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# Perspectives about Scales and Hierarchies in a Three-Dimensional Quantum Vacuum Ruled by Generalized Uncertainty Relations

**Davide Fiscaletti**[1*], **Amrit Sorli**[2]

[1]SpaceLife Institute, Via Roncaglia, 35 – 61047 San Lorenzo in Campo (PU), Italy
[2]Bijective Physics Institute, Ptuj, Slovenia
[*]Corresponding author's E-mail: spacelife.institute@gmail.com

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**Abstract.** A model of a three-dimensional dynamic quantum vacuum defined by a variable energy density and ruled by generalized uncertainty relations is considered, which leads to a unifying treatment of microphysics of elementary particles and macrophysics of black holes in terms of a generalized Compton wavelength. In this model, new keys of explanation of scales, hierarchies and Higgs mass generation of the Standard Model are explored as a consequence of dissipative features of the vacuum originated by elementary sub-Planckian objects at the generalized Compton wavelength.

KEY WORDS: generalized uncertainty relations; three-dimensional dynamic quantum vacuum; variable energy density; generalized Compton wavelength; hierarchies; Higgs mass generation.

## 1 Introduction

The Standard Model (SM) of particle physics constitutes the fundamental theory of contemporary physics which provides a detailed description of the elementary particles of matter and specifies how they interact. Despite its extraordinary predictive power and success in describing particle physics up to at least a few TeV as revealed in experiments at the LHC and in low-energy precision experiments such as electron electric dipole measurements and precision measurements of the fine structure constant, new physics seems necessary in order to clear various compelling observations, such as the nature and generation of neutrino masses, the hierarchies among fermion masses, the nature of dark matter, the baryon asymmetry in the universe and the origin of electroweak symmetry breaking [1, 2].

In SM the spontaneous symmetry breaking mechanism emerges as the fundamental element that has the role to generate the masses of the weak gauge bosons, to give rise to the appearance of the Higgs boson and consequently to the appearance of the fermion masses and mixings. However, the discovery of the Higgs boson at CERN in 2012 does not mean the end of the story in the sense that the problem of Higgs boson's couplings is far from being solved and the mass of the Higgs boson turns out to be characterized by a quadratically divergent counterterm which would push its value towards the Planck scale, thus leading to the necessity to develop a beyond the Standard Model physics.

In order to extend the SM beyond the TeV scale, the Higgs sector seems to play a key role in the sense that provides a portal between the visible and a dark sector [3–6], is the ultimate source of the interactions with right-handed neutrinos in the leptogenesis framework which can reproduce the baryon asymmetry [7], and leads to a possible explanation of the origin of the electroweak symmetry breaking if the Higgs field is coupled to additional scalar particles [8–11]. However its features imply that SM turns out to be affected by a 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" [12]. On the other hand, the hierarchy problem of SM 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 the cosmological constant of vacuum energy density which drives the accelerating expansion of the universe is characterized by a scale of 0,002 eV, very much less than the Higgs mass, QCD and Planck scales.

Among the theories that address the hierarchy problem at the TeV scale, one can mention supersymmetric extensions [13–16], new strong dynamics or technicolor [17, 18] composite Higgs [19–21] and extra dimensions [22–24] and it must be emphasized that the minimal versions of these models are nowadays rather fine-tuned in order to stay compatible with experiments [12,25–27]. More recently, 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 [2].

In [28], the scale hierarchies of SM have been treated by considering the interplay of Poincaré invariance, mass generation and renormalization group invariance, which leads to the idea of an emergent SM and to the fact that the measured cosmological constant scale is associated with higher dimensional terms in the action, suppressed by power of the large emergence scale, thus implying that the cosmological constant scale and neutrino masses should be of similar size. In this paper, in the spirit of an emergent explanation of the hierarchies of SM, we provide an alternative key of explanation of the hierarchy scales of SM by considering a toy-model of a three-dimensional (3D) dynamic quantum vacuum (DQV) defined by a variable energy density, proposed recently by the authors in several papers [29–40]. In this model, the fundamental reality is the energy density of the 3D DQV while ordinary matter, dark matter and dark energy are emergent structures, forms of collective organizations, which assume the form of specific excited states of the DQV corresponding to specific fluctuations of the quantum vacuum energy density. The variable energy density of the 3D DQV can be associated to a deformation of the geometry of the background described by opportune generalized uncertainty relations, which has the fundamental property of leading to a suggestive unification of the microscopic regime of elementary particles and the macroscopic domain of black holes, in the sense that a scale exists where Compton wavelength and Schwarzschild radius are unified and thus microscopic systems and macroscopic regime can be seen as emergent physical structures which derive from more elementary objects. Here, our aim is to explore how this model of a 3D DQV defined by a variable energy density and characterized by generalized uncertainty relations leads to suggestive keys of explanation of the scales, hierarchies and the Higgs mass generation of SM.

The paper is so structured. In Section 2 we review the fundamental features of the geometry of the 3D quantum vacuum defined by a variable energy density showing in what sense it leads to the existence of a scale where Compton wavelength and Schwarzschild radius are unified. In Section 3 we develop the mathematical formalism which describes the deviations of the 3D quantum vacuum from the superfluid features near the Planck scale and show how these deviations determine the scales, hierarchies and mass generation of the SM particles. In Section 4 we make some considerations as regards gauge symmetries and cosmological constant in this approach. In Section 5 we summarize the main results of the paper.

## 2 The Geometry of the Three-Dimensional Quantum Vacuum Ruled by Generalized Uncertainty Relations

In a series of recent works [29–40], the authors developed a model of a timeless 3D DQV defined by a Planckian metric and a variable quantum vacuum energy density, where time is not a primary physical reality but exists only as a mathematical parameter measuring the sequential numerical order of material changes. According to this approach, in absence of material objects, the 3D DQV is defined by a ground state that is described by the maximum value of the quantum vacuum energy density which corresponds to the Planck energy density

$$\rho_{pE} = \frac{m_p c^2}{l_p^3} = 4.641266 \times 10^{113}\ \text{J/m}^3\,, \tag{1}$$

(where $m_P$ is Planck's mass, $c$ is the light speed and $l_p$ is Planck's length). The appearance of ordinary matter corresponds to an opportune excited state of the 3D quantum vacuum which is described by an opportune diminishing of the quantum vacuum energy density corresponding to elementary reduction-state (RS) processes of creation/annihilation of virtual particle/antiparticle pairs, given by relation

$$\Delta\rho_{qvE} \equiv \rho_{pE} - \rho = \frac{mc^2}{V} \tag{2}$$

with respect to the ground state, depending on the amount of mass $m$ and the volume $V$ of the particle. Each excited state of the DQV 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

$$\begin{pmatrix} H & 0 \\ 0 & -H \end{pmatrix} C = 0\,, \quad \text{where } H = -\hbar^2\partial^\mu\partial_\mu + \frac{V^2}{c^2}(\Delta\rho_{qvE})^2 \tag{3}$$

and $\Delta\rho_{qvE}$ is the change of the quantum vacuum energy density and the RS processes turn out to be choreographed by the quantum potential of the vacuum

$$Q_{Q,i} = \frac{\hbar^2 c^2}{V^2\left(\Delta\rho_{qvE}\right)^2}\left(\begin{array}{c} \dfrac{\left(\nabla^2 - \dfrac{1}{c^2}\dfrac{\partial^2}{\partial t^2}\right)|\psi_{Q,i}|}{|\psi_{Q,i}|} \\ -\dfrac{\left(\nabla^2 - \dfrac{1}{c^2}\dfrac{\partial^2}{\partial t^2}\right)|\varphi_{Q,i}|}{|\varphi_{Q,i}|} \end{array}\right), \tag{4}$$

which emerges as the ultimate entity guiding the occurring of the processes of creation or annihilation events in space. As a consequence of the primary physical reality of the processes of creation and annihilation and of the non-local action of the quantum potential, inside the 3D DQV model the behaviour of the ordinary matter existing in the universe can be seen as an undivided network of RS processes that take place in a 3D timeless non-local quantum vacuum.

This model of 3D DQV, despite the consideration of a series of specific hypotheses regarding the relations between the states of the vacuum and a variable quantum vacuum energy density, has the merit to suggest interesting perspectives of unification of gravity and quantum theory and a unifying treatment of dark energy and dark matter in terms of more fundamental quantum vacuum energy density fluctuations.

In this model, the variable energy density of the 3D DQV can be associated to a deformation of the geometry of the background which correspond to a breakdown of the Heisenberg uncertainty relations at Planck scale. In particular, by starting from the operators

$$\hat{P}_k^2 = \left(1 + \beta l_p^2 \frac{\Delta\rho_{qvE}^2 V^2}{\hbar^2 c^2}\right)\hat{p}_k\,, \tag{5}$$

$$\hat{X}_j = \hat{x}_j + O\left(\beta^2\right), \tag{6}$$

where $\hat{x}_j$ and $\hat{p}_k$ satisfy the ordinary Heisenberg uncertainty relations, which obey the commutator

$$\left[\hat{X}, \hat{P}\right] = i\hbar \left(1 + \beta l_p^2 \frac{\Delta\rho_{qvE}^2 V^2}{\hbar^2 c^2}\right), \tag{7}$$

the microscopic geometry of the fundamental background of processes represented by the 3D DQV turns out to be characterized by the following generalized uncertainty relations, which are valid at the Planck scale:

$$\Delta x \Delta p \geq \frac{\hbar}{2}\left(1 + \beta l_p^2 \frac{\Delta\rho_{qvE}^2 V^2}{\hbar^2 c^2}\right). \tag{8}$$

In equation (8) the parameter $\beta$ is a fluctuating quantity which expresses the fact that here space-time fluctuations fix the minimal length scale only on average and can be associated with the Planck scale, in analogy with what happens in quantum foam scenarios such as loop quantum gravity as well as cellular automaton interpretation of quantum mechanics [41–48].

In epistemological affinity with the results obtained by Carr [49–55] regarding the duality between elementary particles and black holes in the picture of generalized uncertainty relations, in our model of 3D DQV characterized by the generalized uncertainty relations (8) one can obtain a general scheme which provides an unification of the Compton wavelength describing the microscopic regime of elementary particles and the Schwarzschild radius describing the macroscopic domain of black holes. In fact, taking account of Carr's results [49,55], by starting from the generalized uncertainty relations (8), one can define a generalized Compton wavelength in the variable energy density of the vacuum, given by relation

$$R'_C = \frac{\hbar c}{\Delta\rho_{qvE} V} + \beta l_p^2 \frac{\Delta\rho_{qvE} V}{\hbar c} \tag{9}$$

and then a unified expression for the generalized Compton wavelength and Schwarzschild radius

$$R'_C = R'_S = \sqrt{\left(\frac{\beta\hbar c}{\Delta\rho_{qvE} V}\right)^2 + \left(\beta l_p^2 \frac{\Delta\rho_{qvE} V}{\hbar c}\right)^2}. \tag{10}$$

The physical meaning of equation (10) is that the fundamental quantum vacuum energy density fluctuations, which are associated to elementary RS processes of creation/annihilation of virtual particles, imply the existence of a physical link between the uncertainty principle on the scale of elementary particles and the regime of black holes in macrophysics. In other words, on the basis of the mathematical formalism represented by equations (9)–(10), one can say that, at a fundamental level of the 3D DQV, a scale exists where Compton wavelength and Schwarzschild radius are unified and thus microscopic systems and macroscopic regime can be seen as emergent physical structures which derive from more elementary objects, namely mechanical objects which simultaneously have the properties of elementary particles and of black holes, which can be seen as the collective behaviour of the more fundamental variable quantum vacuum energy density. These elementary objects can be conveniently called "sub-Planckian black holes of the variable energy density of the 3D DQV". In this picture, therefore, we can say that all black holes have an ultimate quantum nature and each elementary particle can be seen as something similar to a black hole, in other words black holes and elementary particles can be seen as distinct aspects of the same underlying physical reality.

## 3 Scales, Hierarchies and Higgs Mechanism in the Superfluid Dissipative Vacuum

Recent research have shown that spacetime emerges as a collective excitation from an underlying microscopic Bose-Einstein condensate in the long-wavelength limit, that the energy exchange between collective excitations of the deep level and the spacetime fundamental degrees of freedom may be treated in terms of a dissipative hydrodynamics and, in particular, that these collective degrees of freedom can be described through a nonlinear logarithmic Schrödinger-like equation [56–58].

In our model of 3D DQV ruled by generalized uncertainty relations (8), and thus by the generalized Compton wavelength (10) intended as the ultimate origin of the appearance both of microscopic particles and of black holes, in epistemological affinity with the results obtained in [56–58], we consider that the energy fluctuations of the vacuum correspond physically to a dissipative hydrodynamics that can be described through a nonlinear Schrödinger-like equation. In the bath constituted by these elementary quantum vacuum energy density fluctuations, the virtual particles of the medium continuously appear and disappear and give rise to a total zero spin, thus constituting an organized Bose ensemble. As a consequence of these elementary processes characterizing the 3D DQV, space-time can be seen as a collective excitation emerging from the elementary modes of the vacuum defined by frequency

$$\omega_i = \frac{2\Delta\rho_{qvE}V}{\hbar n} \tag{11}$$

associated with the Bose-Einstein condensate of the virtual sub-particles, where these modes are characterized by deviations from the perfect superfluid limit close to the Planck scale. In equation (11) $\Delta\rho_{qvE}$ are the energy density fluctuations of the vacuum in the volume $V$, $n$ is the number of the virtual particles in the volume $V$. We assume that these deviations of the vacuum from the superfluid features near the Planck scale can be expressed by an opportune dispersion relation of the form

$$\omega^2 = c^2 k^2 - \frac{c^4 \hbar^2}{{\Delta\rho_{qvE}}^2 V^2} k^4 \,. \tag{12}$$

Now, since in our model the key point is represented by the existence of the unifying underlying scale (10), the wave number $k$ appearing in (12) may be assimilated to the unified Compton wavelength (10), namely

$$k = \frac{1}{\sqrt{\left(\frac{\beta\hbar c}{\Delta\rho_{qvE} V}\right)^2 + \left(\beta l_p^2 \frac{\Delta\rho_{qvE} V}{\hbar c}\right)^2}} \,. \tag{13}$$

Thus, if one substitutes equation (13) into (12), this dispersion relation of the vacuum reads

$$\begin{aligned} \omega^2 = & \frac{c^2}{\left(\frac{\beta\hbar c}{\Delta\rho_{qvE} V}\right)^2 + \left(\beta l_p^2 \frac{\Delta\rho_{qvE} V}{\hbar c}\right)^2} \\ & - \frac{c^4\hbar^2}{{\Delta\rho_{qvE}}^2 V^2 \left[\left(\frac{\beta\hbar c}{\Delta\rho_{qvE} V}\right)^2 + \left(\beta l_p^2 \frac{\Delta\rho_{qvE} V}{\hbar c}\right)^2\right]^2} \,. \end{aligned} \tag{14}$$

The physical meaning of equation (14) is the following: the fluctuations of the quantum vacuum energy density correspond, at the Planck scale, to elementary objects, namely the "sub-Planckian black holes of the variable energy density of the 3D DQV", which have the crucial role to generate the dissipative features of the vacuum (and here the second term

$$\frac{c^4\hbar^2}{{\Delta\rho_{qvE}}^2 V^2 \left[\left(\frac{\beta\hbar c}{\Delta\rho_{qvE} V}\right)^2 + \left(\beta l_p^2 \frac{\Delta\rho_{qvE} V}{\hbar c}\right)^2\right]^2}$$

is responsible of the magnitude of the Lorentz violation).

Now, in our approach, in the light of these dissipative features, the behaviour and evolution of the wave function of the 3D DQV can be described by the following non-linear Schrödinger equation

$$i\hbar\frac{\partial\psi}{\partial t} = \frac{-\hbar^2}{2m}\nabla^2\psi + \nu m|\psi|^2\psi + U\psi, \tag{15}$$

where $m$ is the mass of each virtual particle (namely sub-planckian black hole) of the physical vacuum, $U$ is the potential energy relating to the single virtual particle and $\nu$ is a viscosity coefficient having the dimensions $\frac{\text{length}^2}{\text{time}}$ which can be expressed as $\nu = a^2\omega/2\pi$ where $a$ is the scattering length between the virtual particles and $\omega$ is given by the dispersion relation (14). Equation (15) can be considered as a new peculiar version of the Gross–Pitaevskij equation with the presence of a new fundamental term, linked with $|\psi|^2$ and the viscosity coefficient $\nu$. In particular, in the light of the dispersion relation (14), equation (15) may be conveniently expressed as:

$$i\hbar\frac{\partial\psi}{\partial t} = \frac{-\hbar^2}{2m}\nabla^2\psi + \frac{a^2}{2\pi}\left[\frac{c^2}{\left(\frac{\beta\hbar c}{\Delta\rho_{qvE}V}\right)^2 + \left(\beta l_p^2\frac{\Delta\rho_{qvE}V}{\hbar c}\right)^2} - \frac{c^4\hbar^2}{\Delta{\rho_{qvE}}^2V^2\left[\left(\frac{\beta\hbar c}{\Delta\rho_{qvE}V}\right)^2 + \left(\beta l_p^2\frac{\Delta\rho_{qvE}V}{\hbar c}\right)^2\right]^2}\right]^{\frac{1}{2}} m|\psi|^2\psi + U\psi. \quad (16)$$

In order to explore the consequences of the non-linear Schrödinger equation (16), we recast this equation by the Madelung transformation, writing the wave function as

$$\psi = Re^{iS/\hbar}. \quad (17)$$

By substituting (17) into equation (16) and separating real and imaginary parts, one obtains a continuity equation

$$\frac{\partial\rho}{\partial t} + \frac{\hbar}{m}\nabla\left(\rho\nabla S\right) = 0 \quad (18)$$

and the Hamilton-Jacobi equation

$$\frac{\partial}{\partial t}S + \frac{1}{2m}(\nabla S)^2 + U + Q - \frac{a^2}{2\pi}\left[\frac{c^2}{\left(\frac{\beta\hbar c}{\Delta\rho_{qvE}V}\right)^2 + \left(\beta l_p^2\frac{\Delta\rho_{qvE}V}{\hbar c}\right)^2} - \frac{c^4\hbar^2}{\Delta{\rho_{qvE}}^2V^2\left[\left(\frac{\beta\hbar c}{\Delta\rho_{qvE}V}\right)^2 + \left(\beta l_p^2\frac{\Delta\rho_{qvE}V}{\hbar c}\right)^2\right]^2}\right]^{\frac{1}{2}} \nabla^2 S = 0\,, \quad (19)$$

where

$$Q = \frac{P_1 + P_2}{\rho} = \frac{\hbar^2}{8m}\left(\frac{\nabla\rho}{\rho}\right)^2 - \frac{\hbar^2}{4m}\frac{\nabla^2\rho}{\rho} \quad (20)$$

is the quantum potential, where $\rho = n/V$, where $n$ is the number of the virtual particles (“sub-Planckian black holes of the variable energy density of the 3D DQV”) in the volume $V$. On the basis of relation (20), in the case of bound systems, the points where the quantum potential (20) tends to zero indicate the boundary of the region where the virtual “sub-Planckian black holes of the variable energy density of the 3D DQV” are delocalized.

Since, on the basis of equation (20), the quantum potential cannot be ever null because it represents the internal pressure divided by the density distribution of the particle-antiparticle pairs (and in fact the internal pressure cannot ever be null), in the limit of $Q \to \infty$, one obtains the configuration of the maximum degree of non-locality. In virtue of these features of the quantum potential (20), one can say that the texture of the superfluid vacuum is characterized by an inner non-locality, which implies that even what appears localized (real) is woven into the non-locality.

The model, here developed, of the 3D DQV – characterized by a dissipative hydrodynamics originating from the "sub-Planckian black holes of the variable energy density of the 3D DQV" – allows us to throw new light in the explanation of the formation of the mass of elementary particles, introducing new perspectives in the interpretation of the Higgs boson and explaining in what sense not all the values of energy coming from the 3D DQV can give origin to a minimal substitution.

In SM the masses of the W and Z gauge bosons and charged fermions emerge from coupling to the Higgs boson with a finite Higgs vacuum expectation value (vev) and the renormalized Higgs mass squared comes with the divergent counterterm

$$m^2_{h\,\text{bare}} = m^2_{h\,\text{ren}} + \delta m_h^2\,, \tag{21}$$

where

$$\delta m_h^2 = \frac{K^2}{16\pi^2}\frac{6}{v^2}\left(m_h^2 + m_Z^2 + 2m_W^2 - 4m_t^2\right) \tag{22}$$

relates the renormalized and bare Higgs mass, $K$ is an ultraviolet scale identifying the limit of SM, $v$ is the Higgs vev, $m_h$ is the Higgs mass, $m_Z$ is the mass of the Z boson, $m_W$ is the mass of the W boson, $m_t$ is the mass of the top quark, and the Veltman condition [59] given by

$$m_h^2 + m_Z^2 + 2m_W^2 = 4m_t^2 \tag{23}$$

leads to an equality of renormalized and bare masses with no hierarchy problem, implying a Higgs mass of 314 GeV, much above the measured value.

In our approach of 3D DQV characterized by a dissipative hydrodynamics described by the Gross-Pitaevskji equation (16), in order to face the hierarchy problem that affects the SM, our starting point is to consider a vacuum energy linked with the fluctuations of the superfluid vacuum, given by relation

$$\rho_{\text{vac}} = \frac{1}{2}\frac{t_p c^2}{\hbar n l_p}\sum_{\text{virtual particles}} g_i \int_0^{\Delta\rho_{qvE}^{\max}} \frac{d^3\Delta\rho_{qvE}V}{c^2(2\pi)^3}\sqrt{\frac{\hbar k^2}{\omega_i^2} + m^2}\,, \tag{24}$$

where $m$ is the mass of the virtual particles, $k$ is the wave number given by (13), $\omega_i$ are the frequencies of the modes given by (11), $g_i = (-1)^{2j}(2j+1)f$ is the degeneracy factor for a particle $i$ of spin $j$, and $g_i > 0$ for bosons and $g_i < 0$ for fermions. By substituting equations (13) and (11) inside (24), this latest equation reads:

$$\rho_{\text{vac}} = \frac{1}{2}\frac{t_p c^2}{\hbar n l_p}\sum_{\text{virtual particles}} g_i \int_0^{\Delta\rho_{qvE}^{\max}} \frac{d^3\Delta\rho_{qvE}V}{c^2(2\pi)^3} \times \left[\frac{\hbar}{\frac{4\Delta\rho_{qvE}{}^2V^2}{\hbar^2 n^2}\left[\left(\frac{\beta\hbar c}{\Delta\rho_{qvE}V}\right)^2 + \left(\beta l_p^2\frac{\Delta\rho_{qvE}V}{\hbar c}\right)^2\right]} + m^2\right]^{\frac{1}{2}}. \quad (25)$$

The factor $f$ is 1 for bosons, 2 for each charged lepton and 6 for each flavour of quark (2 charge factors for the quark and antiquark, each with 3 colours). Here, by invoking a Lorentz covariant regularization, one obtains

$$\frac{1}{2}\frac{t_p c^2}{\hbar n l_p}\sum_{\text{virtual particles}} g_i \int_0^{\Delta\rho_{qvE}^{\max}} \frac{d^3\Delta\rho_{qvE}V}{c^2(2\pi)^3} \times \left[\frac{\hbar}{\frac{4\Delta\rho_{qvE}{}^2V^2}{\hbar^2 n^2}\left[\left(\frac{\beta\hbar c}{\Delta\rho_{qvE}V}\right)^2 + \left(\beta l_p^2\frac{\Delta\rho_{qvE}V}{\hbar c}\right)^2\right]} + m^2\right]^{\frac{1}{2}} = -\hbar g_i \frac{m^4}{64\pi^2}\left[\frac{2}{\varepsilon} + \frac{3}{2} - \theta - \ln\left(\frac{m^2}{4\pi\mu^2}\right)\right] + \cdots, \quad (26)$$

where $D = 4 - \varepsilon$ is the number of dimensions, $\mu$ is the renormalization scale and $\theta$ is Euler's constant. The physical meaning of the renormalization equation (26) is that the renormalization, which leads to a vanished zero-point energy for photons and which for SM particles is induced by the Higgs field, here is not a requirement which is imposed a priori (as it occurs in SM), but receives a more fundamental explanation, in the sense that can be ultimately associated with opportune networks of the elementary virtual "sub-Planckian black holes of the variable energy density of the 3D DQV". In other words, in the light of the renormalization equation (26) of the 3D quantum vacuum characterized by a dissipative hydrodynamics ruled by a Gross–Pitaevskij equation, we can say that the ultimate origin of the action of the Higgs field is represented by the virtual "sub-Planckian black holes of the variable energy density of the 3D DQV" providing the dissipative features of the vacuum. Moreover, in the light of equation (26), by applying the Pauli constraint for cancelling the zero-point energy, one finds, compatibly with the results obtained in [28], that the requirement of the mass of Higgs boson of 125 GeV follows as a direct consequence of more fundamental constraints on the collective excitations of the "sub-Planckian black holes of the variable energy density of the 3D DQV", expressed by relations

$$\sum_i g_i \frac{\hbar^6 n^4}{16\Delta\rho_{qvE_i}^4 V^4\Big[\Big(\frac{\beta\hbar c}{\Delta\rho_{qvE_i}V}\Big)^2+\Big(\beta l_p^2\frac{\Delta\rho_{qvE_i}V}{\hbar c}\Big)^2\Big]^2}=0\,, \quad (27)$$

$$\sum_i g_i \frac{\hbar^6 n^4}{16\Delta\rho_{qvE_i}^4 V^4\Big[\Big(\frac{\beta\hbar c}{\Delta\rho_{qvE_i}V}\Big)^2+\Big(\beta l_p^2\frac{\Delta\rho_{qvE_i}V}{\hbar c}\Big)^2\Big]^2} \times \ln\left[\frac{\hbar^3 n^2}{4\Delta\rho_{qvE_i}^2 V^2\Big[\Big(\frac{\beta\hbar c}{\Delta\rho_{qvE_i}V}\Big)^2+\Big(\beta l_p^2\frac{\Delta\rho_{qvE_i}V}{\hbar c}\Big)^2\Big]}\right]=0\,. \quad (28)$$

Therefore, if in the current extensions of the Standard Model the appearance of SM fermions when the zero-point energy is negative is assured by invoking some extra bosons such as 2 Higgs Doublet Models [60], where the second Higgs doublet is constituted by 5 Higgs bosons, two neutral scalars $h$ and $H$, one pseudoscalar $A$ and two charged Higgs states $H^{\pm}$, where the neutral scalars $h$ is a lot like the SM Higgs, now in our model of 3D DQV ruled by a Gross-Pitaevskij hydrodynamics, on the basis of equations (24)–(28), we can provide a deeper characterization of the origin of these extra bosons, as emergent entities from more fundamental networks of the virtual "sub-Planckian black holes of the variable energy density of the 3D DQV".

On the other hand, we emphasize that, on the basis of the experimental results obtained at LHC as regards the particle masses and couplings, the SM works as a consistent theory up to the Planck scale. One finds that the electroweak vacuum sits very close to the border of stable and metastable suggesting possible new critical phenomena in the ultraviolet, within 1.3 standard deviations of being stable on relating the top quark Monte-Carlo and pole masses if we take just the SM with no coupling to undiscovered new particles [61]. While in current models which face the hierarchy problem of the SM, the question of vacuum stability depends on whether the Higgs self-coupling crosses zero or not deep in the ultraviolet and involves a delicate balance of SM parameters, our model of 3D quantum vacuum characterized by a dissipative hydrodynamics originating at the scale of the Compton wavelength, expressed in the form of energy fluctuations associated to the collective organization of the "sub-Planckian black holes of the variable energy density of the 3D DQV", the perspective is opened that the action of the Higgs field and other particle masses have their fundamental origin in the physics close to the Planck scale in a causal way inside an emergent picture.

Moreover, our model allows a dynamical spontaneous symmetry breaking to be achieved in the hidden sector generating the TeV scale of strong interactions as a consequence of opportune energy fluctuations of the 3D quantum vacuum linked with the virtual "sub-Planckian black holes of the variable energy density of the 3D DQV". In this regard, by following Yamada [62], a spontaneous dynamical scale symmetry breaking can be obtained by considering the mean-field approximated effective Lagrangian of the form

$$\mathcal{L}_{\text{MFA}} = ([\partial^{\mu} s_R]^{+}\partial_{\mu} s_R) - \varepsilon^2 (s_R^{+} s_R) - \lambda_C (H^{+}H)^2 + N_f (N_f \lambda_S + \lambda'_S) f^2 + \frac{\lambda'_S}{2} (\phi^a)^2 - 2\lambda'_S \phi^a (s_R^{+} t_{ij}^a s_R)\,, \quad (29)$$

where $s_R$ is a scalar field depending on the energy fluctuations of the vacuum, $f = \left(s_R^{+} s_R\right)/N_f$, $H$ is the Higgs doublet field which ultimately emerges from the renormalization constraint (26) and therefore from the fundamental network of "sub-Planckian black holes of the variable energy density of the 3D DQV", and $\phi^a = 2(s_R^{+} t_{ij}^a s_R)$ are auxiliary fields with $t_{ij}^a$ generators of the flavour $SU(N_f)$ transformation, and $\varepsilon = \Delta\rho_{qvE}^{\text{constituent}}$ is a "constituent" scalar variable quantum vacuum energy of the hidden sector of the strong interactions – which is determined by opportune collective excitations of the virtual "sub-Planckian black holes of the variable energy density of the 3D DQV" – given by relation

$$\varepsilon^2 = 2(N_f \lambda_S + \lambda'_S) f - \lambda_{SC} (H^{+}H)\,. \quad (30)$$

Here, if one sets $\phi^a = 0$ in the mean-field approximation lagrangian, one can obtain the effective potential

$$V_{\text{MFA}} = \Delta\rho_{qvE}{}^2 (\bar{s}_R^{+} \bar{s}_R) + \lambda_C (H^{+}H)^2 - N_f (N_f \lambda_S + \lambda'_S) f^2 + \frac{N_C N_f}{32\pi^2} \Delta\rho_{qvE}{}^4 \ln \frac{\Delta\rho_{qvE}{}^2}{\Lambda_C^2}\,, \quad (31)$$

where $\bar{s}_R$ is the background field of the scalar field $s_R$. The effective potential (31), by applying the dimensional regularization and the $\bar{M}S$ scheme to substract a ultraviolet divergence, leads then directly to the following expressions for the changes of the quantum vacuum energy associated to the collective excitations of the virtual "sub-Planckian black holes of the variable energy density of the 3D DQV", and for the Higgs mass, which generate a spontaneous symmetry breaking at the TeV scale

$$\langle \Delta\rho_{qvE}^2 \rangle = \frac{4N_f \lambda_C \lambda_S - N_f \lambda_{SC}^2 + 4\lambda_C \lambda'_S}{2\lambda_C} \langle (s_R^{+} s_R)/N_f \rangle\,, \quad (32)$$

$$M_h^2 \cong 2N_f \lambda_{SC} \langle (s_R^{+} s_R)/N_f \rangle\,, \quad (33)$$

where a small $\lambda_{SC}$ is assumed. On the basis of equations (32) and (33), we can say that a scale-generation mechanism in the interactions predicted by the SM emerges naturally from opportune collective excitations of the virtual "sub-Planckian black holes of the variable energy density of the 3D DQV". And, in this scheme, the variable quantum vacuum energy, the scalar field $s_R$ depending on the energy fluctuations of the dissipative vacuum, as well as the scalar couplings $\lambda_{SC}$, $\lambda_C$, $\lambda_S$ associated with the vacuum 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. In other words, in the light of equations (32) and (33), the action of the Higgs boson can be considered as a "mechanism", as an emerging process. It is the interplay of opportune fluctuations of the energy of the superfluid quantum vacuum which indeed determines the action of the Higgs boson generating a spontaneous symmetry breaking at the TeV scale.

Moreover, as regards the approach here suggested, by investigating quantum gravity effects on the effective potential (31), one obtains the following renormalization group equations for the scalar mass:

$$\frac{\partial}{\partial t}\bar{m}^2 = \left(-2 + \gamma_m^g\right)\bar{m}^2\,, \tag{34}$$

where

$$\gamma_m^g = \frac{g_N}{6\pi}\Big[\frac{20}{(1-v_0)^2} + \frac{1}{(1-v_0/4)^2}\Big] \tag{35}$$

is the graviton anomalous dimension, where $v_0 = 16\pi g_N \tilde{U}_0$ with $\tilde{U}_0 = \Lambda_{CC}/k^4$ the dimensionless cosmological constant. In the light of the graviton anomalous dimension $\gamma_m^g$ determined by the vacuum fluctuations, the energy scaling of coupling constants above the Planck scale turns out to be drastically modified. If $\gamma_m^g$ is larger than 2, the scalar mass parameter becomes irrelevant. In this situation, one gets the following two potential solutions to the gauge hierarchy problem. On one hand, one deals with the resurgence mechanism in which the small Higgs mass parameter $m_H^2/M_{Pl}^2 \cong 10^{-36}$ is self-organized by quantum gravity effects. In other words, the scalar mass parameter shrinks towards zero above the Planck scale and then increases such that $m_H^2/v_h^2 \cong 0.2$ at the electroweak scale, as a consequence of the decoupling of quantum gravity effects below the Planck scale. On the other hand, one has the perspective of classical scale invariance, namely the scale invariance at the Planck scale could be naturally realized as a consequence of the irrelevance of the scalar mass parameter above the Planck scale. Anyway, inside our approach, one can say that a gauge hierarchy problem is originated when there is a large intermediate scale between the Planck scale and the electroweak scale, for example, the grand unification scale, $\Lambda_{\text{GUT}}$ [62].

Finally, our model of 3D DQV with dissipative features in the form of energy fluctuations associated to the virtual "sub-Planckian black holes of the variable energy density of the 3D DQV" has the merit to provide a natural explanation for the anomalous results known as "negative mass square problem". As we know from the data on the solar and atmospheric neutrino [63], the mass-squared difference for the neutrino oscillation is given, in two-flavour mixing approximation, by the following values:

$$\Delta m^2_{\text{atm}} = 2.5\times 10^{-3}\ \text{eV}^2\,; \qquad \Delta m^2_{\text{sol}} = 6.9\times 10^{-5}\ \text{eV}^2\,, \tag{36}$$

which lead to a relation between the gravity-electroweak unification scale and observational data. In this regard, in [64] a fundamental intrinsic relation between mass, gravity, space-time symmetry and the Higgs mechanism has been explored by involvement of the de Sitter (false) vacuum as its basic ingredient, leading to the following mass-squared difference:

$$\Delta m^2 = \frac{\hbar^2}{c^2 r_0^2} = \frac{8\pi}{3}\frac{\rho_0}{\rho_P} m_{Pl}^2 \tag{37}$$

for both right-handed and left-handed fields, where $\rho_0$ is the vacuum density associated to the scale $r_0$ characteristic of the de Sitter radius given by

$$r_0^2 = \frac{3c^2}{8\pi G \rho_0}\,. \tag{38}$$

Therefore, if one identifies $\rho_0$ as the origin of the gravito-electroweak scale $M_{\text{unif}}$, the mass-squared difference (37) can be connected directly with the unification scale of gravity and electroweak scale as follows:

$$\Delta m^2 = \frac{8\pi}{3}\left(\frac{M_{\text{unif}}}{m_{Pl}}\right)^4 m_{Pl}^2\,, \tag{39}$$

thus leading to the following expression of the unification scale

$$M_{\text{unif}} = \left[\frac{3}{8\pi}\left(\frac{\Delta m^2}{m_{Pl}^2}\right)\right]^{1/4} m_{Pl}\,. \tag{40}$$

Now, in our approach of 3D DQV defined by a variable energy density and characterized by a dissipative hydrodynamics determined by the "sub-Planckian black holes of the variable energy density of the 3D DQV", the fundamental scale that represents the ultimate origin of the appearance both of microscopic particles and of black holes is the generalized Compton wavelength (10). As a consequence, the de Sitter radius (38) invoked in [63] can be here replaced by the generalized Compton wavelength (10). In this way, in our model, in the interaction vertex a particle can be described by a state given by relation

$$I_1' = \mu^2 c^2 \pm \frac{\hbar^2}{2r_0^2}\,, \tag{41}$$

where $r_0$ is associated to the generalized Compton wavelength (10), namely:

$$r_0^2 = \left(\frac{\beta\hbar c}{\Delta\rho_{qvE} V}\right)^2 + \left(\beta l_p^2 \frac{\Delta\rho_{qvE} V}{\hbar c}\right)^2. \tag{42}$$

By taking account [65], the state (41), during its evolution in the Minkowski space, assumes the form of a linear superposition of two different mass eigenstates

$$m_1^2 = \mu^2 + \frac{\hbar^2}{2c^2\left[\left(\frac{\beta\hbar c}{\Delta\rho_{qvE}V}\right)^2 + \left(\beta l_p^2 \frac{\Delta\rho_{qvE}V}{\hbar c}\right)^2\right]},$$
$$m_2^2 = \mu^2 - \frac{\hbar^2}{2c^2\left[\left(\frac{\beta\hbar c}{\Delta\rho_{qvE}V}\right)^2 + \left(\beta l_p^2 \frac{\Delta\rho_{qvE}V}{\hbar c}\right)^2\right]} \tag{43}$$

with equal weights. The resulting symmetry induced by the vacuum energy density of the 3D DQV in the gravito-electroweak vertex generates an exact bi-maximal mixing for neutrinos, leading to the following mass-squared difference between atmospheric and solar neutrinos:

$$\Delta m^2 = \frac{\hbar^2}{2c^2\left[\left(\frac{\beta\hbar c}{\Delta\rho_{qvE}V}\right)^2 + \left(\beta l_p^2 \frac{\Delta\rho_{qvE}V}{\hbar c}\right)^2\right]} \tag{44}$$

for both the right and left handed fields. On the basis of equation (44), the physical reason for the mass-squared difference between atmospheric and solar neutrinos lies in the collective excitations of the virtual "sub-Planckian black holes of the variable energy density of the 3D DQV", namely it can be seen as an emergent effect from the dissipative features of the 3D DQV at the Planck scale.

Now, by equating (44) and (39), one can obtain an expression for the gravito-electroweak scale $M_{unif}$ in the 3D DQV characterized by a dissipative hydrodynamics

$$\frac{8\pi}{3}\left(\frac{M_{\text{unif}}}{m_{Pl}}\right)^4 m_{Pl}^2 = \frac{\hbar^2}{2c^2\left[\left(\frac{\beta\hbar c}{\Delta\rho_{qvE}V}\right)^2 + \left(\beta l_p^2 \frac{\Delta\rho_{qvE}V}{\hbar c}\right)^2\right]}, \tag{45}$$

namely

$$(M_{\text{unif}})^4 = \frac{3\hbar^2 m_{Pl}^2}{16\pi c^2\left[\left(\frac{\beta\hbar c}{\Delta\rho_{qvE}V}\right)^2 + \left(\beta l_p^2 \frac{\Delta\rho_{qvE}V}{\hbar c}\right)^2\right]}, \tag{46}$$

namely

$$M_{\text{unif}} = \frac{1}{2}\left(\frac{3\hbar^2 m_{Pl}^2}{\pi c^2\left[\left(\frac{\beta\hbar c}{\Delta\rho_{qvE}V}\right)^2 + \left(\beta l_p^2 \frac{\Delta\rho_{qvE}V}{\hbar c}\right)^2\right]}\right)^{1/4}. \tag{47}$$

On the basis of relation (47), in the model of the 3D DQV ruled by generalized uncertainty relations at the Planck scale, the gravito-electroweak scale $M_{\text{unif}}$ turns out to be directly fixed by the generalized Compton wavelength where microscopic particles and black holes receive a unifying treatment. Moreover, the mass unification scale (47) implies that the mass-squared differences of neutrinos determined by fluctuations of the quantum vacuum energy density associated with the virtual "sub-Planckian black holes of the variable energy density of the dissipative 3D DQV, in the light of the observational data (36) lead to the following corresponding values of the unification scale for solar and atmospheric neutrinos:

$$M_{\text{unif(atm)}} \approx 14.5\ \text{TeV}\,, \qquad M_{\text{unif(sol)}} \approx 5.9\ \text{TeV}\,. \tag{48}$$

The values (48) turn out to be in good agreement with the results obtained in [63] as well as in other previous theories of electroweak unification [66–68]. The novelty of our approach, with respect the previous theories of electroweak unification, lies in the fact that the unification scale for solar and atmospheric neutrinos emerges directly from the interplay of the virtual "sub-Planckian black holes of the variable energy density of the 3D DQV" close to the Planck scale.

## 4 Gauge Symmetry and Cosmological Constant

Gauge symmetries play a relevant role in SM as they determine the interactions of elementary particles and are a characteristic element in the description of emergent phenomena in quantum condensed matter systems with long range entanglement and topological order [69–77]. If SM is mathematically valid up to the Planck scale and if in SM hadrons and their interactions are emergent from more fundamental QCD quark and gluon degrees of freedom and the structure of ordinary matter is emergent from QED, one expects that at a deeper level the gauge symmetries might be emergent below an energy close to the Planck scale. This means that the usual SM would be supplemented with a tower of higher dimensional operator contributions, like in effective field theory, with extra global symmetry breaking in the higher dimensional operators suppressed by powers of the large scale of emergence. Besides their connection to elementary particle dynamics, the gauge symmetries of particle physics turn out to be interconnected with Lorentz invariance and thus any emergent gauge symmetry might perhaps be accompanied by emergent Lorentz invariance or spontaneously broken Lorentz symmetry, with effects of spontaneously broken Lorentz symmetry suppressed by at least some powers of the large scale of emergence.

In order to understand the physics of emergent gauge symmetries in particle physics, the requirement of considering quantum many-body systems which involve quantum phase transitions with long range entanglement where the building blocks of particle physics are observed, viz., emergent gauge symmetries, Lorentz invariance and spin statistics, Higgs phenomena and chiral fermions, has been recently considered [78]. Moreover, a mechanism has been developed for the emergence of non-Abelian gauge symmetries, by starting from a few simple principles, i.e. low-energy Lorentz invariance, emergence of massless vector fields describable by an action quadratic in these fields and their derivatives, and self-coupling to a conserved current associated with specific rigid symmetries, which assure that any theory satisfying them must be equivalent to a Yang-Mills theory at low energies [79]. In this picture, the emergence process is related on a peculiar parameter, something like the temperature in a condensed matter system, in the sense that below a certain temperature this effective field theory provides a convenient description of the system, whilst above this temperature the description could be very different and not easily connected to the former. Finally, on the basis of the strategy that gauge symmetry breaking terms become negligible at low energies, thereby making the dynamics effectively gauge invariant in this limit, three-dimensional lattice gauge theories have been considered, obtained by discretizing the action of corresponding quantum field theories, where gauge symmetry breaking perturbations at the critical transitions of gauge-invariant models break gauge invariance in the low-energy or large-distance behavior (continuum limit).

In the model of 3D DQV ruled by generalized uncertainty relations, developed in this paper, we expect that the processes regarding the emergent features of the gauge symmetries are fixed by opportune behaviour of the collective excitations of the virtual sub-Planckian black holes of the variable energy density of the dissipative vacuum too. In this picture, one can suggest that new critical phenomena in the ultraviolet appear as the long range tail of a critical Planck-scale system ruled by the value $M_{\text{unif}}$ given by equation (47) and therefore fixed by the generalized Compton wavelength (10) and associated with the virtual "sub-Planckian black holes of the variable energy density of the 3D DQV". This scenario differs from standard unification models which have maximum symmetry at the highest energies and where one invokes a spontaneous symmetry breaking, e.g. mass terms induced by the Higgs mechanism and chiral symmetry breaking in QCD, a procedure of a low-energy expansion which leads to a suppression of any unitarity violating terms by powers of the large ultraviolet scale [1].

The approach suggested in this paper introduces the perspective that the cosmological constant and the hierarchy problem could be resolved as a consequence of specific behaviour of the 3D DQV characterized by a dissipative hydrodynamics and, in particular, near to the scale $M_{\text{unif}}$ fixed by the generalized Compton wavelength (10) and associated with the virtual "sub-Planckian black holes of the variable energy density of the 3D DQV" generating the gravity-electroweak unification scale. As a consequence, the gauge symmetries of the SM would be emergent from the collective features of the network of the "sub-Planckian black holes of the variable energy density of the 3D DQV" characterizing this unification scale $M_{\text{unif}}$.

If one takes the SM gauge symmetries as emergent and dynamically generated by the collective behaviour of the elementary constituents of the 3D dissipative quantum vacuum, SM can be interpreted as 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. At low energies the physics is determined by a relatively small number of operators with mass dimension at most four. For these terms, gauge invariance and renormalizability limit the number of possible operator contributions and strongly constrain the global symmetries of the system. Extra symmetry breaking terms can occur in higher dimensional operators which enter the action suppressed by powers of the large scale of emergence, for example with lepton and baryon number violation. These higher-dimensional terms only become active in the particle dynamics when mass and energy scales close to the large emergence scale are approached.

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 about $10^{10}$ GeV and perhaps between $10^{15}$ GeV and the Planck scale of $1.2 \times 10^{19}$ GeV. In this regard, the superfluid 3D DQV characterized by fluctuations determined by the network of its fundamental "sub-Planckian black holes of the variable energy density of the 3D DQV" emerges as a possible candidate to define this scale and explains its appearance in a natural and direct way. The $M$-scale suppressed higher dimensional terms only start to dominate the physics when scales close to $M$ are approached. In the model of a cyclic universe in dynamic equilibrium, where one deals with the cyclic transformation space-matter-space-matter-... in the active galactic nuclei, this occurs when the process of emission of fresh gas by the active galactic nuclei takes place, that is to say when space is transformed into matter; instead, in the traditional model of big bang, the process happens close to the start of the Universe.

The emergence implies that the global symmetries would be restored with increasing large energy until we come close to the large ultraviolet energy scale $M$, where higher dimensional terms become important. In other words, our model implies that at the highest energies the system becomes increasingly chaotic, characterized by a maximum symmetry breaking in the extreme ultraviolet as a consequence of the specific collective behaviour and features of the virtual "sub-Planckian black holes of the variable energy density of the 3D DQV", in contrast to unification models which exhibit the maximum symmetry in the extreme ultraviolet.

Experimental signatures which show how higher dimensional operators may contribute to new global symmetry breaking beyond SM as truncated to mass-dimension four, are lepton-number violating interactions at dimension-five with Majorana neutrino masses and neutrino-less double $\beta$-decays and, at dimension-six, baryon number violation which might also induce proton decays. In this regard, an emergent picture of SM gauge symmetries from the interplay of the virtual "sub-Planckian black holes of the variable energy density of the 3D DQV" generating dissipative features, may open new scenarios of explanations of various puzzles present in particle physics. For example, the tiny neutrino masses with large values of the ultraviolet scale $M$, about $10^{15}$ GeV, implying the non-conservation of the lepton number at energies typical of the phase of emission of fresh gas by the active galactic nuclei (in the cosmological models of cyclic universe), or of the very early universe (in the big-bang model), may be explained through the Weinberg dimension-five operator

$$O_5 = \frac{(HL)_i^T \lambda_{ij} (H)_j}{M}\,, \tag{49}$$

regarding Majorana neutrino mass, where here the Higgs doublet $H$ is ultimately associated with more elementary fluctuations of the superfluid 3D DQV determined by the collective excitations of the virtual "sub-Planckian black holes of the variable energy density of the 3D DQV" describing its dissipative features, $L_i$ denotes the SU (2) left-handed lepton doublets and $\lambda_{ij}$ is a matrix in flavour space. In analogous way, the four-fermion operator

$$O_6 = \frac{1}{M^2} QQQL\,, \tag{50}$$

where $L$ and $Q$ are the lepton and quark doublets, implies the possibility of the violation of the baryon number which itself becomes active at energies typical of the beginning of the phase of emission of fresh gas by the active galactic nuclei (in the cosmological models of cyclic universe), or in very early universe (in the big-bang model), might play an important role in understanding the matter-antimatter asymmetry in the Universe and can be seen as a consequence of the dissipative features of the vacuum determined by collective excitations of the virtual "sub-Planckian black holes of the variable energy density of the 3D DQV".

On the other hand, another important consideration regarding the crucial role of the scale of emergence in models of emergent SM, lies in the fact that if electroweak symmetry breaking and emergence were to happen at the same scale, then the scenario of inflation would involve totally new physics with different unknown degrees of freedom. We know that electroweak physics is characterized by parity violating couplings of the gauge bosons and possible Majorana neutrinos, thus leading to the issue whether chirality (and neutrinos) might assume a special role in any ultraviolet critical phenomena and a consequent emergent gauge symmetry in the infrared. In this regard, the model of the 3D superfluid quantum vacuum with dissipative features expressed by fluctuations generated by the virtual "sub-Planckian black holes of the variable energy density of the 3D DQV", on the basis of equation (26) which expresses the origin of the Higgs field and equation (47) which expresses the gravity-electroweak unification scale, suggests new perspectives of explanation. One can say that the special role of chirality and neutrinos in the ultraviolet critical phenomena or of the emergent gauge symmetry in the infrared, can be seen as a consequence of the specific behaviour of the dissipative features of the 3D DQV associated with the interplay of the sub-Planckian black holes of the variable energy density at the different scales.

A similar discussion can be made for the cosmological constant which appears in the right-hand side of Einstein's equations of general relativity and can be associated with the vacuum energy density of general relativity ($\langle\rho_{\text{vac}}\rangle$), which is equivalent to a contribution to the 'effective' cosmological constant

$$\Lambda_{\text{eff}} = \Lambda_0 + \frac{8\pi G}{c^4}\langle\rho_{\text{vac}}\rangle\ , \tag{51}$$

where $\Lambda_0$ denotes Einstein's own 'bare' cosmological constant which in itself leads to a curvature of empty space, i.e. when there is no matter or radiation present. Once equation (51) is established, it follows that anything which contributes to the quantum field theory vacuum energy density is also a contribution to the effective cosmological constant in general relativity.

In our approach, the cosmological constant is directly induced by the elementary fluctuations of the quantum vacuum energy density corresponding to the dissipative features determined by the sub-Plackian black holes of the 3D DQV: these fluctuations determine, at un upper level, any (dynamically generated) potential in the vacuum, e.g. associated with the Higgs and QCD condensates, as well as a renormalized version of the bare gravitational term $\rho_\Lambda$. In light of these considerations, the net vacuum energy density may thus be expressed in the following form

$$\rho_{\text{vac}} = \rho_{qvE} + \rho_{\text{potential}} + \rho_\Lambda\ , \tag{52}$$

which turns out to be renormalization scale invariant, drives the accelerating expansion of the Universe and is independent of the way it is computed [28], namely

$$\frac{d}{d\mu^2}\rho_{\text{vac}} = 0\,, \tag{53}$$

where $\mu$ is a substraction scale that remains after renormalization.

In our model of 3D DQV with dissipative features, the contributions to the quantum vacuum energy density $\rho_{qvE}$ in equation (52) are scale dependent both through explicit $\mu^2$ dependence and through the network of the virtual "sub-Planckian black holes of the variable energy density of the 3D DQV". For QCD, the degrees of freedom depend on the resolution. Deep in the ultraviolet one has asymptotic freedom. For massless quarks, the quantum vacuum energy density vanishes. Quark-gluon interactions are chiral symmetric at these scales. In the infrared, confinement and dynamical chiral symmetry breaking take over: the degrees of freedom are protons, neutrons, pions, nucleon resonances... The Higgs potential is renormalization scale dependent as a consequence of the scale dependence of the Higgs mass and Higgs self-coupling, which ultimately derives from the elementary virtual "sub-Planckian black holes of the variable energy density of the 3D DQV" on the basis of equation (26) and determines the stability of the electroweak vacuum ultimately emerging from the unification scale (52). Renormalization scale dependence cancels to give the scale invariant $\rho_{\text{vac}}$.

Moreover, as regards the issue of renormalization, by following Solà [80], in our model one obtains the following relation which expresses the link between the renormalized vacuum energy and the substraction scale $\mu$ that remains after renormalization

$$\rho_{\text{vac}} = \rho_\Lambda(\mu) + \frac{3\hbar^3 m_{Pl}^2}{16\pi^3 c^2 \left[ \left( \frac{\beta\hbar c}{\Delta\rho_{qvE} V} \right)^2 + \left( \beta l_p^2 \frac{\Delta\rho_{qvE} V}{\hbar c} \right)^2 \right]}$$
$$\times \left( \ln \frac{3\hbar^2 m_{Pl}^2}{16\pi c^2 \mu^2 \left[ \left( \frac{\beta\hbar c}{\Delta\rho_{qvE} V} \right)^2 + \left( \beta l_p^2 \frac{\Delta\rho_{qvE} V}{\hbar c} \right)^2 \right]} + \text{finite constants} \right). \quad (54)$$

On the basis of equation (54), the crucial message of the renormalization group becomes the following: the sum of the various $\mu$-dependencies must cancel in the renormalized effective action as a consequence of the peculiar behaviour of the quantum vacuum energy density fluctuations and thus of the degree of the dissipative features of the vacuum.

In current physics, if one supposes that the vacuum including condensates with finite vevs is translational invariant and flat space-time is consistent at dimension four, just as suggested by the success of the SM, then the Renormalization Group invariant scales $\Lambda_{\text{QCD}}$ and electroweak $\Lambda_{\text{ew}}$ might enter the cosmological constant with the scale of the leading term suppressed by $\Lambda_{\text{ew}}/M$ (in this regime $\rho_{\text{vac}} \sim (\Lambda_{\text{ew}}^2/M)^4$ with one factor of $\Lambda_{\text{ew}}^2/M$ for each dimension of space-time). Therefore, since in our model of an emergent picture of the SM and its gauge symmetries from the ultimate superfluid quantum vacuum characterized by a network of virtual "sub-Planckian black holes of the variable energy density of the 3D DQV" describing its dissipative features at the Planck scale, the scale of emergence $M$ depends on opportune fluctuations of the superfluid dissipative vacuum determined by the network of the virtual "sub-Planckian black holes of the variable energy density of the 3D DQV", it follows that the same result of the SM regarding the relation between the Renormalization Group invariant scales $\Lambda_{\text{QCD}}$ and electroweak $\Lambda_{\text{ew}}$ and the cosmological constant in terms of the scale of the leading term suppressed by $\Lambda_{\text{ew}}/M$, turn out to be directly fixed and determined by the dissipative features of the 3D DQV at the Planck scale. This scenario allows an explanation of the reason why the cosmological constant scale 0.002 eV is similar to what we expect for the neutrino masses [81], themselves linked to a dimension five operator with $m_\nu \sim \Lambda_{\text{ew}}^2/M$ and Majorana neutrinos [82], as a consequence of the interplay of the collective excitations of fundamental virtual "sub-Planckian black holes of the variable energy density of the 3D DQV" describing the dissipative features characterizing the Planck scale. And here the cosmological constant would vanish at dimension four, namely $\rho_{\text{vac}} = 0$ follows as a renormalization condition at dimension four set by space-time translational invariance, which can be seen as a result of the dissipative hydrodynamics of the vacuum, even in the presence of the energetic fluctuations mimicking the action of the Higgs and of QCD vacuum condensates. The precision of global symmetries in our experiments, e.g. lepton and baryon number conservation, teach us that the scale of emergence should be deep in the ultraviolet, much above the Higgs and other SM particle masses, close to the Planck scale, just as a consequence of the collective behaviour of the virtual "sub-Planckian black holes of the variable energy density of the 3D DQV".

## 5 Conclusions

If Standard Model explains a wide range of phenomena regarding interactions between elementary particles over many orders of magnitude, it has many defects, in the sense cannot explain several issues and, in particular, there is no explanation for why the scale of the mass of Higgs boson is so much different from naive quantum-mechanical expectations, and thus whether or not there is an extended Higgs sector, why there are multiple generations of fermions with a large mass hierarchy. For these (and many other) reasons, the Standard Model is considered to be an effective field theory that describes interactions near the TeV scale and that physics beyond the Standard Model should exist. In this regard, several strategies exist in the literature in order to develop extensions of the Standard Model, many of which contain predictions of new particles or dynamics that could manifest in proton-proton collisions at the Large Hadron Collider but, until now, it seems that none have been observed, and much of the available phase space for natural solutions to outstanding problems is excluded [83].

The considerations made in this paper allow us to throw new light for the physics of Beyond Standard Model, in a picture in which emergence plays the crucial role. The generalized uncertainty relations characterizing the geometry of the fundamental three-dimensional quantum vacuum defined by a variable energy density lead to a unifying treatment of microphysics of elementary particle and macrophysics of black holes in terms of a generalized Compton wavelength which opens new suggestive unifying perspectives of solution of the hierarchy problem of the Standard Model. In this picture, the three-dimensional quantum vacuum is characterized by a dissipative hydrodynamics described by a Gross-Pitaevskij formalism. The generalized Compton wavelength lead to the existence of virtual "sub-Planckian black holes of the variable energy density of the three-dimensional dynamic quantum vacuum", which constitute the ultimate origin of the action of the Higgs field. Therefore, Higgs field can be considered a mechanism, as an emerging process: the interplay of opportune fluctuations of the energy of the three-dimensional quantum vacuum characterized by a dissipative hydrodynamics determines the action of the Higgs boson generating a spontaneous symmetry breaking at the TeV scale, in the sense that, in the hidden sector generating the TeV scale of strong interactions, a dynamical spontaneous symmetry breaking is achieved as a consequence of opportune energy fluctuations of the 3D quantum vacuum linked with the virtual "sub-Planckian black holes of the variable energy density of the three-dimensional dynamic quantum vacuum".

Moreover, the gravito-electroweak unification scale $M_{\text{unif}}$ turns out to be directly fixed by the generalized Compton wavelength and therefore associated with the virtual "sub-Planckian black holes of the variable energy density of the three-dimensional dynamic quantum vacuum". The virtual sub-Planckian black holes of the variable energy density characterizing the geometry of the three-dimensional quantum vacuum and generating its dissipative features have the merit to provide a natural explanation for the "negative mass square problem", in the sense that the physical reason of the mass-squared difference between atmospheric and solar neutrinos can be seen as an emergent effect from the dissipative features of the three-dimensional quantum vacuum at the Planck scale. Finally, in this approach, the interesting perspective is opened that also the gauge symmetries of the Standard Model be derived from the ultimate network of virtual sub-Planckian black holes of the variable energy density describing the dissipative features of the three-dimensional quantum vacuum at the Planck scale.

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