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Towards a Non-Local Timeless Quantum Cosmology for the Beyond Standard Model Physics

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Abstract. The search for a consistent quantum theory of gravity and cosmology, which moreover allows a resolution of the problems of the Standard Model of particle physics, is among the biggest open problems of fundamental physics. Here, we provide arguments towards the development of a non-local timeless quantum cosmology, where the fundamental arena of the universe is a non-local three-dimensional quantum vacuum which yields relevant hints of a physics beyond the Standard Model.

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1 Introduction

Quantum cosmology has the purpose to provide a quantum description to the universe as a whole. Its construction conceptually requires a quantum theory of gravity, since gravity constitutes the dominating interaction at large scales. Quantum cosmology may serve as a test bed for quantum gravity in a mathematically simpler setting and may be directly relevant for an understanding of the real universe.

In order to provide a quantum description of gravitational interaction at large scales, despite the absence until now of real clues in this sense, it seems natural to expect that the linearity of quantum theory breaks down in situations where the gravitational field becomes strong (see, for example, the papers of Penrose [1], Singh [2], and Bassi et al. [3]). If a popular approach which challenges the direct quantization of the gravitational field is the "emergent gravity" (see, for example, [4]), the thermodynamic properties of black holes seem to suggest that the gravitational field is an effective thermodynamic entity that does not need its direct quantization but is directed towards the existence of new microscopic degrees of freedom underlying gravity, which are yet far unknown. Despite the fact that until now it is not clear if the gravitational field is an effective thermodynamic entity, there may exist microscopic degrees of freedom

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for which a quantum treatment of gravitational processes would apply. Whether this kind of approaches leads to a quantized metric or not is not clear. For example, string theory implies that gravity is an emergent interaction, but in this specific approach to the treatment of gravity still the metric is quantized, and the standard approach of quantum gravitational perturbation theory can be naturally embedded.

However, many important arguments suggest that the gravitational interaction must be quantized [5]. Before all, gravity acts universally to all forms of energies and thus a unified theory of *all* interactions including gravity should not be a hybrid theory in utilizing classical and quantum concepts. In order to provide a coherent quantum theory of all interactions (namely what today is often called "theory of everything" or TOE), a preliminary requirement is the necessity to embed a quantum description of the gravitational field. On the other hand, an important argument for the quantization of gravity lies in the necessity to avoid singularities such as the cases of the big bang and the black holes predicted by Einstein's theory of general relativity (GR) (see, for example, Hawking and Penrose [6] and Rendall [7]). One would thus expect that a more fundamental theory dealing with gravitational interaction does not predict any singularities. A third motivation is the so-called "problem of time." In standard quantum mechanics, time is absolute, is a special physical quantity which plays the role of the independent variable of physical evolution. In quantum field theory, even if time by itself is no longer absolute, the Minkowski four-dimensional spacetime serves as the arena of processes, namely is the fixed background structure on which the dynamical fields act: as a consequence, in relativistic quantum field theories, the peculiar time variable of a particular Lorentz frame is used to describe the evolution, which is generated by a Hamiltonian and thus time continues to be treated as a background external parameter. Instead, GR is of a very different nature. According to the Einstein equations, spacetime is no longer fixed, but is dynamical, interacting in a complicated manner with energy and matter. As a consequence, in GR, there is no preferred independent observable time variable, but change is described in terms of a relation among equal footing variables. As regards this issue of GR, the absence of a fixed background structure is also called "background independence" (see, for example, [8]). Therefore, one can conclude that the concepts of time (spacetime) in quantum theory and GR are drastically different and incompatible one with the other. One thus needs a more fundamental theory, which deals with the quantum gravity domain, able to provide a coherent notion of time.

As we know, in quantum gravity and cosmology universe can be described by a wave-functional Ψ which satisfies the Wheeler-DeWitt (WDW) equation (here we have made the position $\hbar = c = 1$):

$$\left[(8\pi G)\, G_{abcd}p^{ab}p^{cd} + \frac{1}{16\pi G}\sqrt{g}\left(2\Lambda - {}^{(3)}R\right)\right]\Psi = 0\,, \tag{1}$$

where $G_{abcd} = \frac{1}{2}\sqrt{g}\left(g_{ac}g_{bd} + g_{ad}g_{bc} - g_{ab}g_{cd}\right)$ is the supermetric, p^{ab} are the momentum operators related to the 3-metric g_{ab}, $g = \det g_{ij}$, ${}^{(3)}R$ is the 3-dimensional curvature scalar, Λ is the cosmological constant, G is the gravitational constant. As regards homogeneous models (also called minisuperspace models), in which the simplest assumption is isotropy, taking account that the line element for the classical spacetime metric is given by

$$ds^2 = -N\left(t\right)^2 dt^2 + a\left(t\right)^2 d\Omega_3^2\,, \tag{2}$$

where $d\Omega_3^2$ is the line element of a constant curvature space with curvature index $k = 0, \pm 1$, the Wheeler–DeWitt (WDW) equation (1) becomes the following two-dimensional partial differential equation for a wave function $\psi\left(a, \varphi\right)$:

$$\left(\frac{\hbar^2\kappa^2}{12}a\frac{\partial}{\partial a}a\frac{\partial}{\partial a} - \frac{\hbar^2}{2}\frac{\partial^2}{\partial\varphi^2} + a^6\left(V(\varphi) + \frac{\Lambda}{\kappa^2}\right) - \frac{3ka^4}{\kappa^2}\right)\Psi(a,\varphi) = 0\,, \tag{3}$$

where Λ is the cosmological constant, $\kappa^2 = 8\pi G$, φ is a homogeneous scalar field with potential $V\left(\varphi\right)$ which defines the matter degree of freedom. In many versions of quantum cosmology, Einstein's theory is the classical starting point. More general approaches include supersymmetric quantum cosmology [9], string quantum cosmology, noncommutative quantum cosmology [10], Hořava–Lifshitz quantum cosmology [11] and third-quantized cosmology [12].

In loop quantum cosmology, the standard programme lies in applying features from full loop quantum gravity on cosmological models [13]. In loop quantum gravity one of the main features is represented by the discrete nature of geometric operators, and this implies that in this picture the WDW equation (1) is replaced by a difference equation. This difference equation turns out to be indistinguishable from the WDW equation at scales exceeding the Planck length, at least in certain models. In virtue of mathematical difficulties, in order to provide a solution of this difference equation, one can use an effective theory [14].

Many features of quantum cosmology are discussed in the limit when the solution of the WDW equation assumes a semiclassical or WKB form [15]. This occurs, in particular, for concrete models in which one applies the no-boundary proposal or the tunnelling proposal for the wave function. The no-boundary condition was originally formulated by Hawking in 1982 [16] and then elaborated by Hartle and Hawking in 1983 [17] and Hawking in 1984 [18]. The no-boundary condition, in which the wave function is expressed by an Euclidean path integral, states that – apart from the boundary where the three metric is specified – there is no other boundary on which initial conditions have to be specified. However, the no-boundary condition leads to many solutions, and here the integration has to be performed over complex metrics (see, for example the references [19,20]). Moreover, the path integral defining the no-boundary condition can usually only be evaluated in a semiclassical limit (using the saddle-point approximation), so it is hard to make a general statement about singularity avoidance. In particular, in a Friedmann model with scale factor a and a scalar field φ with a potential $V(\varphi)$, the no-boundary condition gives the semiclassical solution [18]

$$\psi_{NB} \propto \left(a^2 V(\varphi) - 1\right)^{-1/4} \exp\left(\frac{1}{3V(\varphi)}\right) \times \cos\left(\frac{\left(a^2 V(\varphi) - 1\right)^{3/2}}{3V(\varphi)} - \frac{\pi}{4}\right), \quad (4)$$

which corresponds to the superposition of an expanding and a recollapsing universe (and implies that the no-boundary wave function is always real).

Another prominent boundary condition is the tunnelling proposal, originally defined by the choice of taking "outgoing" solutions at singular boundaries of superspace (see, for example the reference [21]). By applying this condition to the same Friedmann model here one obtains

$$\psi_T \propto \left(a^2 V(\varphi) - 1\right)^{-1/4} \exp\left(-\frac{1}{3V(\varphi)}\right) \times \exp\left(-\frac{i}{3V(\varphi)} \frac{\left(a^2 V(\varphi) - 1\right)^{3/2}}{3V(\varphi)} - \frac{\pi}{4}\right) \quad (5)$$

from which, considering the conserved Klein–Gordon current

$$j = \frac{i}{2}\left(\psi^* \nabla \psi - \psi \nabla \psi^*\right) \quad (6)$$

with $\nabla j = 0$, ∇ indicating the derivatives in minisuperspace, one obtains for a WKB solution of the form $\psi \approx C \exp(iS)$ the following expression:

$$\psi \approx -\left|C\right|^2 \nabla S\,. \quad (7)$$

Here, the tunnelling proposal physically means that the current (6) should point outwards at large a and φ (if ψ is of WKB form). Although here a complex solution is chosen, again also in this proposal – in analogy to the no-boundary condition – the wave function is of semiclassical form. In this regard, it has even been suggested that the wave function of the universe may be interpreted only in the semiclassical WKB limit, because only in this case a time parameter and an approximate (functional) Schrödinger equation are available [22].

On the other hand, this can lead to a conceptual confusion. Implications for the meaning of the quantum cosmological wave functions should be derived as much as possible from exact solutions. This happens because the WKB approximation breaks down in many interesting situations, even for a universe of macroscopic size. One example is represented by a closed Friedmann universe with a massive scalar field [23]. The conceptual confusion regarding cosmological wave functions has been recently analyzed by Kiefer in his paper *Conceptual problems* *in quantum gravity and cosmology* [24]. In this paper, in his discussion of the present status of research on quantum gravity, Kiefer explains that the conceptual confusion regarding cosmological wave functions is linked to the fact that, for a classically recollapsing universe, one must impose the boundary condition that the wave function goes to zero for large scale factors, $\psi \to 0$ for large a. As a consequence, narrow wave packets do not remain narrow because of the ensuing scattering phase shifts of the partial waves (that occur in the expansion of the wave function into basis states) from the turning point. The correspondence to the classical model can only be understood if the quantum-to-classical transition (in the sense of decoherence) is invoked.

Another example is the case of classically chaotic cosmologies, as has been studied, for example, by Calzetta and Gonzalez [25] and by Cornish and Shellard [26]. Here, one can see that the WKB approximation breaks down in many situations. This is, of course, a situation well known from quantum mechanics. One of the moons of the planet Saturn, Hyperion, is characterized by chaotic rotational motion. Treating it quantum-mechanically, one recognizes that the semiclassical approximation breaks down and that Hyperion is expected to be in an extremely nonclassical state of rotation (in contrast to what is observed). This apparent conflict between theory and observation can be understood by invoking the influence of additional degrees of freedom in the sense of decoherence, as shown for example in [27] and [28]. The same mechanism should rectifies the situation for classically chaotic cosmologies [29].

A central problem in the search for a quantum theory of gravity and cosmology is the current lack of a clear empirical guideline. This is partly related to the fact that the relevant scales, on which quantum effects of gravity should definitely be relevant, are far remote from being directly explorable. The scale is referred to as the Planck scale and consists of the Planck length, Planck time and Planck mass, respectively. In this paper we introduce a non-local timeless quantum cosmology in the picture of a three-dimensional (3D) quantum vacuum model recently proposed by the author and Sorli in the papers [30–33] and we will explore the perspectives opened by this approach towards a beyond Standard Model physics. We call this model as 3D quantum vacuum cosmology model. In chapter 2 we review the fundamental features of the 3D quantum vacuum established by our approach. In chapter 3 we will analyse the perspectives introduced by this 3D quantum vacuum in quantum cosmology as regards Wheeler-deWitt equation. In chapter 4 we will propose a completion of the Standard Model based on the processes of the 3D quantum vacuum which can avoid the problems connected with the Higgs mechanism. Finally, in chapter 5 we will analyse some elements that evidence the insufficiency of big-bang cosmology in the 3D quantum vacuum model.

2 The Three-Dimensional Quantum Vacuum and Its Properties and Processes

The existence of the physical vacuum can be considered one of the most relevant predictions of modern quantum field theories, such as quantum electrodynamics, the Weinberg-Salam-Glashow theory of electroweak interactions, and the quantum chromodynamics of strong interactions. The physical vacuum can be seen as a real relativistically invariant quantum medium (a kind of quantum fluid) filling out all the world space and realizing the lowest energy state of quantum fields.

In the last decade, the notion of a physical vacuum have come into wide use in cosmology [34–37] in connection with the concept of "dark energy" that accounts for 73% of the entire energy of the universe, in the context of the Friedmann equations of the general theory of relativity. It is believed that "dark energy" is uniformly "spilled" in the universe, its unalterable density being $\varepsilon_V = \lambda c^4/8\pi G$, where λ and G are the cosmological and the gravitational constant, respectively. The Standard Model also considers another physically hard-to-imagine substance – dark matter – whose energy content amounts to 23%, which is introduced into the Friedmann equations in order to remove contradictions between the magnitudes of the apparent masses of gravitationally bound objects, as well as systems of such objects, and their apparent parameters, including the structural stability of galaxies and galactic clusters in the expanding universe. Apart from the introduction of the physically obscure entities here mentioned – dark energy and dark matter – there are relevant problems in the construction of the Standard Model as a consequence of the unsuccessful attempts to tie in the apparent value $\varepsilon_V \approx 0,66 \cdot 10^{-8}$ erg/cm^3 [38] with the parameters of the physical vacuum introduced in elementary particle physics, the quantum chromodynamics vacuum (QCD vacuum). The above discrepancies come to more than 40 orders of magnitude if the characteristic energy scale of the quantum chromodynamics vacuum is taken to be $E_{QCD} \approx 200$ MeV [34,39,40], with its energy density being $\varepsilon_{QCD} = E^4_{QCD}/\left(2\pi\hbar c\right)^3$, and over 120 orders of magnitude if one is orientated towards the vacuum of physical fields, wherein quantum effects and gravitational effects would manifest themselves simultaneously, with the Planck energy density

$$\rho_{pE} = \frac{m_p \cdot c^2}{l_p^3} = 4,641266 \cdot 10^{113}\,\frac{\mathrm{Kg}}{\mathrm{ms}^2}\,, \tag{8}$$

(where m_P is Planck's mass, c is the light speed and l_p is Planck's length) playing the part of the characteristic energy scale.

The 3D quantum vacuum model proposed by the author of this paper allows us to resolve various important problems regarding the Standard Model of particle physics (such as the explanation of dark energy, dark matter and the interpretation of gravity) by introducing non-locality as the essential, ultimate visiting card of quantum processes in the context of a 3D non-local quantum vacuum as the fundamental background. In this picture, the behaviour of a subatomic particle such as the electron can be seen as the effect of more elementary processes of formation and dissolving of quanta of the 3D quantum vacuum. Here, the key point of non-locality derives from the introduction of Bohm's quantum potential into a 3D isotropic quantum vacuum characterized by a Planckian metric and defined by elementary processes of creation/annihilation of quanta corresponding to Chiatti's and Licata's transactions.

According to the approach suggested by the author and Sorli in [30–33], the ultimate constituents of the universe are packets of energy having the size of Planck volume which give rise to a 3D vacuum whose most universal property is its energy density. On the basis of the Planckian metric, the maximum energy density characterizing the minimum quantized space constituted by Planck's volume is given by the Planck energy density (8) and this defines a universal property of space. In the free space, in the absence of matter, the energy density of the 3D quantum vacuum is at its maximum and is given by (8). The Planck energy density (8) can be defined as the energy density of the "ground state" of the 3D quantum vacuum. Material objects correspond indeed to "excited states" of the 3D quantum vacuum characterized by a diminishing of the energy density of the quantum vacuum, expressed by relation

$$\rho_{qvE} = \rho_{pE} - \frac{m \cdot c^2}{V} \,, \tag{9}$$

m and V being the mass and volume of the object, and this fundamental diminishing of the quantum vacuum energy density causes a curvature of space.

In this model, the changes and fluctuations of the quantum vacuum energy density can be considered the origin of a curvature of space-time similar to the curvature produced by a "dark energy" density [30–33]. This means that, contrary to what happens in the Standard Model where dark matter and dark energy are "unexpected hosts" and do not receive consistent explanations except from ad hoc considerations, here dark matter and dark energy are a direct consequence of the properties of the fundamental 3D quantum vacuum. The changes of the quantum vacuum energy density act through a quantized metric of the 3D quantum vacuum condensate which determines the appearance of the dark energy, is associated with an underlying microscopic geometry depending of the Planck scale and allows the quantum Einstein equations of general relativity to be obtained directly. The quantized metric of the 3D quantum vacuum condensate is

$$d\hat{s}^2 = \hat{g}_{\mu\nu} dx^\mu dx^\nu \,, \tag{10}$$

whose coefficients (in polar coordinates) are defined by equations

$$\begin{aligned} &\hat{g}_{00} = -1 + \hat{h}_{00} \,, && \hat{g}_{11} = 1 + \hat{h}_{11} \,, && \hat{g}_{22} = r^2(1 + \hat{h}_{22}) \,, \\ &\hat{g}_{33} = r^2 \sin^2\vartheta(1 + \hat{h}_{33}) \,, && \hat{g}_{\mu\nu} = \hat{h}_{\mu\nu} && \text{for } \mu \neq \nu \,, \end{aligned} \tag{11}$$

where multiplication of every term times the unit operator is implicit and, at the order $O\left(r^2\right)$, one has

$$\langle \hat{h}_{\mu\nu} \rangle = 0 \;\; \text{except} \;\; \langle \hat{h}_{00} \rangle = \frac{8\pi G}{3}\left(\frac{\Delta\rho_{qvE}}{c^2} + \frac{35Gc^2}{2\pi\hbar^4 V}\left(\frac{V}{c^2}\Delta\rho_{qvE}^{DE}\right)^6\right) r^2 \tag{12}$$

$$\text{and} \;\; \langle \hat{h}_{11} \rangle = \frac{8\pi G}{3}\left(-\frac{\Delta\rho_{qvE}}{2c^2} + \frac{35Gc^2}{2\pi\hbar^4 V}\left(\frac{V}{c^2}\Delta\rho_{qvE}^{DE}\right)^6\right) r^2,$$

where $\Delta\rho^{DE}{}_{qvE} = \dfrac{m_{DE}\, c^2}{V}$ are the opportune changes of the quantum vacuum energy density associated with the dark energy density $\rho_{DE} = m_{DE}\, c^2$. The quantized metric (10) is associated with an underlying microscopic geometry expressed by equations

$$\Delta x \geq \frac{\hbar}{2\Delta p} + \frac{\Delta p}{2\hbar}\left(2\pi^2/3\right)^{2/3} l^{2/3} l_P^{4/3}\,, \tag{13}$$

(which indicates that the uncertainty in the measure of the position cannot be smaller than an elementary length proportional to Planck's length),

$$\Delta t \geq \frac{\hbar}{2\Delta E} + \frac{\Delta E T_0^2}{2\hbar} \tag{14}$$

which is the time uncertainty and

$$\Delta L \cong \frac{\left(2\pi^2/3\right)^{1/3} l^{1/3} l_p^{2/3} T_0 E}{2\hbar}\,, \tag{15}$$

which indicates in what sense the curvature of a region of size L can be related to the presence of energy and momentum in it [31–33].

Furthermore, in epistemological affinity with Chiatti's and Licata's transactional approach (developed in [41–44]), the appearance of baryonic matter derives from an opportune excited state of the 3D quantum vacuum defined by opportune changes of the quantum vacuum energy density and corresponding to specific reduction-state (**RS**) processes of creation/annihilation of quanta [30, 32]. The excited state of the quantum vacuum corresponding to the appearance of a material particle of mass m is defined (in the centre of that particle) by the energy density (9) (and thus by a diminishing with respect to the Planck energy density characterizing the ground state) and its evolution is determined by opportune **RS** processes of creation/annihilation of quanta 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

$$\begin{pmatrix} H & 0 \\ 0 & -H \end{pmatrix} C = 0\,, \tag{16}$$

where $H = \Big(- \hbar^2 \partial^\mu \partial_\mu + \frac{V^2}{c^2} (\Delta\rho_{qvE})^2 \Big)$ and $\Delta\rho_{qvE} = (\rho_{PE} - q_{qvE})$ is the change of the quantum vacuum energy density. Equation (16) corresponds to the following two equations:

$$\Big(- \hbar^2 \partial^\mu \partial_\mu + \frac{V^2}{c^2} (\Delta\rho_{qvE})^2 \Big) \psi_{Q,i}(x) = 0 \tag{17}$$

for creation events and

$$\Big(\hbar^2 \partial^\mu \partial_\mu - \frac{V^2}{c^2} (\Delta\rho_{qvE})^2 \Big) \varphi_{Q,i}(x) = 0 \tag{18}$$

for destruction events.

At the non-relativistic limit, equation (16) becomes a pair of Schrödinger-type equations

$$- \frac{\hbar^2 c^2}{2V\Delta\rho_{qvE}} \nabla^2 \psi_{Q,i}(x) = i\hbar \frac{\partial}{\partial t} \psi_{Q,i}(x), \tag{19}$$

$$- \frac{\hbar^2 c^2}{2V\Delta\rho_{qvE}} \nabla^2 \varphi_{Q,i}(x) = -i\hbar \frac{\partial}{\partial t} \varphi^*_{Q,i}(x). \tag{20}$$

In the view of a 3D quantum vacuum, the evolution of a particle of object is determined by appropriate waves of the vacuum associated with the spinor which describes the amplitude of creation or destruction events. The waves of the vacuum act in a non-local way through an appropriate quantum potential of the vacuum

$$Q_{Q,i} = \frac{\hbar^2 c^2}{V^2 (\Delta\rho_{qvE})^2} \left(\frac{\left(\nabla^2 - \frac{1}{c^2} \frac{\partial^2}{\partial t^2} \right) |\psi_{Q,i}|}{|\psi_{Q,i}|} - \frac{\left(\nabla^2 - \frac{1}{c^2} \frac{\partial^2}{\partial t^2} \right) |\varphi_{Q,i}|}{|\varphi_{Q,i}|} \right) \tag{21}$$

which becomes

$$Q_{Q,i} = - \frac{\hbar^2 c}{2V(\Delta\rho_{qvE})} \left(\frac{\nabla^2 |\psi_{Q,i}|}{|\psi_{Q,i}|} - \frac{\nabla^2 |\varphi_{Q,i}|}{|\varphi_{Q,i}|} \right) \tag{22}$$

in the non-relativistic limit) which guides the occurring of the processes of creation or annihilation of quanta in the 3D quantum vacuum in a non-local, instantaneous manner. The quantum potential of the vacuum is the fundamental mathematical entity which emerges from the very real extreme primary physical realities, namely from the processes of creation and annihilation of quanta. In virtue of the primary physical reality of the processes of creation and annihilation and of the non-local features of the quantum potential which is associated with the amplitudes of them, in the 3D quantum vacuum the duration of the processes from the creation of a particle or object till its annihilation has not a primary physical reality but exists only in the sense of numerical order. In other words, in the 3D quantum vacuum time exists merely as a mathematical parameter measuring the dynamics of a particle or object. This approach implies thus that, at a fundamental level, events run only in space and time is a mathematical emergent quantity which measures the numerical order of changes' evolution [30–33].

3 The Three-Dimensional Quantum Vacuum Cosmology, Its Processes and the Symmetrized Quantum Potential for Gravity

In the Bohm approach, the fundamental object of quantum gravity is the geometry of three-dimensional spacelike hypersurfaces, which is assumed to exist independently of any observation or measurement, and the same thing is valid for its canonical momentum, the extrinsic curvature of the spacelike hypersurfaces. Its evolution, labelled by some time parameter, is ruled by a quantum evolution which is different from the classical one due to the presence of a quantum potential emerging naturally from the WDW equation. One of the important results obtained in the de Broglie-Bohm approach to quantum cosmology lies in the elimination of cosmological singularities, which has been proved at least for some particular but relevant cases.

In the Bohmian approach, by following the treatment made for example in [45–50], if one decomposes the wave-functional Ψ in polar form $\Psi = Re^{iS/\hbar}$, the WDW equation becomes

$$(8\pi G)\, G_{abcd} \frac{\delta S}{\delta g_{ab}} \frac{\delta S}{\delta g_{cd}} - \frac{1}{16\pi G}\sqrt{g}\left(2\Lambda - {}^{(3)}R\right) + Q_G = 0\,, \qquad (23)$$

where

$$Q_G = \hbar^2 N g G_{abcd} \frac{1}{R} \frac{\delta^2 R}{\delta g_{ab} \delta g_{cd}}\,. \qquad (24)$$

N being the lapse function. The term Q_G can be defined "quantum potential for gravity". Moreover, in the Bohmian approach, Einstein's equations – in absence of source of matter-energy – assume the following forms:

$$R^{\mu\nu} - \frac{1}{2} g^{\mu\nu} R = -\frac{1}{N} \frac{\delta \int Q_G d^3x}{\delta g_{ij}} \qquad (25)$$

for the dynamical parts, and

$$R^{0\nu} - \frac{1}{2} g^{0\nu} R = \frac{Q_G}{2\sqrt{-g}} g^{0\nu} \qquad (26)$$

for the non-dynamical part.

Equations (23), (25) and (26) show that the term Q_G is responsible of the behaviour of the universe intended as a whole. On the basis of equations (23)–(26) regarding the Bohmian approach to WDW equation, one can say that universe presents a sort of aggregate, comprehensive "order" which guides it: this order is just determined by the "quantum potential for gravity" (24).

The quantum potential for gravity (24) can be thus considered as a sort of generalization of the Bohmian quantum potential to the universe as a whole, the crucial element that guides the behaviour of the universe. Moreover, as it was recently underlined in the reference [51], the quantum potential of the universe can be interpreted as the active information which characterizes the quantum creation after Planck's time and the evolution of the universe from the many-four geometries of the pre-planckian time. In this picture, the homogeneity and isotropy of cosmic microwave background radiation lies in the cosmic entanglement associated with the quantum potential of the universe: all the parts of the universe (and also photons of cosmic microwave background radiation) have a common origin and their entanglement emerges directly from the quantum potential of the universe (as regards the idea that photons of cosmic microwave background radiation cannot be considered as separable particles but parts of a unique fundamental field, see also the reference [52]).

Now, in the picture of the 3D quantum vacuum characterized by **RS** processes of creation/annihilation of quanta corresponding to elementary fluctuations of the energy density, the WDW equation may be formulated in the following generalized way. The evolution of the state of the universe is determined by opportune **RS** processes of creation/annihilation of quanta described by a wave-functional $C = \begin{pmatrix} \psi \\ \phi \end{pmatrix}$ at two components (where the first component regards the creation events, the second component regards the destruction events) satisfying a time-symmetric extension of the WDW equation of the form

$$\begin{pmatrix} H & 0 \\ 0 & -H \end{pmatrix} C = 0\,, \tag{27}$$

where

$$H = \left[(8\pi G)\, G_{abcd} p^{ab} p^{cd} + \frac{1}{16\pi G} \sqrt{g} \left(2\Lambda - {}^{(3)}R \right) \right]. \tag{28}$$

Here, if one decomposes the time-symmetric WDW equation (27) into two real equations, by expressing the wave-functionals Ψ and Φ in polar form

$$\Psi = R_1 e^{iS_1}\,, \tag{29}$$

$$\Phi = R_2 e^{iS_2}\,, \tag{30}$$

where R_1 and R_2 are real amplitude functionals and S_1 and S_2 are real phase functional, and inserts (29) and (30) into (27) and separates into real and imaginary parts, one obtains the following generalized quantum Hamilton-Jacobi equation for quantum general relativity in the 3D quantum vacuum

$$(8\pi G)G_{abcd}\begin{pmatrix}\frac{\delta S_1}{\delta g_{ab}}\frac{\delta S_1}{\delta g_{cd}}\\ \frac{\delta S_2}{\delta g_{ab}}\frac{\delta S_2}{\delta g_{cd}}\end{pmatrix}-\frac{1}{16\pi G}\sqrt{g}\begin{pmatrix}2\Lambda-{}^{(3)}R\\ -2\Lambda+{}^{(3)}R\end{pmatrix}+\begin{pmatrix}Q_{G1}\\ Q_{G2}\end{pmatrix}=0\,, \quad (31)$$

where

$$Q_{G1}=\hbar^2 NgG_{abcd}\frac{1}{R_1}\frac{\delta^2 R_1}{\delta g_{ab}\delta g_{cd}}\,, \quad (32)$$

$$Q_{G2}=-\hbar^2 NgG_{abcd}\frac{1}{R_2}\frac{\delta^2 R_2}{\delta g_{ab}\delta g_{cd}}\,. \quad (33)$$

In WDW equation regime, the 3D quantum vacuum is therefore characterized by a symmetrized quantum potential for gravity at two components of the form

$$Q_G=\begin{pmatrix}\hbar^2 NgG_{abcd}\frac{1}{R_1}\frac{\delta^2 R_1}{\delta g_{ab}\delta g_{cd}}\\ -\hbar^2 NgG_{abcd}\frac{1}{R_2}\frac{\delta^2 R_2}{\delta g_{ab}\delta g_{cd}}\end{pmatrix}\,. \quad (34)$$

The first component (32) coincides with the original "quantum potential for gravity" (24): it guides the occurring of the **RS** processes of creation in the 3D quantum vacuum in the quantum gravity domain. The second component (33) regards the behaviour of the **RS** processes of annihilation in the quantum gravity domain. The symmetrized quantum potential for gravity physically indicates that the 3D quantum vacuum acts as a direct, immediate information medium as regards the processes of the quantum gravity domain. It implies that, also in the quantum gravity domain, the parameter time does not exist as a primary physical reality but exists only as an emergent mathematical parameter measuring the numerical order of material changes [53].

4 Towards a Completion of the Standard Model of the Particle Physics in the Three-Dimensional Quantum Vacuum Model

In the Standard Model of particle physics there are contributions to the vacuum energy that come from the spontaneous symmetry breaking of the electroweak gauge symmetry, specifically from the Higgs mechanism. These contributions are related to the vacuum expectation value of the Higgs potential and behave as $\langle V\rangle \approx v^2 M_H^2 \approx 10^8$ GeV^4, where $v = \mathrm{O}\,(100)$ GeV is the vacuum expectation value that defines the electroweak scale, and $M_H = 125$ GeV is the presumed physical mass of the Higgs boson. These contributions to the vacuum expectation value of the Higgs potential determine a devastating fine tuning problem, which is further aggravated at the quantum level when we consider the many higher loop effects involved. Although the Standard Model agrees very well with experimental results, a list of open questions remain unanswered and lead to the conclusion that this theory might not be the final theory of the universe. Fundamental topics which are waiting for a consistent and satisfactory explanation regard, for example, the search of the ultimate mechanism that can be considered the real origin of particles' masses, what is the origin of the difference between matter and antimatter, the nature and the origin of the dark matter and of the dark energy and how one can unify the fundamental interactions and quantize gravity. In the previous chapters we have seen how our model of 3D quantum vacuum defined by **RS** processes of creation/annihilation of quanta corresponding to elementary changes of its energy density allow us to provide an answer as regards dark energy and gravity: dark energy is energy of the 3D quantum vacuum itself and gravity is an immediate phenomenon associated with the fluctuations of the quantum vacuum energy density. In this chapter, we will show how the 3D quantum vacuum model can face other relevant problems of the current Standard Model of particle physics, leading to a completion of the Standard Model which allows us to provide a consistent interpretation of the electroweak scale and of its spontaneous symmetry breaking as well as to avoid the problems connected with the Higgs mechanics in the generation of the mass of material particles [54].

In this regard, by following the treatment made in [54], in our model the most general scalar potential invariant under the Standard Model gauge group may be expressed as

$$V = \lambda_C C^4 + \lambda_I s_I^4 + \lambda_{RI} s_I^2 s_R^2 + \lambda_R s_R^4 + \lambda_{IC} C^2 s_I^2 + \lambda_{RC} C^2 s_R^2 \,. \tag{35}$$

Here, $C = \begin{pmatrix} \psi_{Q,i} \\ \varphi_{Q,i} \end{pmatrix}$ is the wave function at two components describing the probability of the occurrence of a creation/destruction event for a quantum particle Q of a given mass determined by an opportune change $\Delta\rho_{qvE}$ of the quantum vacuum energy density (given by equation (9)) in a point event x, 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 energy density, λ_C is the coupling associated with the wave function C, λ_R is the coupling associated with the real part s_R of the singlet field S, λ_I is the coupling associated with the imaginary part s_I of the singlet field S and one has

$$\lambda_R = \lambda_S + \lambda'_S + \lambda''_S \,, \tag{36}$$

$$\lambda_I = \lambda_S + \lambda'_S - \lambda''_S \,, \tag{37}$$

$$\lambda_{RI} = 2(\lambda_S - 3\lambda'_S) \,, \tag{38}$$

$$\lambda_{RC} = \lambda_{SC} + \lambda'_{SC} \,, \tag{39}$$

$$\lambda_{IC} = \lambda_{SC} - \lambda'_{SC} \,. \tag{40}$$

The one-loop renormalization group equations of the scalar couplings in terms of the top Yukawa coupling y_t and the Standard Model gauge couplings g and g' are

$$
\begin{aligned}
16\pi^2\beta_{\lambda_C} &= \frac{3}{8}\left(3g^4 + 2g^2g'^2 + g'^4\right) + \frac{1}{2}\left(\lambda_{RC}^2 + \lambda_{IC}^2\right) \\
&\quad + 24\lambda_C^2 - 3\lambda_C\left(3g^2 + g'^2 - 4y_t^2\right) - 6y_t^4 \qquad (41)\\
16\pi^2\beta_{\lambda_R} &= 18\lambda_R^2 + 2\lambda_{RC}^2 + \frac{1}{2}\lambda_{RI}^2 \qquad (42)\\
16\pi^2\beta_{\lambda_I} &= 18\lambda_I^2 + 2\lambda_{IC}^2 + \frac{1}{2}\lambda_{RI}^2 \qquad (43)\\
16\pi^2\beta_{\lambda_{RI}} &= 4\lambda_{IC}\lambda_{RC} + 6\lambda_{RI}\left(\lambda_I + \lambda_R\right) + 4\lambda_{RI}^2 \qquad (44)\\
16\pi^2\beta_{\lambda_{RC}} &= -\frac{3}{2}\lambda_{RC}\left(g'^2 + 3g^2 - 4y_t^2\right) + \lambda_{IC}\lambda_{RI} \\
&\quad + 6\lambda_{RC}\left(2\lambda_C + \lambda_R\right) + 4\lambda_{RC}^2 \qquad (45)\\
16\pi^2\beta_{\lambda_{IC}} &= -\frac{3}{2}\lambda_{IC}\left(g'^2 + 3g^2 - 4y_t^2\right) + \lambda_{RC}\lambda_{RI} \\
&\quad + 6\lambda_{IC}\left(2\lambda_C + \lambda_I\right) + 4\lambda_{IC}^2\,. \qquad (46)
\end{aligned}
$$

If one considers λ_R as

$$
\lambda_R = \beta_{\lambda_R}\ln\frac{|s_R|}{s_0}\,, \qquad (47)
$$

where β_{λ_R} is the always positive beta function of λ_R, and s_0 is the scale at which λ_R becomes negative, in the basis (C, s_R) the square quantum vacuum energy density matrix for CP-even fields becomes

$$
\begin{pmatrix}
2v^2\lambda_C & -\sqrt{2}v^2\sqrt{\lambda_C\left|\lambda_{RC}\right|} \\
-\sqrt{2}v^2\sqrt{\lambda_C\left|\lambda_{RC}\right|} & \left|\lambda_{RC}\right|v^2 + \dfrac{2\beta_{\lambda_R}\lambda_C v^2}{\left|\lambda_{RC}\right|}
\end{pmatrix}, \qquad (48)
$$

where

$$
v = \frac{s_0}{e^{1/4}}\sqrt{\frac{\left|\lambda_{RC}\right|}{2\lambda_C}}\,. \qquad (49)
$$

In the case of small λ_{RC} the square matrix (48) leads to the following eigenvalues for the energy density of the quantum vacuum:

$$
\rho_h^2 \cong v^2\left(2\lambda_C - \frac{\lambda_{RC}^2}{\beta_{\lambda_R}}\right), \qquad (50)
$$

$$
\rho_s^2 \cong v^2\left(2\frac{\beta_{\lambda_R}\lambda_C}{\left|\lambda_{RC}\right|} + \frac{\lambda_C^2}{\beta_{\lambda_R}} + \left|\lambda_{RC}\right|\right), \qquad (51)
$$

while the CP-odd quantum vacuum energy density is

$$\rho_s^2 \cong v^2 \left(2\frac{\lambda_C \lambda_{RI}}{|\lambda_{RC}|} + \frac{\lambda_{IC}}{2} \right). \tag{52}$$

Equations (50)–(51) are valid only if $\frac{\lambda_{RC}^2}{\beta_{\lambda_R}} \ll 1$. If this is not true, the eigenvalues of the density matrix (48) for the energy density of quantum vacuum are

$$\rho_h^2 \cong v^2 \left(2\lambda_C + |\lambda_{RC}| + \beta_{\lambda_R} \right), \tag{53}$$

$$\rho_s^2 \cong v^2 \left(2\frac{\beta_{\lambda_R} \lambda_C}{|\lambda_{RC}|} + \beta_{\lambda_R} \right). \tag{54}$$

On the basis of equations (50)–(54), the real singlet s_R derives from a quantum vacuum energy density which is associated to a mass lighter than the Higgs boson. Equations ((50)–(54) suggest that the singlet s_R decays to Standard Model particles via more fundamental values of the quantum vacuum energy density. The approach here proposed implies in this way that the mixing action of the Higgs boson in the production of the mass of Standard Model particles cannot be considered as a fundamental physical reality but derives from more fundamental entities, represented by opportune physical values of the quantum vacuum energy density, given just by equations (50)–(54). One can say also that, in this picture, at a fundamental level, the Higgs boson does not exist as physical reality: the action of the Higgs boson is only an emerging reality, it is the interplay of opportune fluctuations of the quantum vacuum energy density which indeed determines the action of the Higgs boson.

Another merit of this approach lies in the possibility to remove the global minimum of the Standard Model Higgs potential

$$V(h) = -\mu^2 h^2 + \lambda_H(h) h^4, \tag{55}$$

($-\mu^2$ being the Higgs mass parameter, h the Higgs field strength, λ_H the Higgs quartic coupling) in the vicinity of the scale $\approx 10^{26}$ GeV (where λ_H runs negative) and generate the electroweak symmetry breaking minimum, thanks to the various couplings of the scalar sector.

By following the philosophy that is at the basis of the programme proposed by Gabrielli *et al.* in [55], let us start by analysing the running of λ_R. Since the beta-function (42) is always positive, λ_R will grow when running towards higher energy and will cross zero at some scale s_0 above the electroweak scale. This scale is provided by the initial value of λ_R at the electroweak scale and by the slope of the running set by the beta-function. Because of the smallness of λ_R itself near the scale s_0, and of the requirement that also λ_{RC} to be small in order to keep the mixing between s_R and the regime of small wave function C, the beta-function (42) turn out to be dominated by λ_{RI} at low scales. In order to avoid a huge hierarchy between s_0 and the electroweak scale, the running of λ_R has to be sufficiently rapid, implying that λ_{RI} cannot be very small.

The global minimum characterizing the Standard Model Higgs potential may be avoided by adding a supplementary positive term to the beta-function of λ_C. In the light of equation (41), this can be achieved by the term $\lambda_{RC}^2 + \lambda_{IC}^2$, and thus, since λ_{RC} is small to avoid large mixing namely this term is dominated by λ_{IC}, by setting a sizable initial value for λ_{IC} at the electroweak scale.

A vacuum expectation value for the imaginary part s_I is avoided, by setting a small positive initial value for λ_I at the electroweak scale. Because of the positive contribution contained in the beta-function (43) of λ_I, deriving from both λ_{IC} and λ_{RI}, the running of λ_I turns out to be quite rapid, eventually running into a Landau pole. By choosing the initial values for the parameters at the top mass scale as follows: λ_{RI} =0.3, $\lambda_R = -1.2 \cdot 10^{-3}$, $\lambda_{IC} = 0.35$, $\lambda_I = 0.01$, $\lambda_{RC} = -10^{-4}$, $\lambda_C = 0.12879$ and $m_t = 173.1$ GeV, and using beta functions at first order in the scalar couplings and second order in gauge couplings, in this picture, from the couplings of this approach a Higgs self coupling λ_H is derived which remains positive and therefore the Standard Model global minimum at 10^{26} GeV is removed, while λ_R becomes negative around $s_0 \approx 10^4$ GeV.

On the basis of equations (50)–(54), the electroweak symmetry breaking is indeed determined by the real component of the singlet field S (while the imaginary component remains stable because of the CP-invariance of the general scalar potential (35)). The wave function of the quantum vacuum associated to the occurrence of creation/destruction events which trigger the electroweak symmetry breaking can be therefore expressed in the following form:

$$C = \exp\left\{i\frac{\sigma_i}{2}\theta_i\left(x\right)\right\}\frac{1}{\sqrt{2}}\begin{pmatrix}0\\ \lambda_R + s_R(x)\end{pmatrix}. \tag{56}$$

Now, in analogy to the Standard Model, by defining the covariant derivative as

$$D^\mu C = \left[\partial^\mu + ig\tilde{W}^\mu + ig' y_\varphi B^\mu\right]C\,, \tag{57}$$

where

$$\tilde{W}_{\mu\nu} = \frac{\sigma_i}{2}W^i_{\mu\nu}\,, \qquad W^i_{\mu\nu} = \partial_\mu W^i_\nu - \partial_\nu W^i_\mu - g\varepsilon^{ijk}W^i_\mu W^k_\nu\,, \tag{58}$$

$\vec{W}_\mu$ being the mass less isovector triplet (for $SU\left(2\right)_L$), g being the coupling of the isospin current $\vec{J}_\mu$ of the fermions to $\vec{W}_\mu$, B_μ being the mass isosinglet (for $U\left(1\right)_Y$), g' being the coupling of the hypercharge current of the same fermions to B_μ, as in the original Weinberg-Glashow-Salam model [56–58], if one takes the physical unitary gauge $\theta_i\left(x\right) = 0$, by applying the electroweak symmetry breaking one obtains

$$(D^\mu C)^+ D^\mu C \xrightarrow{\theta^i \to 0} \frac{1}{2}\partial_\mu s_R \partial^\mu s_R + (\lambda_R + s_R)^2\left\{\frac{g^2}{4}W^+_\mu W^\mu + \frac{g^2}{8\cos^2\theta_W}Z_\mu Z^\mu\right\}. \tag{59}$$

In the light of the kinetic piece of the lagrangian in the electroweak symmetry breaking regime (59), the vacuum expectation value of the neutral scalar generates a quadratic term for the gauge bosons $W^{\pm}$ and the Z, and thus leads those gauge bosons to acquire masses on the basis of the following relation:

$$M_Z \cos\theta_W = M_W = \frac{75}{2\sin\theta_W}\ \text{GeV} = \frac{1}{2}\lambda_R g\,, \tag{60}$$

θ_W being the weak mixing angle. Therefore, one finds that in the electroweak symmetry breaking regime the coupling λ_R associated with the real part of the singlet field S has the following expression:

$$\lambda_R = \frac{75}{g\sin\theta_W}\,. \tag{61}$$

The general scalar gauged potential (35) suggests therefore a new interesting manner to give masses to fermions as well as to the intermediate carriers of the weak force. On the basis of the consideration of the kinetic piece (59) of the lagrangian, in the 3D non-local quantum vacuum one can define a new effective lagrangian, which can be defined as "beyond Standard Model lagrangian", which, on one hand, is invariant under gauge transformations and guarantees the renormalizability of the associated quantum field theory (as it occurs in the original Weinberg-Glashow-Salam theory [59]) and, on the other hand, allows electroweak symmetry breaking to occur dynamically via dimensional transmutation determined by the singlet couplings associated with the singlet field S which is a function of the changes and fluctuations of the energy density of the timeless 3D quantum vacuum, thus removing the global minimum of the Standard Model Higgs potential. This "beyond Standard Model lagrangian" is defined as

$$\begin{aligned} L_{\text{effective}}^{\text{beyondSM}} = & -\frac{1}{4}W_{\mu\nu}^{a}W^{a\mu\nu} - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} - g\bar{C}_1\gamma^{\mu}\tilde{W}_{\mu}C_1 \\ & - g\sin\theta_W A_\mu \sum_j \bar{C}_j\gamma^{\mu}Q_jC_j - \frac{g}{2\cos\theta_W}J_\mu^Z Z^\mu \\ & + \frac{1}{2}\partial_\mu s_R\partial^\mu s_R + (\lambda_R + s_R)^2\left\{\frac{g^2}{4}W_\mu^{+}W^{\mu} + \frac{g^2}{8\cos^2\theta_W}Z_\mu Z^\mu\right\} \\ & - \left(\lambda_C C^4 + \lambda_I s_I^4 + \lambda_{RI}s_I^2 s_R^2 + \lambda_R s_R^4 + \lambda_{IC}C^2 s_I^2 + \lambda_{RC}C^2 s_R^2\right), \end{aligned} \tag{62}$$

where C_1 is the wave function of the quantum vacuum determining the appearance of left-handed electron and neutrino in the state $\psi_1 = \begin{pmatrix}\nu_e \\ e^-\end{pmatrix}_L$. In the light of the effective lagrangian which determines the electroweak Symmetry Breaking dynamically via dimensional transmutation by means of the couplings associated with the singlet field S of the timeless 3D quantum vacuum, the Vacuum Expectation Value of the scalar sector then induces the Standard Model Higgs Vacuum Expectation Value through a portal coupling.

In summary, if the Standard Model lagrangian contains only four parameters, g, g', μ^2 and h, thus requiring the introduction in an ad hoc form of the Higgs field which yields a global minimum at $\approx 10^{26}$ GeV, which provokes significant problems in this energy range, in the light of Gabrielli's results [32], instead, in this model of 3D quantum vacuum, in the gauge and scalar sector, the beyond Standard Model lagrangian allows us to face in a significant and coherent way different problems encountered by the Standard Model (in connection to the electroweak symmetry breaking and the possibility to remove the global minimum at $\approx 10^{26}$ GeV): the real explanation lies always in the elementary fluctuations of its energy density corresponding to elementary **RS** processes of annihilation/creation of quanta.

5 About of the Insufficiency of Big-Bang Cosmology in the Three-Dimensional Quantum Vacuum Model

The model of the 3D quantum vacuum which acts as a non-local, immediate information medium in ruling the behaviour of quantum matter as well as in the quantum gravity domain implies that universe is a timeless phenomenon where time is merely a mathematical parameter measuring numerical order of material changes and motions. The 3D quantum vacuum is always NOW in which past, present, future have only a mathematical existence. In this picture, common understanding of the Big bang cosmology where universe is expanding in time as a physical reality cannot be considered appropriate any more [60]. Universe is timeless in a sense that time is not a physical dimension in which universe exists. This view is also confirmed by the well known research of Kurt Gödel. By 1949, Gödel had remarked: "In any universe described by the Theory of Relativity, time cannot exist" [61]. Gödel discovered that closed "time-lines" in general relativity allow hypothetical travels in time which lead to contradictions. Considering time has only mathematical existence there are no contradictions, one can travel in 3D quantum vacuum only and time is duration of this motion.

In the picture of the non-local, timeless universe predicted by the 3D quantum vacuum model, some considerations and new re-readings of experimental data become natural and necessary. Before all, if one assumes that the fundamental arena of the universe is a timeless, non-local 3D quantum vacuum, which is NOW, cosmic microwave background radiation cannot have its source in some hypothetical physical past and time cannot be transmittor of cosmic microwave background radiation. The source of cosmic microwave background radiation is present in the actual universe that we observe. In particular, it can be associated to the quantum potential of the 3D quantum vacuum. Moreover, also existence of one single big bang and eternal expansion of the universe is questionable. The only reasonable cosmological model based on big bang seems a cyclic universe where big bang is followed by expansion which stops at a certain period and universe starts collapsing in a big crunch which explodes in a new big bang. The view of the non-local, timeless 3D quantum vacuum suggests that universe is a system characterized by a dynamic equilibrium with no beginning and no end and by a permanent energy flow which has origin in variable energy density of quantum vacuum.

In the non-local quantum cosmology of the 3D quantum vacuum, also BICEP2 model of gravitational waves as ripples of space-time which have origin in big bang becomes questionable [62]. If gravitational waves exist, they should have origin in the 3D quantum vacuum which is NOW, namely in a source which is present in the universe we observe. On the other hand, the "B-mode" polarizations of the cosmic microwave radiation observed by the BICEP telescope at the South Pole seem most likely to be "local" galactic contamination rather than an imprint left behind by the rapid "inflation" of the early universe [63].

Stability of elementary particles requires a certain energy density of 3D quantum vacuum. As a consequence of the quantum potential of the vacuum which rules the occurring of the **RS** processes of creation/annihilation, the following scenario emerges. In the centre of black holes energy density of quantum vacuum turns out to be at the minimum and reaches below required energy density which is giving stability to elementary particles. In singularities, matter is not stable anymore and disintegrates back into fundamental primordial energy of quantum vacuum. In intergalactic areas energy density of quantum vacuum turns out to be at the maximum and thus is continuously transforming in cosmic rays and this further in elementary particles [64]. This circulation of energy "matter –empty vacuum– matter" is in a permanent dynamic equilibrium.

In black holes singularities "old matter" is transformed into "fresh" fundamental primordial energy of quantum vacuum which is not created and cannot be destroyed. Increasing of entropy of matter that we observe in the universe does not increase the entropy of entire universe which indeed has no entropy. Black holes are rejuvenating universe which is ageless. According to the 3D quantum vacuum model, universe is a non-created system. In the universe galaxies, stars and planets appear and disappear; universe itself is eternal [65].

Idea that universe is expanding makes sense only if we propose universe is finite. Only a finite system can expand. NASA results confirm universal space correspond Euclidean geometry (is flat with only a 0.4% margin of error) and is infinite [66]. Infinite system cannot expand and cannot contact. Expansion of observable universe is questionable because "red shift" can also be interpreted as a consequence of light pulling from the strong gravity [67]. This so called "gravitational red shift" is a basis for "tired light" hypothesis of Swiss astronomer Fritz Zwicky [68]. Considering that red shift has gravitational origin, expansion of observable universe is not certain any more [69].

Finally, some further interesting considerations may be made as regards the physics of black holes. As known, a famous prediction of quantum field theory in a curved spacetime is the Hawking effect according to which every stationary black hole is characterized by the temperature

$$T_{BH} = \frac{\hbar\kappa}{2\pi k_B c}\,, \tag{63}$$

where κ is the surface gravity of a stationary black hole, which by the no-hair theorem is exclusively characterized by its mass M, its angular momentum J, and (if present) its electric charge q [70]. Since black holes have a temperature, they also have an entropy. It is called "Bekenstein-Hawking entropy" and is found from thermodynamic arguments to be given by the universal expression

$$S_{BH} = \frac{k_B A}{4l_p^2}\,, \tag{64}$$

where A is the surface of the event horizon. Many of the open questions which have to be addressed in any theory of quantum gravity and cosmology are related with the temperature and the entropy of black holes [71]. The two most important questions concern the microscopic interpretation of entropy and the final fate of a black hole, where in particular the latter is deeply connected with the problem of information loss. Hawking's calculation leading to (63) breaks down when the black hole becomes small. According to equation (63), the radiation of the black hole is thermal. Thus, the following natural question emerges. What does it happen in the final phase of the black-hole evolution and thus when effects of quantum gravity (Planck scale) come into play? If only thermal radiation was left, all initial states that lead to a black hole would end up in one and the same final state—a thermal state, that is, the information about the initial state would be lost, a prediction which is incompatible with standard quantum theory for a closed system, for which the von Neumann entropy $S = -k_B tr\,(\rho ln\rho)$ is constant, where ρ denotes the density matrix of the system [72]. It must be emphasized that, in the Planck scale regime, the information-loss problem regarding black holes is strictly tied to the fate of the singularity in the sense that, if the singularity remains in quantum gravity, information will indeed be destroyed. Instead, in the picture of the timeless universe whose fundamental arena is the non-local 3D quantum vacuum characterized by **RS** processes of creation/annihilation corresponding to elementary fluctuations of the quantum vacuum energy density, there is indeed no information-loss problem for black holes approaching the Planck scale. In fact, in the approach developed in this paper, there is no beginning and no end of the universe and in black hole singularities "old matter" is transformed into "fresh" fundamental primordial energy of quantum vacuum which is not created and cannot be destroyed. Increasing of entropy of matter acts only in the sense that the sum of the entropy of matter and of the entropy of space is constant and this implies that the results about the information-loss problem are in agreement with standard quantum theory. Therefore, the 3D non-local quantum vacuum cosmology allows us to resolve in a simple and elegant way also the information-loss problem.

6 Conclusions

The considerations made in this paper suggest that the fundamental arena of the universe, both in the quantum domain and in the quantum gravity domain represented by the WDW equation regime, is a 3D quantum vacuum characterized by opportune processes of creation and annihilation of quanta corresponding to elementary changes of the quantum vacuum energy density. A non-local, timeless quantum cosmology thus emerges where universe is a eternal system in permanent dynamic equilibrium, which is infinite and is not expanding. The variable energy density of quantum vacuum associated to the processes of creation/annihilation of quanta emerges as the fundamental reality determining what happens in the universe, and this is valid both for microphysics and for macrophysics (leading to a suggestive completion of the Standard Model of particle physics which allows a satisfactory resolution of various relevant problems of the Standard Model, such as dark energy as well as the problems connected with the Higgs mechanism and, at the same time, introducing suggestive perspectives as regards the role of black holes and their behaviour).

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