cE+\hbar D(r)}\\ \dfrac{-p_{3}c^{2}}{cE+\hbar D(r)}\end{bmatrix} \tag{40}$$

$$W^3 = \sqrt{\frac{cE + \hbar D(r)}{2\hbar D(r)}} \begin{bmatrix} \frac{p_3 c^2}{cE + \hbar D(r)} \\ \frac{(p_1 + ip_2)c^2}{cE + \hbar D(r)} \\ 1 \\ 0 \end{bmatrix} \tag{41}$$

$$W^4 = \sqrt{\frac{cE + \hbar D(r)}{2\hbar D(r)}} \begin{bmatrix} \frac{(p_1 - ip_2)c^2}{cE + \hbar D(r)} \\ \frac{-p_3 c^2}{cE + \hbar D(r)} \\ 0 \\ 1 \end{bmatrix} \tag{42}$$

where $E = \left[k^2 c^2 + \frac{\hbar^2 (D(r))^2}{c^2} \right]^{1/2}$ is the energy of the quantum-gravity space (which depends on the density of cosmic space $D(r)$ and on the modulus of the momentum of the particle generated by the density of cosmic space $D(r)$).

Moreover, if Planck-Fiscaletti granules of the a-temporal quantum-gravity space emerge as forms of collective excitations of the most elementary fluctuations of the primordial 3D DQV as a consequence of the spontaneous symmetry breaking from fine-grained histories towards coarse-grained histories, in the same way the baryonic matter of the Standard Model can be seen as an emergent structure from the density of cosmic space of the a-temporal quantum-gravity space, which satisfies the following equation

$$\begin{cases} -\hbar^2 \frac{\partial^2}{[(2\pi\tau')]^2} \varphi(\tau') = \left(\frac{D(r) r^2 c^2}{G}\right)^2 \phi(\tau') \quad for\ \tau' \in [-\vartheta/2, \vartheta/2] \\ \varphi(\tau') = 0 \quad otherwise \end{cases} \tag{43}$$

where $\varphi(\tau')$ is an internal wave function factor (inaccessible by direct observation), which is real and harmonic in an internal time variable τ' of the vacuum background, null at the boundary and outside of the interval $\left[-\frac{\vartheta_0}{2}, \frac{\vartheta_0}{2}\right]$, under the constraints $c\vartheta_0 \approx 10^{-13} cm$ and

$$mc^2 = n' \frac{\hbar c^2}{V^2 \vartheta_0} \tag{44}$$

where n'=0, ½, 1, 3/2, ... is an integer for odd solutions, a half-integer for even solutions. In epistemological affinity with a recent approach proposed by Licata and Chiatti where quantum jumps are processes of entry and exit from the usual temporal domain to a timeless vacuum [32, 33], in this unifying framework of the a-temporal quantum-gravity space theory and the 3D DQV model, a real quantum massive particle of the Standard Model is given by the sum of the nascent "bare" mass produced by the virtual particles of the 3D quantum vacuum, and a term ε/c^2 associated with the self-interaction, which, if the particle is subjected to gauge fields, is given by relation:

$$\frac{\varepsilon}{c^2} = -\frac{e}{c^2}\int \bar{\phi}\gamma^{\mu}A_{\mu}\phi dV \tag{45}$$

where A_{μ} is the self-field, ϕ is the spinor satisfying the non-linear generalized Dirac equation for the density of cosmic space

$$\left(i\gamma^{\mu}\partial_{\mu} - \frac{D(r)}{c^2}\right)\psi_S = 0 \tag{46}$$

3. Perspectives about scales, hierarchies, spontaneous symmetry breaking and Higgs mechanism of the Standard Model

Atomic and subatomic phenomena put in evidence how, following a spontaneous symmetry breaking, the system under study overcomes a drastic energetic reorganization by getting collectively and spontaneously a property which is not present in its fundamental rules. The spontaneous symmetry breaking manifests itself at a phenomenological level with the creation of ordinate structures (such as in the case of superconductivity or superfluidity), by providing a simple and convincing example of the way nature can acquire a great complexity, even if the fundamental principles ruling it are simple.

Today, quantum physics teaches us that, in the context of particle physics, we deal with the generation, following processes of spontaneous symmetry breaking, of forms of collective organization which are not ascribable to the properties of the elementary constituents. Think, for example, of the weakening of the force acting between quarks with the reduction of the distance and of its unlimited increasing if you try to separate them, as well as of the Higgs mechanism invoked to assign a mass to elementary particles. And, at the same time, the spontaneous symmetry breaking turns out to have a crucial role also in the cosmological scenario: the function performed by the various fundamental interactions existing in nature in the structuring of the universe, in the evolution of the cosmos, is in fact to lead to the formation of increasingly complex structures, in which organization and collective behaviours have an increasingly relevant importance.

Ultimately, we can say – paraphrasing Nobel laureate Robert Laughlin – that superconductivity and various phenomena of particle physics, as well as the role of fundamental interactions in the structuring of the cosmos, constitute tangible proof that in the physical world it is the organization that determines the laws, that the laws of nature emerge through collective self-organization and it is not essential to know what they are made of in order to understand and use them. The most careful studies of the microscopic details have revealed that, at least at a fundamental level, the principles of collective organization are at the origin of all physical laws, in short, that the world of nature is characterized by a hierarchical structure with interdependent generation, in which each level is described by its own appropriate mathematical formalism and opportune link hypotheses must be invoked in order to understand and describe the functioning of the world [34].

By following the lesson of condensed matter physics, the Standard Model of electroweak and strong interactions can be considered a low-energy effective theory which can be associated to the emergence of new forms of organization as consequence of a spontaneous symmetry breaking. In this regard, in [35, 36] Volovik suggests that the Standard Model of particle physics and general relativity can be considered as the low-energy phenomena emerging in the quantum vacuum in the context of a topological approach, in the sense that momentum space topology divides the quantum vacuum into universality classes which are characterized by different types of topological invariants. The momentum-space topology determines the effective quantum field theory in topological media at low energy and low temperature, as well as the type of the energy spectrum of fermionic excitations. In this picture, in the vacuum of Standard Model below the electroweak transition, the momentum space topology rules thus the appearance of masses for all fermionic excitations: quarks and leptons.

In Volovik's approach, all the ingredients of Standard Model may be derived from the vacuum, characterized by the existence of the topologically protected Fermi points in momentum space, namely the points where the energy of the fermionic excitations becomes necessarily null as a consequence of a non-zero topological invariant. Such points regard both the phenomena of particle physics as well as of condensed matter physics. As a consequence of the existence of topologically protected Fermi points in momentum space, as regards the Standard Model, at low energy, the fermionic excitations behave as relativistic particles – chiral (left handed or right handed) Weyl fermions – interacting with effective gauge fields and gravitational fields.

In the light of these results of Volovik's research, here we are taking into account the applicability of our model of a-temporal quantum-gravity space emerging from the 3D quantum vacuum defined by energy density fluctuations in correspondence to RS processes of creation/annihilation of virtual particles, in order to provide a new reading to the Standard Model. Our aim is to show how, by considering the lesson from condensed matter physics in the light of Volovik's research, one has the possibility to derive the effective theory of the Standard Model and Higgs mechanism as emergent processes from the fundamental background of our unifying approach of the a-temporal quantum-gravity space and the non-local 3D DQV.

An important epistemological motivation for developing an approach of this type lies in Volovik's result: in the vacuum of Standard Model below the electroweak transition, the appearance of masses for all fermions is determined by momentum space topology at low energy as a consequence of the existence of topologically protected Fermi points in momentum space. In the spirit of Volovik's research, here we consider the possibility that the appearance of particles correspond to the regions of the quantum-gravity space where the density of cosmic space has the maximum value (thus determining a spontaneous symmetry breaking with respect to the fluid features of the density of cosmic space).

In our theory, the motion of the virtual particles corresponding to the elementary fluctuations of the quantum vacuum energy density imply that, at the upper level of quantum-gravity space, the density of cosmic space is filled with virtual radiation with frequency

$$\omega = \frac{2D(r)c^2r^2}{G\hbar n} \tag{47}$$

The elementary fluctuations of the microscopic 3D quantum vacuum, as a consequence of the action of a filter function which determines a dynamic spontaneous symmetry breaking towards coarse-grained histories, generate a virtual radiation of the quantum-gravity space as a form of collective excitation. This means that, as a consequence of the motion of the virtual particles of the fundamental 3D quantum vacuum, the density of cosmic space generates a material object corresponding to a peculiar fundamental oscillation (47). Now, by virtue of the frequency (47), the density of cosmic space has a velocity which may be expressed as

$$v(r,t) = \frac{\Gamma}{2\pi r}\left(1 - exp\left\{-\frac{r^2}{4\pi\left(\frac{\hbar G}{D(r)r^2}/2\pi\right)\left(sin\left(\frac{2D(r)c^2r^2}{G\hbar n}t+\varphi\right)+n\right)}\right\}\right) \tag{48}$$

where ϕ is the uncertain phase, Γ is an opportune constant having dimension $length^2 / time$ and $n>1$ is an additional number that prevents appearance of singularity in the cases when $sin\left(\frac{2D(r)c^2r^2}{G\hbar n}t+\varphi\right)$ tends to -1. The density of cosmic space here can be seen as a counterpart of the topologically protected Fermi points in momentum space of Volovik's approach. The dynamics of the density of cosmic space implies that in the very centre the speed of the density of cosmic space, which can be also called the "core" of the density of cosmic space, vanishes. By following [37, 38], if one equates to zero the first derivative by r of equation (34), the radius of this core can be expressed as

$$r_{core} \approx 2\sqrt{a_0\left(n + sin\left(\frac{2D(r)c^2r^2}{G\hbar n}t\right)\right)}\sqrt{\frac{G^2\hbar^2n^2}{2[D(r)]^2c^4r^4}} \tag{49}$$

where $a_0 = 1.2564$ is a root of the equation $ln(2a_0 + 1) - a_0 = 0$.

Now, in this theory, the non-locality of the laboratory level can be considered as a special case of a more fundamental non-locality of the quantum-gravity space, which in turn has origin in the deepest non-locality of the 3D quantum vacuum. Therefore, since the fundamental degree of non-local correlation, at the most fundamental level, is measured by the Bell length of the vacuum (18), one may equate equations (49) and the first component of equation (18) and obtains

$$a_0\left(n + sin\left(\frac{2D(r)c^2r^2}{G\hbar n}t\right)\right)\frac{G^2\hbar^2n^2}{2[D(r)]^2c^4r^4} = \frac{V\Delta\rho_{qvE}}{2}\frac{|\psi_{Q,i}|}{\left(\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right)|\psi_{Q,i}|} \tag{50}$$

The physical meaning of equation (50) is the following. When the oscillation frequency of the density of cosmic space of the Planck-Fiscaletti granules characterizing the quantum-gravity space – generated by the motion of the virtual particles of the 3D quantum vacuum – is increasing and is approaching a threshold value, a degree of non-locality emerges in the upper level represented by density of cosmic space, namely by the Planck-Fiscaletti granules, whose boundary is determined by the Bell length of the vacuum (18). If in the Volovik's theory about the vacuum of Standard Model below the electroweak transition, the appearance of masses for all fermions are determined by momentum space topology at low energy, in the same way, in our unifying model of the a-temporal quantum gravity space and of the 3D DQV, a real particle of ordinary quantum physics may be seen as a result of the dynamics of the density of cosmic space generated by the virtual particles of the 3D DQV inside the non-local boundary described by equation (50).

In other words, according to our approach, the topologically protected Fermi points in momentum space of Volovik's theory may be assimilated to the different frequencies of oscillation of the Planck-Fiscaletti granules, characterizing the quantum gravity-space, given by $\frac{2D(r)c^2r^2}{G\hbar n}$. Both the topologically protected Fermi points in momentum space and the different oscillations of the Planck-Fiscaletti granules characterizing the quantum-gravity space can be considered as forms of collective organization, emerging from the fundamental background of the vacuum under opportune physical constraints, which generate the appearance of the particles which are revealed in our experiments.

On the other hand, every theory which has the purpose of extending the Standard Model beyond the TeV scale is likely to introduce new degrees of freedom which couple with the Standard Model particles. In this regard, the Higgs sector is usually taken as a portal between the visible and a dark sector [39-42], plays a key role in the interactions with right-handed neutrinos in the leptogenesis framework in order to reproduce the baryon asymmetry [43], and provides a possible explanation of the origin of the electroweak symmetry breaking if the Higgs field is coupled to additional scalar particles [44-47].

However, the existence of interactions between the Higgs boson and any heavier state of new physics comes at the price of generating quantum corrections to the Higgs mass that are quadratic in the mass of the heavy particle and that cannot be avoided on the basis of symmetry arguments [48-52]. In this way, the Standard Model turns out to be affected by the so-called hierarchy problem, namely, in light of the absence of new-physics signatures at the TeV scale and beyond, the observed Higgs mass appears rather "unnatural", as quadratic corrections would involve increasingly higher energy scales and turns out to be much smaller than Planck scale [53]. On the other hand, the hierarchy problem of the Standard Model can also be viewed as a fine-tuning problem, since the parameters of new high-scale physics have to be chosen very carefully in order to result in the observed low-energy parameters. As a consequence, one must face the issue about why electroweak scale is so much different (100 GeV) from the Planck scale ($10^{18}\ GeV$).

In the Standard Model, the Higgs potential is usually expressed as

$$V = m_H^2|H|^2 + \lambda|H|^4 \tag{51}$$

where H is the Higgs field, m_H is the mass of the Higgs boson and λ is a free parameter which is constrained by vacuum expectation value. In particular, a nonzero vacuum expectation value leads to $\langle H\rangle = \sqrt{-m_H^2/2\lambda}$, where $\langle H\rangle = 174\ GeV$ and the observed Higgs mass is around 125 GeV. If one considers the couplings of the Higgs field to Standard Model fermions one gets higher-order corrections to m_H such as

$$\Delta m_H^2 = -\frac{|\lambda_f|^2}{8\pi}\Lambda_{UV}^2 \tag{52}$$

where λ_f is the Yukawa coupling of the fermion f to the Higgs field and Λ_{UV} is some upper cutoff of the matrix-element integral to yield a finite result. Here there is no physical mechanism within the Standard Model itself to yield a small value of Λ_{UV} to arrive at the observed Higgs boson mass, so either the Standard Model is valid up to the Planck scale (resulting in $\Lambda_{UV} = \Lambda_{Planck}$), necessitating extremely fine-tuned higher-order corrections, or a new physical scale exists, Λ_{BSM}, between the electroweak and Planck scales, interpreted as the scale of beyond Standard Model physics [54].

Among the theories that address the hierarchy problem at the TeV scale, one can mention supersymmetric extensions [55-58], new strong dynamics or technicolor [59, 60] composite Higgs [61-63] and extra dimensions [58-60] and it must be emphasized that the minimal versions of these models are nowadays rather fine-tuned in order to stay compatible with experiments [53, 67-69]. More recently, in [70] a decoupling method, which freezes the effects of heavy particles on the renormalization group running of the light degrees of freedom at low energies, is considered but this approach, despite leading to an acceptable and convergent effective potential, does not solve the fine-tuning problem that is inherent to the hierarchy problem of multi-scale theories.

An important aspect of the fine-tuning problem connected to the hierarchy problem of the Standard Model lies in the fact that in the Standard Model there is no corresponding scale to the electroweak one, so that one needs a scale-generation mechanism, i.e. scalegenesis. In this regard, one of the possible ways to generate a scale is the Coleman-Weinberg mechanism [71], in which scale symmetry is broken by the scale anomaly. The Coleman-Weinberg mechanism, however, is not compatible with the observed masses of Standard Model particles in order to generate the electroweak scale and thus an extension of this mechanism is required. The other scenario for scalegenesis relies on the strong dynamics like quantum chromodynamics.

In both cases, a degree of freedom of a dimensionless coupling changes to that of a dimensionful parameter, thus generating the so-called dimensional transmutation. The scale invariant Standard Model, however, cannot realize electroweak scalegenesis, so that a scale invariant extension of the Standard Model is required. In this regard, the simplest extension is an introduction of a scalar field coupled to the Higgs field via the Higgs-portal coupling. If the dynamics in the new (hidden) sector generates a TeV scale, the electroweak symmetry breaking is triggered through the Higgs-portal coupling. Many possible scale invariant extensions as a hidden sector, together with other issues in the Standard Model such as dark matter, neutrino masses and Baryogenesis have been suggested.

In the recent paper [72] Yamada discusses an extension of the Standard Model defined by the generation of a scale Λ_H which induces the electroweak scale and based on the strongly interacting scalar-gauge theory in the hidden sector. In this approach, a scalar field S is coupled to the Higgs field H via the Higgs-portal coupling $\lambda_{HS}(H^+H)(S^+S)$, which leads to a proportionality of the Higgs mass parameter with the quadratic scale, i.e. $m_H^2 \approx \lambda_{HS}\Lambda^2$, by considering a lagrangian of the form

$$\mathcal{L} = \mathcal{L}_{SM}|_{m_H\to 0} - \lambda_{HS}(H^+H)(S^+S) + \mathcal{L}_S|_{m_S\to 0} \tag{53}$$

where $\mathcal{L}_S|_{m_S\to 0}$ is the lagrangian for the scalar field S which defines the hidden sector (whose explicit form is not specified). In particular, by considering the example of scalegenesis owed to the strong dynamics of the gauge interactions, the Lagrangian for the hidden sector is

$$\mathcal{L}_{hidden} = -\frac{1}{2}TrF^2 + \left([D^\mu S_i]^+ D_\mu S_i\right) - \hat{\lambda}_S\left({S_i}^+S_i\right)\left({S_j}^+S_j\right) - \hat{\lambda}_S'\left({S_i}^+S_j\right)\left({S_j}^+S_i\right) + \hat{\lambda}_{HS}\left({S_i}^+S_i\right)H^+H \tag{54}$$

where $F = F^a\tau^a$ is the field strength of $SU(N_C)$ gauge field A_μ^a , τ^a is the generator of $SU(N_C)$ gauge transformation; S_i and H are the scalar field and the Higgs doublet field respectively; indices on the scalar field S stand for the flavour indices; and $D_\mu = \partial_\mu - igA_\mu^a t^a$ is the covariant derivative. Yamada considers that the $SU(N_C)$ gauge symmetry is not broken by the dynamics in the hidden sector, but scale symmetry is spontaneously broken. Due to the strong dynamics of the gauge field in the low energy region the $SU(N_C)$ invariant scalar bilinear condensate takes place such that

$$\langle {S_i}^+S_j\rangle = \langle \textstyle\sum_{a=1}^{N_C} {S_i}^{a+}S_j^a\rangle \propto \delta_{ij} \tag{55}$$

Thus the Higgs portal coupling takes the form of the (negative) Higgs mass parameter

$$m_H^2 = -\hat{\lambda}_{HS}\left({S_i}^+S_i\right) \tag{56}$$

As a consequence, the Higgs field has a non-trivial vacuum $\nu_h = \sqrt{m_H^2/\lambda_H}$.

Hence, in Yamada's approach, by ignoring anomalous breaking effects in low energy regions, a spontaneous dynamical scale symmetry breaking is obtained by considering the mean-field approximated effective Lagrangian of the form

$$\mathcal{L}_{MFA} = \left([\partial^\mu S_i]^+\partial_\mu S_i\right) - M^2\left({S_i}^+S_i\right) - \lambda_H(H^+H)^2 + N_f\left(N_f\lambda_S + \lambda_S'\right)f^2 + \frac{\lambda_S'}{2}(\phi^a)^2 - 2\lambda_S'\phi^a\left({S_i}^+t_{ij}^aS_j\right) \tag{57}$$

where $f = (S_i^+ S_i)/N_f$ and $\phi^a = 2(S_i^+ t_{ij}^a S_j)$ are auxiliary fields with t_{ij}^a generators of the flavour $SU(N_f)$ transformation, and the "constituent" scalar mass is

$$M^2 = 2(N_f \lambda_S + \lambda_S{}')f - \lambda_{HS}(H^+ H) \tag{58}$$

Assuming that the bilinear condensate $\langle S_i{}^+ S_j \rangle = \langle \sum_{a=1}^{N_C} S_i{}^{a+} S_j^a \rangle \propto \delta_{ij}$ is invariant under the $U(N_f)$ transformation, one can consider a vacuum state $\langle f \rangle \neq 0$ and $\langle \phi^a \rangle = 0$. Thus by setting $\phi^a = 0$ in the mean-field approximation lagrangian, one can obtain the effective potential

$$V_{MFA} = M^2(\bar{S}_i{}^+ \bar{S}_i) + \lambda_H (H^+ H)^2 - N_f(N_f \lambda_S + \lambda_S{}')f^2 + \frac{N_C N_f}{32\pi^2} M^4 ln \frac{M^2}{\Lambda_H^2} \tag{59}$$

where $\bar{S}_i$ is the background field of the scalar field S_i and the dimensional regularization and the $\overline{MS}$ scheme to substract a UV divergence are performed, and Λ_H is a renormalization point at which the quantum effect vanishes for $M = \Lambda_H$. In this way, by finding the vacuum of this system, Yamada finds that the constituent scalar mass and the Higgs mass are given by relations

$$\langle M^2 \rangle = \frac{G}{2\lambda_H} \langle f \rangle \tag{60}$$

$$M_h^2 \cong 2N_f \lambda_{HS} \langle f \rangle \tag{61}$$

where a small λ_{HS} in the Higgs mass is assumed. In this picture, the dimensional quantity Λ_H is generated at the quantum level and is responsible of the origin of the electroweak scale and the Higgs mass.

Now, in analogy with Yamada's approach, in our model of 3D quantum vacuum, the hierarchy problem is faced in terms of scalar couplings of a scalar field depending on the variable quantum vacuum energy density. More precisely, in our approach, our aim is to throw new light into the hierarchy problem by invoking a general effective potential – expressed in terms of couplings associated with the properties of the 3D DQV – which provides a scenario which resembles a high-energy extension of the Standard Model. When new mass scales are introduced, the sensitivity of the low-energy parameters to the high-energy ultraviolet physics is reflected in different observables obtained from this general potential of the 3D DQV. This general potential, which is invariant under the Standard Model gauge group, is given by relation

$$V = \lambda_C C^4 + \lambda_I s_I{}^4 + \lambda_{RI} s_I{}^2 s_R{}^2 + \lambda_R s_R{}^4 + \lambda_{IC} C^2 s_I{}^2 + \lambda_{RC} C^2 s_R{}^2 \tag{62}$$

where $C = \begin{pmatrix} \psi_{Q,i} \\ \phi_{Q,i} \end{pmatrix}$ is the wave function at two components describing the probability of the appearance of a virtual particle/antiparticle of a given mass m in a point event, s_R and s_I are the real and imaginary parts of a singlet field S which is a function of the changes and fluctuations of the quantum vacuum (associated with the creation/annihilation of the virtual particles of the medium), λ_C is the coupling associated with the wave function at two components C, λ_R is the coupling associated with the real part of the singlet field S, λ_I is the coupling associated with the imaginary part of the singlet field S and one has

$$\lambda_R = \lambda_S + \lambda_S' + \lambda_S'' \quad (63)$$

$$\lambda_I = \lambda_S + \lambda_S' - \lambda_S'' \quad (64)$$

$$\lambda_{RI} = 2(\lambda_S - 3\lambda_S') \quad (65)$$

$$\lambda_{RC} = \lambda_{SC} + \lambda_{SC}' \quad (66)$$

As shown in [73, 74], in the light of the behaviour of the scalar couplings (63)-(66), the approach based on the potential (62) allows us to avoid the global minimum of the Standard Model Higgs potential occurring at $\approx 10^{26}\,GeV$ (which seems to invalidate the Standard Model as a phenomenologically acceptable model in this energy range), in agreement with the treatment of Gabrielli and his colleagues in [75], in a picture where the action of the Higgs boson is a "mechanism", an emerging process (namely it is the interplay of opportune fluctuations of the energy density of the 3D DQV which indeed determines the action of the Higgs boson).

Moreover, in this model, the scalar couplings λ_C, λ_R, λ_I, λ_{RI}, λ_{RC}, λ_{IC} lead to the following one-loop renormalization group equations in terms of the top Yukawa coupling y_t and the Standard Model electroweak gauge couplings g, g':

$$16\pi^2 \beta_{\lambda_C} = \frac{3}{8}\left(3g^4 + 2g^2 g'^2 + g'^4\right) + \frac{1}{2}\left(\lambda_{RC}^2 + \lambda_{IC}^2\right) + 24\lambda_C^2 - 3\lambda_C\left(3g^2 + g'^2 - 4y_t^2\right) - 6y_t^4 \quad (67)$$

$$16\pi^2 \beta_{\lambda_R} = 18\lambda_R^2 + 2\lambda_{RC}^2 + \frac{1}{2}\lambda_{RI}^2 \quad (68)$$

$$16\pi^2 \beta_{\lambda_I} = 18\lambda_I^2 + 2\lambda_{IC}^2 + \frac{1}{2}\lambda_{RI}^2 \quad (69)$$

$$16\pi^2 \beta_{\lambda_{RI}} = 4\lambda_{IC}\lambda_{RC} + 6\lambda_{RI}\left(\lambda_I + \lambda_R\right) + 4\lambda_{RI}^2 \quad (70)$$

$$16\pi^2 \beta_{\lambda_{RC}} = -\frac{3}{2}\lambda_{RC}\left(g'^2 + 3g^2 - 4y_t^2\right) + \lambda_{IC}\lambda_{RI} + 6\lambda_{RC}\left(2\lambda_C + \lambda_R\right) + 4\lambda_{RC}^2 \quad (71)$$

$$16\pi^2 \beta_{\lambda_{IC}} = -\frac{3}{2}\lambda_{IC}\left(g'^2 + 3g^2 - 4y_t^2\right) + \lambda_{RC}\lambda_{RI} + 6\lambda_{IC}\left(2\lambda_C + \lambda_I\right) + 4\lambda_{IC}^2 \quad (72)$$

[69, 70].

Let us see now how, in this unifying approach of the a-temporal quantum-gravity space and 3D DQD, a dynamical spontaneous symmetry breaking can be achieved in the hidden sector generating the TeV scale of strong interactions. In this regard, on the basis of Yamada's results, a spontaneous dynamical scale symmetry breaking can be obtained by considering the mean-field approximated effective Lagrangian of the form

$$\mathcal{L}_{MFA} = \left([\partial^\mu s_R]^+\partial_\mu s_R\right) - \Delta\rho_{qvE}{}^2({s_R}^+ s_R) - \lambda_C(H^+H)^2 + N_f\left(N_f\lambda_S + \lambda_S{}'\right)f^2 + \frac{\lambda_S{}'}{2}(\phi^a)^2 - 2\lambda_S{}'\phi^a\left({s_R}^+ t_{ij}^a s_R\right) \quad (73)$$

where $f = ({s_R}^+ s_R)/N_f$ and $\phi^a = 2\left({s_R}^+ t_{ij}^a s_R\right)$ are auxiliary fields with t_{ij}^a generators of the flavour $SU\left(N_f\right)$ transformation, and $\Delta\rho_{qvE}{}^2$ is a "constituent" scalar variable quantum vacuum energy density of the hidden sector of the strong interactions given by relation

$$\Delta\rho_{qvE}{}^2 = 2\left(N_f\lambda_S + \lambda_S{}'\right)f - \lambda_{SC}(H^+H) \quad (74)$$

By following Yamada [74], if one sets $\phi^a = 0$ in the mean-field approximation lagrangian, one can obtain the effective potential

$$V_{MFA} = \Delta\rho_{qvE}{}^2({\bar{s}_R}^+ \bar{s}_R) + \lambda_C(H^+H)^2 - N_f\left(N_f\lambda_S + \lambda_S{}'\right)f^2 + \frac{N_C N_f}{32\pi^2}\Delta\rho_{qvE}{}^4 ln\frac{\Delta\rho_{qvE}{}^2}{\Lambda_C^2} \quad (75)$$

where $\bar{s}_R$ is the background field of the scalar field s_R. Hence, by applying the dimensional regularization and the $\overline{MS}$ scheme to substract a ultraviolet divergence and finding the vacuum of the effective potential (75), one gets the following expressions for the changes of the quantum vacuum energy density and the Higgs mass, which generate a spontaneous symmetry breaking at the TeV scale

$$\langle\Delta\rho_{qvE}{}^2\rangle = \frac{4N_f\lambda_C\lambda_S - N_f\lambda_{SC}^2 + 4\lambda_C\lambda_{S'}}{2\lambda_C}\langle({s_R}^+ s_R)/N_f\rangle \quad (76)$$

$$M_h^2 \cong 2N_f\lambda_{SC}\langle({s_R}^+ s_R)/N_f\rangle \quad (77)$$

where here a small λ_{SC} is assumed. On the basis of equations (76) and (77), we can say that a scale-generation mechanism in the interactions predicted by the Standard Model emerges naturally. And, in this scheme, the variable quantum vacuum energy density, the scalar field s_R depending on the energy density fluctuations, as well as the scalar couplings λ_{SC}, λ_C, λ_S associated with the wave function C and with the singlet field depending on the quantum vacuum energy density fluctuations, can be considered the ultimate parameters which are responsible of the generation of the action of the Higgs boson in the high-energy regime.

On the other hand, it must be emphasized that the Standard Model provides an excellent description of nature up to the TeV scale and works as a consistent theory up to the Planck scale with vacuum that sits close to the border of stable and metastable, and this can provide a hint for new critical phenomena in the ultraviolet. Since new particles either interactions have not yet been revealed in experiments, it looks as if the symmetries of the Standard Model turn out to have a special status. As a consequence, an important issue that has to be addressed regards where these symmetries come from, in particular if they emerge from some new critical system which exists close to the Planck scale. In this regard, in [76] Bass makes the following considerations:

> With emergent gauge symmetries, the Standard Model is an effective theory with action containing an infinite series of higher-dimensional operators whose contributions are suppressed by powers of the large scale of emergence. In this scenario, the leading term contributions are renormalizable operators with greatest global symmetry. Experimental constraints on the size of the Pauli term, tiny neutrino masses and constraints on axion masses and proton decay suggest an ultraviolet scale M greater than $10^{10}\ GeV$ and perhaps between $10^{15}\ GeV$ and the Planck scale of $1{,}2 \cdot 10^{19}\ GeV$. It is interesting that considerations of electroweak vacuum stability suggest either a stable vacuum or metastable vacuum with the Higgs self-coupling crossing zero in the same range of energy scales. The M-scale suppressed higher dimensional terms only start to dominate the physics when we become sensitive to scales close to M, e.g. sensitive to physics processes which happened close to the start of the Universe. That is, at the very highest energies the system becomes increasingly chaotic with maximum symmetry breaking in contrast to unification models which exhibit the maximum symmetry in the extreme ultraviolet.

In our theory developed in this paper, which provides a unifying approach of the a-temporal quantum-gravity space theory and the three-dimensional dynamic quantum vacuum model, the suggestive perspective is opened that also the gauge symmetries are emergent phenomena from the primordial elementary fluctuations of the quantum vacuum energy density as a consequence of a spontaneous symmetry breaking which triggers the three-dimensional quantum vacuum to the density of cosmic space of the quantum-gravity space. As regards the mathematical formalism regarding the connection between gauge symmetries and the fluctuations of the quantum vacuum in regime of spontaneous symmetry breaking, much work is of course required and further research will give you more information.

Now, in order to close the circle, we must examine how the regime of a-temporal quantum gravity space described by the generalized Klein-Gordon equation (21) and the generalized Dirac equation (25) for the density of cosmic space, emerges from (and is linked with) the dynamical spontaneous symmetry breaking of the hidden sector of the TeV scale of strong interactions, which leads to equations (76) and (77) expressing the action of the Higgs boson as the result of the interplay of opportune fluctuations of the quantum vacuum energy density. In this regard, since the regime of Planck-Fiscaletti granules of the a-temporal quantum-gravity space is associated to a density of cosmic space that derives directly from the fluctuations of the quantum vacuum energy density on the basis of relation (19) and that corresponds to particles of the Standard Model on the basis of equation (43), in the light of the fundamental equations (56) and (57), we can say that the "constituent" scalar variable quantum vacuum energy density of the hidden sector of the strong interactions given by relation (62) generates – at an upper level – an emergent "constituent" density of cosmic space satisfying equation

$$\langle [D(r)]^2 \rangle = \frac{G^2 V^2}{c^4 r^4} \frac{4N_f \lambda_C \lambda_S - N_f \lambda_{SC}^2 + 4\lambda_C \lambda_{S'}}{2\lambda_C} \langle ({s_R}^+ s_R)/N_f \rangle \tag{78}$$

The physical meaning of equation (78) is that the Planck-Fiscaletti granules of the a-temporal quantum-gravity space can be considered as emergent properties at the TeV scale of strong interactions as a consequence of a fundamental dynamical spontaneous symmetry breaking triggered just by the variable quantum vacuum energy density, the scalar field s_R depending on the energy density fluctuations, as well as the scalar couplings λ_{SC}, λ_C, λ_S. Moreover, by introducing the fundamental equation (78) into equation (50) describing the non-locality of the oscillation frequency of the density of cosmic space of the Planck-Fiscaletti granules, one obtains

$$a_0\left(n+\sin\left(\frac{2\sqrt{\frac{G^2V^2}{c^4r^4}\frac{4N_f\lambda_C\lambda_S-N_f\lambda_{SC}^2+4\lambda_C\lambda_{S'}}{2\lambda_C}\langle(s_R{}^+s_R)/N_f\rangle c^2r^2}}{G\hbar n}t\right)\right)\frac{G^2\hbar^2n^2}{2\frac{G^2V^2}{c^4r^4}\frac{4N_f\lambda_C\lambda_S-N_f\lambda_{SC}^2+4\lambda_C\lambda_{S'}}{2\lambda_C}\langle(s_R{}^+s_R)/N_f\rangle c^4r^4}=\frac{V\Delta\rho_{qvE}}{2}\frac{|\psi_{Q,i}|}{\left(\nabla^2-\frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right)|\psi_{Q,i}|} \tag{79}$$

According to equation (79), one can say that the degree of non-locality characterizing the oscillation frequency of the density of cosmic space of the Planck-Fiscaletti granules of the a-temporal quantum-gravity space – generated by the motion of the virtual particles of the 3D quantum vacuum and associated with elementary quantum vacuum energy density fluctuations – is associated with the TeV scale of strong interactions following a dynamical process of spontaneous symmetry breaking. In the light of the approach based on equations (78) and (79), one can say that, in the subatomic world, different levels and degrees of correlations exist in a scheme of emergent physics, in the sense that the variable quantum vacuum energy density, the scalar field s_R depending on the energy density fluctuations, as well as the scalar couplings λ_{SC}, λ_C, λ_S associated with the wave function C and with the singlet field depending on the quantum vacuum energy density fluctuations, generate a particular level of non-local boundary at the TeV scale, following a dynamical spontaneous symmetry breaking.

At the conclusion of this chapter, let us examine how, from the mathematical point of view, the baryonic matter of the Standard Model can be interpreted as an emergent structure from the density of cosmic space of the a-temporal quantum-gravity space, as a consequence of a spontaneous symmetry breaking at the TeV scale. In this regard, the key in order to derive baryonic matter as a form of collective organization following a dynamical symmetry breaking is always represented by equation (78). By substituting equation (78) into equation (43), one obtains the following fundamental law

$$\begin{cases}-\hbar^2\frac{\partial^2}{[(2\pi\tau')]^2}\phi(\tau')=V^2\frac{4N_f\lambda_C\lambda_S-N_f\lambda_{SC}^2+4\lambda_C\lambda_{S'}}{2\lambda_C}\langle(s_R{}^+s_R)/N_f\rangle\phi(\tau') & \text{for } \tau'\in[-\vartheta/2,\vartheta/2]\\ \varphi(\tau')=0 & \text{otherwise}\end{cases} \tag{80}$$

Equation (80) shows in what sense the baryonic matter of the Standard Model can be seen as an emergent structure from the density of cosmic space of the a-temporal quantum-gravity space in regime of TeV scale as a consequence of a dynamical spontaneous symmetry breaking. In equation (80), $\varphi(\tau')$ is, as usual, an internal wave function factor (inaccessible by direct observation), which is real and harmonic in an internal time variable τ' of the vacuum background, null at the boundary and outside of the interval $\left[-\frac{\vartheta_0}{2},\frac{\vartheta_0}{2}\right]$, under the constraint $c\vartheta_0 \approx 10^{-13}cm$. And, in this regime, a real quantum massive particle of the Standard Model is given by the sum of the nascent "bare" mass produced by the virtual particles of the 3D DQV, and a term ε/c^2 associated with the self-interaction, which ultimately emerges from the Higgs mass (77) – seen as the result of an interplay of opportune quantum vacuum energy density fluctuations – and, therefore, by inserting equation (77) into equation (45), one obtains:

$$\sqrt{2N_f\lambda_{SC}\langle(s_R{}^+s_R)/N_f\rangle} = -\frac{e}{c^2}\int\bar{\phi}\gamma^\mu A_\mu\phi dV \tag{81}$$

where A_μ is the self-field, ϕ is the spinor satisfying the non-linear generalized Dirac equation for the density of cosmic space which in this regime reads

$$\left(i\gamma^\mu\partial_\mu - \frac{\sqrt{\frac{G^2V^2}{c^4r^4}\frac{4N_f\lambda_C\lambda_S-N_f\lambda_{SC}^2+4\lambda_C\lambda_{S'}}{2\lambda_C}\langle(s_R{}^+s_R)/N_f\rangle}}{c^2}\right)\psi_S = 0 \tag{82}$$

The physical meaning of equation (81) is that it expresses the constraint which must be satisfied by the packets of energy of the a-temporal quantum-gravity space – deriving ultimately from the 3D DQV – in order to generate a real particle in the TeV scale of the strong interactions as a consequence of a dynamical spontaneous symmetry breaking, by showing that the self-interaction term A_μ, which makes the particle "dressed", emerges directly from the variable quantum vacuum energy density, the scalar field s_R depending on the energy density fluctuations, as well as the scalar couplings λ_{SC}, λ_C, λ_S.

Finally, in this regime, the generalized Klein-Gordon equation for the Planck-Fiscaletti granules reads

$$\nabla^2\psi_S - \frac{1}{c^2}\frac{\partial^2\psi_S}{\partial t^2} = \frac{G^2V^2}{c^8r^4}\frac{4N_f\lambda_C\lambda_S-N_f\lambda_{SC}^2+4\lambda_C\lambda_{S'}}{2\lambda_C}\langle(s_R{}^+s_R)/N_f\rangle\psi_S \tag{83}$$

Equations (82) and (83) express how the Planck-Fiscaletti granules characterizing the a-temporal quantum-gravity space are linked with the TeV scale of the strong interactions as a consequence of a dynamical spontaneous symmetry breaking, described by the ultimate parameters represented by the variable quantum vacuum energy density, the scalar field s_R depending on the energy density fluctuations, as well as the scalar couplings λ_{SC}, λ_C, λ_S. In summary, on the basis of the approach developed in this chapter, we can conclude that the Planck-Fiscaletti granules of the a-temporal quantum-gravity space can be seen as forms of collective organization which derive from fundamental properties of the 3D DQV, in particular the scalar field s_R depending on the energy density fluctuations, the scalar couplings λ_{SC}, λ_C, λ_S associated with the wave function C and with the singlet field depending on the quantum vacuum energy density fluctuations, as a consequence of a dynamical spontaneous symmetry breaking at the TeV scale of strong interactions.

4. Conclusions

In the spirit of a view of space and particles as emergent properties which derive from a fundamental background, as expressions, constrained and conveyed, of an informational matrix "at the bottom of the world" expressed by a sort of "quantum ether", the unifying approach of the a-temporal quantum-gravity space constituted by Planck-Fiscaletti granules governed by generalized Klein-Gordon and Dirac equation for the density of cosmic space, which emerge from a fundamental three-dimensional dynamic quantum vacuum defined by RS processes of creation/annihilation of virtual particles corresponding to elementary energy density fluctuations, allows us to obtain the quantum behaviour of the particles of the Standard Model as forms of collective organization under opportune physical constraints in a natural way.

In this approach, a scale-generation mechanism in the interactions predicted by the Standard Model emerges directly from the ultimate properties of the 3D quantum vacuum, thus throwing new light into the solution of the hierarchy problem of the Standard Model. The variable quantum vacuum energy density, the scalar field s_R which is the real part of the singlet field S which is a function of the fluctuations of the quantum vacuum energy density, as well as the scalar couplings λ_{SC}, λ_C, λ_S associated with the properties of the dynamic three-dimensional quantum vacuum can be considered the ultimate parameters which are responsible of the generation of the action of the Higgs boson in the high-energy regime and show how Standard Model appears as an effective field theory that describes interactions near the TeV scale and how the Planck-Fiscaletti granules characterizing the a-temporal quantum-gravity space are linked with the TeV scale of strong interactions as a consequence of a dynamical spontaneous symmetry breaking.

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