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About Electroweak Symmetry Breaking, Electroweak Vacuum and Dark Matter in a New Suggested Proposal of Completion of the Standard Model In Terms Of Energy Fluctuations of a Timeless Three-Dimensional Quantum Vacuum

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Abstract: A model of a timeless three-dimensional quantum vacuum characterized by energy fluctuations corresponding to elementary processes of creation/annihilation of quanta is proposed which introduces interesting perspectives of completion of the Standard Model. By involving gravity *ab initio*, this model allows the Standard Model Higgs potential to be stabilised (in a picture where the Higgs field cannot be considered as a fundamental physical reality but as an emergent quantity from most elementary fluctuations of the quantum vacuum energy density), to generate electroweak symmetry breaking dynamically via dimensional transmutation, to explain dark matter and dark energy.

Keywords: Standard Model, timeless three-dimensional quantum vacuum, fluctuations of the three-dimensional quantum vacuum, electroweak symmetry breaking, dark matter.

1 Introduction

The discovery made by ATLAS and CMS at the Large Hadron Collider of the 126 *GeV* scalar particle, which in the light of available data can be identified with the Higgs boson [1-6], seems to have completed the experimental verification of the Standard Model as formulated in 1968 by Weinberg, Glashow and Salam [7-9]. Although the Standard Model of strong and electroweak interactions has passed all experimental tests during the last 40 years, however many relevant questions remain unanswered and lead to the conclusion that this theory might not be the final theory of the universe.

In particular, the most fundamental topics which are waiting for a consistent and satisfactory explanation regard what should be considered the real origin of particles' masses, what is the origin of the difference between matter and antimatter and, above all, 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. Strictly linked with these topics are then the following questions. How is the electroweak symmetry broken? Is there such a thing as an elementary scalar field? What is the fate of the Standard Model at high energies and temperatures? Does the Higgs boson need help, e.g. from supersymmetry? Did the Higgs boson play a role in generating the matter in the Universe? Why is there so little dark energy, despite the propensity of the Higgs field to contribute many orders of magnitude too much? What will we discover beyond the Higgs door?

In the Standard Model with a light Higgs boson, an important problem is that the electroweak potential is destabilized by the top quark. Here, the simplest option in order to stabilise the theory lies in introducing a scalar particle with similar couplings. This programme can delay the collapse of the potential, but implies that the new coupling must be very finely tuned in order to avoid another blow-up. Consequently, the natural step is to stabilize it with a new fermion. In this picture, the new scalar is thus much like the stop quark, the fermion is just like the Higgsino and the resulting theory looks like very much supersymmetry [10].

The fact that the only available "new physics" is the Standard Model Higgs boson strongly motivates studies of its implications for our understanding of the fundamental laws of Nature. In this regard, the first set of questions to address is the phenomenological consistency of the Standard Model itself. The second set of questions to address is what the Standard Model inconsistencies imply for new physics, and how to improve/extend the Standard Model.

On the other hand, investigation of the structure of the Standard Model effective potential at very large field strengths opens a window towards new phenomena and can reveal properties, which lead to an ultraviolet completion of the Standard Model. In particular, as shown recently by Lalak, Lewicki and Olszevski in [11], one of

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the possible windows is the investigation of the structure of the effective potential in the Standard Model. The three authors found that for the central value of the top mass and for the central value of the measured Higgs mass the physical electroweak symmetry breaking minimum becomes metastable with respect to the tunneling from the physical electroweak symmetry-breaking minimum to a deeper minimum located at superplanckian values of the Higgs field strength. The computed lifetime of the metastable Standard Model Universe turns out larger than the presently estimated age of the Universe, however the instability border in the space of parameters $M_{top} - M_{Higgs}$ looks uncomfortably close and this suggests that the result is rather sensitive to various types of modifications that can be brought in by the Standard Model extensions. More precisely, Lalak, Lewicki and Olszevski made a map of the vacuum in the Standard Model extended by non-renormalisable scalar couplings, taking into account the running of the new couplings and going beyond the standard assumptions taken when calculating the lifetime of the metastable vacuum. By considering a modified scalar potential where the order 6 or order 8 coupling constitute the dominant parts in the large field domain, they demonstrated that effective stabilisation of the Standard Model can be achieved by lowering the suppression scale of higher order operators while picking up such combinations of new couplings, which do not deepen the new minima of the potential. Lalak's, Lewicki's and Olszevski's results show the dependence of the lifetime of the electroweak minimum on the magnitude of the new couplings, including cases with very small couplings (which means very large effective suppression scale) and couplings vastly different in magnitude (which corresponds to two different suppression scales).

Another interesting scenario in order to provide a natural and consistent ultraviolet completion of the standard model lies in implementing gauge symmetries in a non-linear way in a sigma model without Higgs bosons [12, 13]. In this regard, as shown by Barr and Calmet in [13], the requirement of a non-trivial fixed point in the SU(2) sector of the weak interactions together with the requirement of the numerical unification of the gauge couplings leads to a prediction for the value of the SU(2) gauge coupling in the fixed point regime to solve the unitarity problem in the elastic scattering of W bosons (under the hypothesis that the fixed point regime be in the TeV region) and to a unification scale at about $10^{14}\,GeV$.

Moreover, in [14] Gabrielli *et al.* found that, due to dimensional transmutation, the Standard Model Higgs potential has a global minimum at $\approx 10^{26}\,GeV$, invalidating the Standard Model as a phenomenologically acceptable model in this energy range. In order to solve this problem, Gabrielli and the other authors of this paper considered a minimal extension of the Standard Model, which consists in introducing a new complex singlet scalar field coupled to the Higgs sector. This minimal extension of the Standard Model by one complex singlet field solves the wrong vacuum problem, stabilising thus the Standard Model Higgs potential, generates electroweak symmetry breaking dynamically via dimensional transmutation (inducing a scale in the singlet sector via dimensional transmutation that generates the negative Standard Model Higgs mass term via the Higgs portal), provides a natural Dark Matter candidate for the Standard Model which is in well agreement with present Dark Matter measurements, and is a candidate for the inflation. Gabrielli and his co-authors write: "Compared to previous such attempts to formulate the new Standard Model, ours has less parameters as well as less new dynamical degrees of freedom. In this framework, the false Standard Model vacuum is avoided due to the modification of the Standard Model Higgs boson quartic coupling Renormalization Group Equations by the singlet couplings. The electroweak scale can be generated from a classically scale invariant Lagrangian through dimensional transmutation in the scalar sector, by letting the quartic coupling of the CP-even scalar run negative close to the electroweak scale. The vacuum expectation value of this scalar then induces the Standard Model Higgs vacuum expectation value through a portal coupling."

In this paper, in order to solve the problems of the current Standard Model mentioned above, we introduce a general scalar potential in the picture of a three-dimensional (3D) timeless quantum vacuum characterized by elementary processes of creation/annihilation of quanta. In this approach, the most general scalar potential invariant under the Standard Model gauge group depends of:

- fluctuations of the quantum vacuum energy density;
- a singlet field *S* which is a function of the changes of the quantum vacuum energy density;
- the physical field associated with the changes of the quantum vacuum energy density (namely the wave function at two components $C = \begin{pmatrix} \psi_{Q,i} \\ \phi_{Q,i} \end{pmatrix}$ describing the probability of the occurrence of a creation/destruction event for a quantum particle *Q* of a given mass – associated with a given change of the quantum vacuum energy density – in a point event *x*);
- Opportune couplings associated respectively with the wave function at two components $C = \begin{pmatrix} \psi_{Q,i} \\ \varphi_{Q,i} \end{pmatrix}$ describing the probability of the occurrence of a creation/destruction event and with the real and imaginary parts of the singlet field *S*.

This plan of this paper is the following. In chapter 2 we review the general features of the 3D timeless quantum vacuum model recently proposed by the author in [15, 16]. In chapter 3 we show how the 3D timeless quantum vacuum model allows us to extend the Standard Model solving the wrong vacuum problem, and thus explaining why the universe exists in the correct vacuum state, generating the electroweak symmetry breaking at the TeV scale dynamically via dimensional transmutation. In chapter 4 we provide an explanation of the dark matter abundance in our model, showing that dark matter can be realized in a clear way starting in terms of the fluctuations of the 3D quantum vacuum. In chapter 5 we show how our model yields a cosmic evolution of all the masses in the universe, both of the nuclei and of the Dark Matter particles, which is compatible with General Relativity. Finally, in chapter 6 we analyse the stability of the Standard Model vacuum in the timeless 3D quantum vacuum approach.

2 The Ontology and the Fundamental Features of the Timeless Three-Dimensional Quantum Vacuum Model

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,

From the quantum field theories which describe the known particles and forces one can derive various contributions to the vacuum energy density which indeed result in a physically real energy density of empty space. Based on the fundamental theories, one can infer that the total vacuum energy density has at least the following three contributions,

$$\begin{pmatrix} Vacuum \\ energy \\ density \end{pmatrix} = \begin{pmatrix} VACUUM \\ ZERO-POINT-ENERGY \\ +FLUCTUATIONS \end{pmatrix} + \begin{pmatrix} QCD \\ gluon-and-quark \\ condensates \end{pmatrix} + \begin{pmatrix} The \\ Higgs \\ field \end{pmatrix} + ... \quad (1)$$

namely the fluctuations characterizing the zero-point field, the fluctuations characterizing the quantum chromodynamic level of subnuclear physics and the fluctuations linked with the Higgs field, and the dots represent contributions from possible existing sources outside the Standard Model (for instance, GUT's, string theories, and every other unknown contributor to the vacuum energy density). There is no structure within the Standard Model which suggests any relations between the terms in equation (1), and it is therefore customary to assume that the total vacuum energy density is, at least, as large as any of the individual terms.

On the other hand, the gravitational effect of a vacuum energy resulting from each of these terms, as well as possible other, at present, unknown fields, might curve spacetime beyond recognition. In this regard, one can assume that the vacuum energy density of general relativity ($\langle \rho_{vac} \rangle$) is equivalent to a contribution to the 'effective' cosmological constant in Einstein equations

$$\Lambda_{eff} = \Lambda_0 + \frac{8\pi G}{c^4}\langle \rho_{vac} \rangle \quad (2)$$

where Λ_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 (2) 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.

As a consequence, taking account of equation (2), in order to reconcile the vacuum energy density estimate within the Standard Model with the observational limits on the cosmological constant $|\Lambda| < 10^{-56} cm^{-2}$, the usual programme is to "fine-tune": for example, if the vacuum energy is estimated to be at least as large as the contribution from the QED sector then Λ has to cancel the vacuum energy to a precision of at least 55 orders of magnitude.

There are several different indications that the vacuum energy density should be non-zero, each indication being based either on laboratory experiments or on astronomical observations. The notions of physical vacuum originated after the birth of quantum mechanics, in connection with the development of the idea of spontaneous emission of an isolated excited atom [17].

It was later found that the polarization of the electromagnetic component of the physical vacuum, the quantum electrodynamics vacuum (QED-vacuum), could manifest itself in the spatial "smearing" of the electron and a change, as a result, of the potential energy of its interaction with the nucleus, thus providing conditions for the removal of the degeneracy of the energies of the 2*S* ½ and 2*P* ½ states in the hydrogen atom – the Lamb shift [18]. It was also demonstrated that the quantum fluctuations of the electromagnetic component of the physical vacuum in regions contiguous with material objects could alter the relativistic quantum relationships in the near-surface regions of the objects and thus give rise to its macroscopic manifestations – the Casimir ponderomotive effect [19, 20], Josephson contact noise [21]. All the effects here mentioned are of electromagnetic nature: they vanish if the fine structure constant $\alpha = \frac{e^2}{\hbar c}$ (where e is the electron charge, c is the velocity of light in a vacuum, and $\hbar$ is Planck's reduced constant) tends to zero [19, 20].

The development of quantum chromodynamics [22] brought interesting results as regards the nature of the physical vacuum on high-energy scales. In particular, it emerged that at an energy density of $E_{QED} \approx 200 MeV$ a phenomenon of confinement-deconfinement transition characterizes the nucleus where quarks were no longer bound in nucleons but formed a quark-gluon plasma or quark soup. The strong interaction constant α_S in that case proved to be dependent on the excitation energy: its magnitude changed from $\alpha_S \sim 1$ at low energies to $\alpha_S \approx 0.3$ at energies of a few gigaelectron-volts, depending but weakly on energy thereafter [22]. In the last decade, the notion of a physical vacuum have come into wide use in cosmology [23-26] 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 $\varepsilon_V \approx 0,66 \cdot 10^{-8} erg / cm^3$ [27] 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 $E_{QCD} \approx 200 MeV$ [23, 28, 29], with its energy density being $\varepsilon_{QCD} = E_{QCD}^4 / \left(2\pi\hbar c\right)^3$, 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

$$\rho_{pE} = \frac{m_p \cdot c^2}{l_p^3} = 4,641266 \cdot 10^{113} \frac{Kg}{ms^2} \qquad (3)$$

(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.

According to the approach suggested by the authors in [15, 16], the fundamental arena of the universe is a 3D isotropic quantum vacuum composed by elementary packets of energy having the size of Planck volume and whose most universal property is its energy density. The ordinary space-time we perceive derives from this 3D isotropic quantum vacuum. Based on the Planckian metric, which defines the 3D quantum vacuum, the maximum energy density characterizing the minimum quantized space constituted by Planck's volume given by the Planck energy density (3) 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 (3). One can say that in the presence of a material object the curvature of space increases and corresponds physically to a more fundamental diminishing of the energy density of the quantum vacuum, which, in the centre of the material object, is given by relation

$$\rho_{qvE} = \rho_{pE} - \frac{m \cdot c^2}{V} \qquad (4)$$

m and V being the mass and volume of the object. The appearance of matter corresponds to a given change of the energy density of quantum vacuum and derives from elementary processes of creation/annihilation of quanta analogous to Chiatti's and Licata's transactions [30-33]. The presence of a given massive particle or massive object in our level of physical reality derives from a more fundamental diminishing of the energy density of quantum vacuum associated to opportune processes of creation and annihilation of quanta.

In this model, the changes and fluctuations of the quantum vacuum energy density, through a quantized metric characterizing the underlying microscopic geometry of the 3D quantum vacuum can be considered the origin of a curvature of space-time similar to the curvature produced by a "dark energy" density [16]. The quantized metric of the 3D quantum vacuum condensate is linked with the changes of the quantum vacuum energy density determining the appearance of matter and the opportune fluctuations of the quantum vacuum energy density determining dark energy. Furthermore, it 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: this means that the curvature of space-time characteristic of general relativity may be considered as a mathematical value which emerges from the quantized metric and thus from the changes and fluctuations of the quantum vacuum energy density. The quantized metric of the 3D quantum vacuum condensate is

$$d\hat{s}^2 = \hat{g}_{\mu\nu} dx^\mu dx^\nu \qquad (5)$$

whose coefficients (in polar coordinates) are defined by equations

$$\hat{g}_{00} = -1 + \hat{h}_{00}, \quad \hat{g}_{11} = 1 + \hat{h}_{11}, \quad \hat{g}_{11} = 1 + \hat{h}_{11},$$
$$\hat{g}_{33} = r^2 \sin^2 \vartheta \left(1 + \hat{h}_{33}\right), \ \hat{g}_{\mu\nu} = \hat{h}_{\mu\nu} \ \text{for} \ \mu \neq \nu \qquad (6)$$

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

$$\left\langle \hat{h}_{\mu\nu} \right\rangle = 0$$

except

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

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

(7)

where $\Delta\rho^{DE}{}_{qvE} = \frac{m_{DE}\cdot c^2}{V}$ is the opportune change of the quantum vacuum energy density associated with the dark energy density $\rho_{DE} = m_{DE}\cdot c^2$. Taking account of Ng's results [34-37] that the structure of the space-time foam can be inferred from the accuracy in the measurement of a distance l – in a spherical geometry over the amount of time $T = 2l/c$ it takes light to cross the volume – given by

$$\delta l \geq \left(2\pi^2/3\right)^{1/3} l^{1/3} l_P^{2/3} \qquad (8)$$

the quantized metric (5) can be associated with an underlying microscopic geometry expressed by equations

$$\Delta x \geq \frac{\hbar}{2\Delta p} + \frac{\Delta p}{2\hbar}\left(2\pi^2/3\right)^{2/3} l^{2/3} l_P^{4/3} \qquad (9)$$

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

$$\Delta t \geq \frac{\hbar}{2\Delta E} + \frac{\Delta E T_0^2}{2\hbar} \qquad (10)$$

which is the time uncertainty and

$$\Delta L \cong \frac{\left(2\pi^2/3\right)^{1/3} l^{1/3} l_p^{2/3} T_0 E}{2\hbar} \qquad (11)$$

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. The quantized metric (5) allows the quantum Einstein equations

$$\hat{G}_{\mu\nu} = \frac{8\pi G}{c^4}\hat{T}_{\mu\nu} \qquad (12)$$

(where the quantum Einstein tensor operator $\hat{G}_{\mu\nu}$ is expressed in terms of the operators $\hat{h}_{\mu\nu}$) to be obtained directly: this means that the curvature of space-time characteristic of general relativity may be considered as a mathematical value which emerges from the quantized metric (5) and thus from the changes and fluctuations of the quantum vacuum energy density (on the basis of equations (6) and (7)) [16].

In the approach proposed by the authors in [15], in analogy with Chiatti's and Licata's transactional approach, the events of preparation of an initial state (creation of a particle or object from the 3D quantum vacuum) and of detection of a final state (annihilation or destruction of a particle or object from the 3D quantum vacuum) can be considered as the two only real primary physical events. These two events are connected by their common origin in the timeless background represented by the 3D quantum vacuum. These two primary extreme physical events of the 3D quantum vacuum are each corresponding to a peculiar reduction of a state vector (which are constituted of interaction vertices in which real elementary particles are created or destroyed). For this reason, they can be also called "**RS** processes" where **RS** stands for *state reduction* in analogy with the **R** processes of the Penrose terminology. Each **RS** process is a self-connection of the timeless 3D quantum vacuum. In this picture, the history of the Universe, considered at the basic level, is given neither by the application of forward causal laws at initial conditions nor by the application of backward causal laws at final conditions. Instead, it is assigned as a whole as a complete network of **RS** processes that take place in the timeless 3D quantum vacuum. Causal laws are only rules of coherence which must be verified by the network and are *per se* indifferent to the arrow of the time of our level of physical reality.

The probability of the occurrence of a creation/destruction event for a quantum particle Q, associated with a certain diminishing of the quantum vacuum energy density in a point event x, is linked with the probability amplitudes $\psi_{Q,i}\left(x\right)$ (for creation events) and $\varphi_{Q,i}\left(x\right)$ (for destruction events) of a spinor $C = \begin{pmatrix}\psi_{Q,i}\\ \varphi_{Q,i}\end{pmatrix}$ at two components. The generic spinor $C = \begin{pmatrix}\psi_{Q,i}\\ \varphi_{Q,i}\end{pmatrix}$ satisfies a time-symmetric extension of Klein-Gordon quantum relativistic equation of the form

$$\begin{pmatrix} H & 0 \\ 0 & -H \end{pmatrix} C = 0 \qquad (13)$$

where $H = \left(-\hbar^2\partial^\mu\partial_\mu + m^2c^2\right)$, $m = \frac{4\pi R^3\Delta\rho_{qvE}}{3c^2}$ is the mass of the quantum particle, R being its radius. Equation (13) corresponds to the following equations

$$\left(-\hbar^2\partial^\mu\partial_\mu+\frac{16\pi^2R^6}{9c^2}\left(\Delta\rho_{qvE}\right)^2\right)\psi_{Q,i}\left(x\right)=0 \quad (14)$$

for creation events

$$\left(\hbar^2\partial^\mu\partial_\mu-\frac{16\pi^2R^6}{9c^2}\left(\Delta\rho_{qvE}\right)^2\right)\varphi_{Q,i}\left(x\right)=0 \quad (15)$$

for destruction events respectively. At the non-relativistic limit, equation (13) becomes a pair of Schrödinger-type equations:

$$-\frac{3\hbar^2c^2}{8\pi R^3\Delta\rho_{qvE}}\nabla^2\psi_{Q,i}\left(x\right)=i\hbar\frac{\partial}{\partial t}\psi_{Q,i}\left(x\right) \quad (16)$$

$$-\frac{3\hbar^2c^2}{8\pi R^3\Delta\rho_{qvE}}\nabla^2\varphi_{Q,i}\left(x\right)=i\hbar\frac{\partial}{\partial t}\varphi^*_{Q,i}\left(x\right) \quad (17).$$

In the view of a timeless 3D quantum vacuum model, 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

$$Q_{Q,i}=\frac{9\hbar^2c^2}{16\pi^2R^6\left(\Delta\rho_{qvE}\right)^2}\left(\frac{\left(\nabla^2-\frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right)\left|\psi_{Q,i}\right|}{\left|\psi_{Q,i}\right|}-\frac{\left(\nabla^2-\frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right)\left|\varphi_{Q,i}\right|}{\left|\varphi_{Q,i}\right|}\right) \quad (18)$$

(which becomes

$$Q_{Q,i}=-\frac{3\hbar^2c}{8\pi R^3\left(\Delta\rho_{qvE}\right)}\left(\frac{\nabla^2\left|\psi_{Q,i}\right|}{\left|\psi_{Q,i}\right|}\;\frac{\nabla^2\left|\varphi_{Q,i}\right|}{\left|\varphi_{Q,i}\right|}\right) \quad (19)$$

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.

The 3D quantum vacuum model described by equations (13)-(18) introduces the perspective to obtain the standard quantum formalism as a particular aspect of such general theory and, on the other hand, a suggestive interpretation of gravity as a phenomenon emerging from the timeless 3D quantum vacuum [15]. The presence of the quantum potential of the vacuum is in fact equivalent to a curved space-time with its metric being given by

$$\tilde{g}_{\mu\nu}=g_{\mu\nu}/\exp Q \quad (20)$$

which is a conformal metric, where here

$$Q_{Q,i}=\frac{9\hbar^2c^2}{16\pi^2R^6\left(\Delta\rho_{qvE}\right)^2}\frac{\left(\nabla^2-\frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right)_g\left|\psi_{Q,i}\right|}{\left|\psi_{Q,i}\right|} \quad (21)$$

is the quantum potential of the vacuum. In this picture, **RS** processes associated with creation events of quantum particles determine a quantum potential of the vacuum which is equivalent to the curvature of the space-time. The quantum potential of the vacuum corresponding to the generic component of the spinor of a quantum particle is tightly linked with the curvature of the space-time we perceive. In other words, one can say that **RS** processes, through the manifestation of the quantum potential of the vacuum (21), lead to the generation, in our macroscopic level of reality, of a curvature of space-time and, at the same time, the space-time metric is linked with the quantum potential of the vacuum which influences and determines the behaviour of the particles (themselves corresponding to creation events from the timeless 3D quantum vacuum). In this model, one can infer that the space-time geometry sometimes looks like gravity and sometimes looks like quantum behaviours and both these features of physical geometry emerge from the **RS** processes of the timeless 3D quantum vacuum.

3 Completing the Standard Model with a scalar potential of the three-dimensional quantum vacuum energy density

In order to solve the problems of the current Standard Model, we suggest to consider a general scalar potential in the picture of a 3D timeless quantum vacuum characterized by elementary processes of creation/annihilation of quanta. In this approach, the most general scalar potential invariant under the Standard Model gauge group has the following form

$$V=\lambda_C C^4+\lambda_I s_I{}^4+\lambda_{RI} s_I{}^2 s_R{}^2+\lambda_R s_R{}^4+\lambda_{IC} C^2 s_I{}^2+\lambda_{RC} C^2 s_R{}^2 \quad (22)$$

where $C=\begin{pmatrix}\psi_{Q,i}\\ \varphi_{Q,i}\end{pmatrix}$ 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 $m=\frac{4\pi R^3\Delta\rho_{qvE}}{3c^2}$ (determined by an opportune change $\Delta\rho_{qvE}$ of the quantum vacuum energy density) 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

$$\lambda_R=\lambda_S+\lambda_S'+\lambda_S'' \quad (23)$$

$$\lambda_I=\lambda_S+\lambda_S'-\lambda_S'' \quad (24)$$

$$\lambda_{RI}=2(\lambda_S-3\lambda_S') \quad (25)$$

$$\lambda_{RC}=\lambda_{SC}+\lambda_{SC}' \quad (26)$$

$$\lambda_{IC}=\lambda_{SC}-\lambda_{SC}' \quad (27).$$

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

$$16\pi^2\beta_{\lambda_C}=\frac{3}{8}\left(3g^4+2g^2g'^2+g'^4\right)+\frac{1}{2}\left(\lambda_{RC}^2+\lambda_{IC}^2\right)+24\lambda_C^2-3\lambda_C\left(3g^2+g'^2-4y_t^2\right)-6y_t^4 \quad (28)$$

$$16\pi^2\beta_{\lambda_R}=18\lambda_R^2+2\lambda_{RC}^2+\frac{1}{2}\lambda_{RI}^2 \quad (29)$$

$$16\pi^2\beta_{\lambda_I}=18\lambda_I^2+2\lambda_{IC}^2+\frac{1}{2}\lambda_{RI}^2 \quad (30)$$

$$16\pi^2\beta_{\lambda_{RI}}=4\lambda_{IC}\lambda_{RC}+6\lambda_{RI}\left(\lambda_I+\lambda_R\right)+4\lambda_{RI}^2 \quad (31)$$

$$16\pi^2\beta_{\lambda_{RC}}=-\frac{3}{2}\lambda_{RC}\left(g'^2+3g^2-4y_t^2\right)+\lambda_{IC}\lambda_{RI}+6\lambda_{RC}\left(2\lambda_C+\lambda_R\right)+4\lambda_{RC}^2 \quad (32)$$

$$16\pi^2\beta_{\lambda_{IC}}=-\frac{3}{2}\lambda_{IC}\left(g'^2+3g^2-4y_t^2\right)+\lambda_{RC}\lambda_{RI}+6\lambda_{IC}\left(2\lambda_C+\lambda_I\right)+4\lambda_{IC}^2 \quad (33)$$

Now we will show in what sense the vacuum expectation value for s_R is generated via dimensional transmutation and how it is transmitted to the Standard Model. In this regard, as in [13] and in [38], the one-loop potential can be approximated just by using a running λ_R in the tree-level potential. One can approximate λ_R by

$$\lambda_R=\beta_{\lambda_R}\ln\frac{|s_R|}{s_0} \quad (34)$$

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 is given by

$$\begin{pmatrix} 2v^2\lambda_C & -\sqrt{2}v^2\sqrt{\lambda_C|\lambda_{RC}|} \\ -\sqrt{2}v^2\sqrt{\lambda_C|\lambda_{RC}|} & |\lambda_{RC}|v^2+\frac{2\beta_{\lambda_R}\lambda_C v^2}{|\lambda_{RC}|}\end{pmatrix} \quad (35)$$

where

$$v=\frac{s_0}{e^{1/4}}\sqrt{\frac{|\lambda_{RC}|}{2\lambda_C}} \quad (36).$$

In the case of small λ_{RC} the square matrix (35) leads to the following eigenvalues for the energy density of the quantum vacuum:

$$\rho_h^2\cong v^2\left(2\lambda_C-\frac{\lambda_{RC}^2}{\beta_{\lambda_R}}\right) \quad (37)$$

$$\rho_s^2\cong v^2\left(2\frac{\beta_{\lambda_R}\lambda_C}{|\lambda_{RC}|}+\frac{\lambda_C^2}{\beta_{\lambda_R}}+|\lambda_{RC}|\right) \quad (38)$$

while the CP-odd quantum vacuum energy density is

$$\rho_s^2\cong v^2\left(2\frac{\lambda_C\lambda_{RI}}{|\lambda_{RC}|}+\frac{\lambda_{IC}}{2}\right) \quad (39).$$

Equations (37)-(38) are valid only if $\frac{\lambda_{RC}^2}{\beta_{\lambda_R}}<<1$. If this is not true, the proper approximation is

$$\rho_h^2\cong v^2\left(2\lambda_C+|\lambda_{RC}|+\beta_{\lambda_R}\right) \quad (40)$$

$$\rho_s^2\cong v^2\left(2\frac{\beta_{\lambda_R}\lambda_C}{|\lambda_{RC}|}+\beta_{\lambda_R}\right) \quad (41),$$

which imply that the real singlet s_R derives from a quantum vacuum energy density which is associated to a mass lighter than the Higgs boson. Based on equations (37)-(41), the singlet s_R decays to Standard Model particles via more fundamental values of the quantum vacuum energy density. The approach here proposed based on equations (37)-(41) 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 (37)-(41). 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 determine the action of the Higgs boson. Moreover, in virtue of equation (38) one can say that the CP-odd component of the complex singlet turns out to be stable due to CP conservation, and will play the role of the dark matter candidate in this approach. The branching ratios of the kinematically allowed decay channels of the real part of the singlet function corresponding to opportune fluctuations of the quantum vacuum energy density are the same as for the Standard Model Higgs boson with mass corresponding to the same changes of the quantum vacuum energy density, and the production cross section is given by the Standard Model Higgs production cross section multiplied by $\sin^2\theta_{SC}$, where θ_{SC} is the mixing angle between the singlet and the wave function associated to opportune processes of creation/annihilation corresponding to those same changes of the quantum vacuum energy density, obtained by diagonalising the mass matrix (35).

Another relevant result of the approach here proposed lies in the possibility to remove the global minimum of the Standard Model Higgs potential

$$V(h) = -\mu^2 h^2 + \lambda_H(h) h^4 \tag{42}$$

($-\mu^2$ 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). In this regard, in analogy to the approach developed by Gabrielli et al. in [14], one can show that the various couplings of the scalar sector have the crucial role in removing the global minimum of the Standard Model Higgs potential (42) and generating the electroweak symmetry breaking minimum.

As demonstrated by Gabrielli and his co-authors in [14], the physically unacceptable global minimum in the effective potential of the Higgs may be removed together with the explicit Higgs mass term at low energy by extending the Standard Model particle content with one complex scalar singlet field *S*. In this picture, the electroweak symmetry breaking scale may be obtained via dimensional transmutation from the Ultraviolet Landau pole and the Dark Matter is stable due to CP conservation of the scalar potential. The Higgs field characterizing the current Standard Model determines a vacuum expectation value of the order of $\approx 10^{26} GeV$ via dimensional transmutation because of the negative value of the Higgs self-coupling λ_H at that scale, thus destabilising the three-level potential and therefore generating a minimum in the effective potential around the scale where the coupling crosses zero.

However, if λ_H were to cross zero around the TeV scale instead of the high scale at $10^{26} GeV$, the vacuum expectation value of the electroweak symmetry breaking could be generated in this manner. Whilst in the standard approach this cannot be achieved with the Standard Model couplings, Gabrielli's approach allows important progresses to be obtained by adding a singlet scalar *S*, and fixing the couplings of *S* so that its self-coupling λ_S crosses zero at a suitable scale, generating a vacuum expectation value for *S*. Moreover, in Gabrielli's model, this vacuum expectation value can be mediated to the Standard Model Higgs via the portal coupling $\lambda_{SH}|S|^2|H|^2$ and here if the sign of the portal coupling is negative, the Higgs gets a negative mass term from the vacuum expectation value of *S* and breaks the electroweak symmetry as in the Standard Model.

By following the philosophy that is at the basis of Gabrielli's programme, in our extended approach of the Standard Model based on the 3D timeless quantum vacuum, let us start by looking at the running of λ_R. We set λ_R to a small negative value at the electroweak scale. Since the beta-function (29) 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. Since λ_R itself has to be small near the scale s_0, and since λ_{RC} is required to be small in order to keep the mixing between s_R and the regime of small wave function *C*, the beta-function (29) is 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.

To remove the global minimum characterizing the

Standard Model Higgs potential we need to add a positive term to the beta-function of λ_C to keep it from crossing zero. From equation (28) we see that this can be achieved by the term $\lambda_{RC}^2 + \lambda_{IC}^2$. Since λ_{RC} is small to avoid large mixing, this term is dominated by λ_{IC}. Thus, to remove the global minimum, we need to set a sizable initial value for λ_{IC} at the electroweak scale.

We want to avoid generating a vacuum expectation value for the imaginary part s_I, which means that λ_I must stay positive. Hence we set a small positive initial value for λ_I at the electroweak scale. The beta-function (30) of λ_I contains a positive contribution from both λ_{IC} and λ_{RI}, which we know from above to have sizable values. Therefore the running of λ_I will be quite rapid, and it will eventually run into a Landau pole. By choosing the initial values for the parameters at the top mass scale as follows: λ_{RI} =0.3, $\lambda_R = -1.2 \cdot 10^{-3}$, λ_{IC} = 0.35, λ_I = 0.01, $\lambda_{RC} = -10^{-4}$, λ_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 $s_0 \approx 10^4 GeV$.

In this framework the false Standard Model vacuum is avoided because of the modification of the Standard Model Higgs boson quartic coupling Renormalization Group Equations determined by the 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. The electroweak scale can be generated by a classically scale invariant Lagrangian through dimensional transmutation in the scalar sector. The vacuum expectation value of this scalar then induces the Standard Model Higgs vacuum expectation value through a portal coupling.

4 About the Link Between Dark Matter and the Timeless Three-Dimensional Quantum Vacuum

As regards the new physics beyond the Standard Model, another cosmological puzzle that requires a solution is the nature of dark matter. Astrophysicists and cosmologists assure us that the formation of structures in the universe and their persistence today is possible only with the help of additional gravitational attraction provided by some form of invisible non-relativistic matter. Various astrophysical candidates such as black holes seem to be excluded, so attention is focused on particle candidates for dark matter. In many scenarios, these dark matter particles were once in thermal equilibrium with the rest of the particles in the universe, in which case general arguments suggest that they probably weigh less than about 1 *TeV*. In order to be 'dark' and not bind to ordinary matter, dark matter particles should have neither electric charge nor strong interactions.

In chapter 3, we have extended the Standard Model particle content with one complex singlet field *S* depending of the fluctuations of the quantum vacuum energy density without imposing any additional discrete symmetry by hand. While the real component of *S* acquires a vacuum expectation value and triggers electroweak symmetry breaking, the imaginary component remains stable because of the CP-invariance of the general scalar potential (22). As a consequence, the corresponding scalar field is the dark matter candidate of our scenario. Here we will use the standard notation for a pseudoscalar and denote this field by *A* inside the most minimal model able to provide dynamical electroweak symmetry breaking and dark matter at the same time. The dark matter particle *A* can annihilate into a couple of CP-even scalars or into the Standard Model particles (in this context, it is known that the smallness of the doublet-singlet mixing constrains significantly the latter processes).

According to the model of the 3D timeless quantum vacuum, the relevant leading terms for the dark matter annihilation cross section times relative velocity can be obtained directly from opportune fluctuations of the quantum vacuum energy density by using the expansion

$$s \cong 4\frac{V^2\left(\Delta\rho_{qvE}^A\right)^2}{c^4} + \frac{V^2\left(\Delta\rho_{qvE}^A\right)^2}{c^4} v_{rel}^2,$$

$$\sigma_{ij} v_{rel} \cong a + b v_{rel}^2 \quad (43),$$

where

$$a = f_{ij}\left[\sum_k \frac{a_{ijk}a_{kAA}}{4\frac{V^2\left(\Delta\rho_{qvE}^A\right)^2}{c^4} - \frac{V^2\left(\Delta\rho_{qvE}^{s_k}\right)^2}{c^4}} - \frac{8a_{iAA}a_{jAA}}{4\frac{V^2\left(\Delta\rho_{qvE}^A\right)^2}{c^4} - \frac{V^2\left(\Delta\rho_{qvE}^{s_i}\right)^2}{c^4} - \frac{V^2\left(\Delta\rho_{qvE}^{s_j}\right)^2}{c^4}} - \lambda_{ij}\right]^2 \quad (44),$$

$$b = \frac{a}{16}\left[\frac{16\left(\Delta\rho_{qvE}^A\right)^4 - \left(\left(\Delta\rho_{qvE}^{s_i}\right)^2 - \left(\Delta\rho_{qvE}^{s_j}\right)^2\right)^2}{512\pi^2\delta_{ij}^2 f_{ij}^2 \frac{V^4\left(\Delta\rho_{qvE}^A\right)^8}{c^8}} - 4\right]$$

$$- f_{ij}M_0\left[\frac{\sum_k a_{ijk}a_{kAA}\left(\frac{V^2\left(\Delta\rho_{qvE}^{s_i}\right)^2}{c^4} - \frac{V^2\left(\Delta\rho_{qvE}^{s_j}\right)^2}{c^4}\right)^2 \frac{V^2\left(\Delta\rho_{qvE}^A\right)^2}{c^4}}{\left(\frac{V^2\left(\Delta\rho_{qvE}^{s_k}\right)^2}{c^4} - 4\frac{V^2\left(\Delta\rho_{qvE}^A\right)^2}{c^4}\right)^2} + 2a_{iAA}a_{jAA}F_{ij}\right]$$

(45)

with

$$f_{ij}=\frac{\sqrt{1+\frac{\left(\left(\Delta\rho_{qvE}^{s_i}\right)^2-\left(\Delta\rho_{qvE}^{s_j}\right)^2\right)^2}{16\left(\Delta\rho_{qvE}^{s_i}\right)^4}-\frac{\left(\Delta\rho_{qvE}^{s_i}\right)^2+\left(\Delta\rho_{qvE}^{s_j}\right)^2}{2\left(\Delta\rho_{qvE}^{s_i}\right)^4}}}{8\pi\left(\delta_{ij}+1\right)\frac{V^2\left(\Delta\rho_{qvE}^{A}\right)^2}{c^4}} \tag{46}$$

$$M_0=2\left[\frac{a_{ijk}a_{kAA}}{\left(4\frac{V^2\left(\Delta\rho_{qvE}^{A}\right)^2}{c^4}-\frac{V^2\left(\Delta\rho_{qvE}^{s_k}\right)^2}{c^4}\right)}+\frac{8a_{iAA}a_{jAA}}{-4\frac{V^2\left(\Delta\rho_{qvE}^{A}\right)^2}{c^4}+\frac{V^2\left(\Delta\rho_{qvE}^{s_i}\right)^2}{c^4}+\frac{V^2\left(\Delta\rho_{qvE}^{s_j}\right)^2}{c^4}}-\lambda_{ij}\right] \tag{47}$$

$$F_{ij}=\left[\frac{32\frac{V^4\left(\Delta\rho_{qvE}^{A}\right)^4}{c^4}-4V^2\left(\Delta\rho_{qvE}^{A}\right)^2\left(\frac{V^2\left(\Delta\rho_{qvE}^{s_i}\right)^2}{c^4}+\frac{V^2\left(\Delta\rho_{qvE}^{s_j}\right)^2}{c^4}\right)-\left(\frac{V^2\left(\Delta\rho_{qvE}^{s_i}\right)^2}{c^2}-\frac{V^2\left(\Delta\rho_{qvE}^{s_j}\right)^2}{c^2}\right)^2}{\frac{3}{c^8}\left[-4V^2\left(\Delta\rho_{qvE}^{A}\right)^2+V^2\left(\Delta\rho_{qvE}^{s_i}\right)^2+V^2\left(\Delta\rho_{qvE}^{s_j}\right)^2\right]^3}\right] \tag{48}$$

where $\Delta\rho_{qvE}^{A}$ is the change of the quantum vacuum energy density producing the mass of dark matter, $\Delta\rho_{qvE}^{s_i}$ are the changes of the quantum vacuum energy density corresponding to CP-even scalar masses, a_{ijk} is the trilinear coupling of $s_i s_j s_k$ which includes also the corresponding combinatorial factor, a_{iAA} is the coupling of the $s_i A^2$ interaction, λ_{ij} is the coupling of the $s_i s_j A^2$ interaction and v_{rel} is the relative dark matter velocity.

In the same way the annihilation cross section into Standard Model particles depends of the fluctuations of the quantum vacuum energy density in the sense that can be derived by the following general equation

$$\sigma_{ij}=\frac{p_f}{4\pi\left(\delta_{ij}+1\right)s\sqrt{s-4\frac{V^2\left(\Delta\rho_{qvE}^{A}\right)^2}{c^4}}}\times$$
$$\left[2\left(\lambda_{ij}-\sum_k\frac{a_{ijk}a_{kAA}}{s-\frac{V^2\left(\Delta\rho_{qvE}^{s_k}\right)^2}{c^4}}\right)^2+\frac{64\left(a_{iAA}a_{jAA}\right)^2}{\left(s-\frac{V^2\left(\Delta\rho_{qvE}^{s_i}\right)^2}{c^4}-\frac{V^2\left(\Delta\rho_{qvE}^{s_j}\right)^2}{c^4}\right)^2-4p_f^2\left(s-4\frac{V^2\left(\Delta\rho_{qvE}^{A}\right)^2}{c^4}\right)}\right.$$
$$\left.+\frac{16a_{iAA}a_{jAA}\operatorname{arctan}h\left(\frac{2p_f\sqrt{s-4\frac{V^2\left(\Delta\rho_{qvE}^{A}\right)^2}{c^4}}}{s-\frac{V^2\left(\Delta\rho_{qvE}^{s_i}\right)^2}{c^4}-\frac{V^2\left(\Delta\rho_{qvE}^{s_j}\right)^2}{c^4}}\right)}{p_f\sqrt{s-4\frac{V^2\left(\Delta\rho_{qvE}^{A}\right)^2}{c^4}}}\left(\frac{2a_{iAA}a_{jAA}}{s-\frac{V^2\left(\Delta\rho_{qvE}^{s_i}\right)^2}{c^4}-\frac{V^2\left(\Delta\rho_{qvE}^{s_j}\right)^2}{c^4}}-\sum_k\frac{a_{ijk}a_{kAA}}{s-\frac{V^2\left(\Delta\rho_{qvE}^{s_k}\right)^2}{c^4}}+\lambda_{ij}\right)\right] \tag{49}$$

where

$$p_f=\frac{1}{2}\sqrt{s\left(1+\frac{\left(\frac{V^2\left(\Delta\rho_{qvE}^{s_i}\right)^2}{c^4}-\frac{V^2\left(\Delta\rho_{qvE}^{s_j}\right)^2}{c^4}\right)^2}{s^2}-2\frac{\frac{V^2\left(\Delta\rho_{qvE}^{s_i}\right)^2}{c^4}+\frac{V^2\left(\Delta\rho_{qvE}^{s_j}\right)^2}{c^4}}{s}\right)} \tag{50}$$

In addition, $\sqrt{s}$ is the total energy in the centre of mass frame. In particular, as regards the Standard Model final states, the relevant leading terms of the cross sections are the following

$$\sigma_{W^+W^-}v_{rel}\cong\frac{\lambda_{IC}^{\ 2}}{\left(\frac{V^2\left(\Delta\rho_{qvE}^{h}\right)^2}{c^4}-4\frac{V^2\left(\Delta\rho_{qvE}^{A}\right)^2}{c^4}\right)^2+\Gamma_h^2\frac{V^2\left(\Delta\rho_{qvE}^{h}\right)^2}{c^4}}\times$$
$$\left[\frac{\sqrt{1-\frac{m_W^2c^4}{V^2\left(\Delta\rho_{qvE}^{A}\right)^2}}\left(4\frac{V^4\left(\Delta\rho_{qvE}^{A}\right)^4}{c^8}-4\frac{V^2\left(\Delta\rho_{qvE}^{A}\right)^2}{c^4}m_W^2+3m_W^4\right)}{8\pi\frac{V^2\left(\Delta\rho_{qvE}^{A}\right)^2}{c^4}}+v_{rel}^{\ 2}\left(\frac{\left(16\frac{V^6\left(\Delta\rho_{qvE}^{A}\right)^6}{c^{12}}-20\frac{V^4\left(\Delta\rho_{qvE}^{A}\right)^4}{c^8}m_W^2+4\frac{V^2\left(\Delta\rho_{qvE}^{A}\right)^2}{c^4}m_W^4+3m_W^6\right)}{64\pi\frac{V^6\left(\Delta\rho_{qvE}^{A}\right)^6}{c^{12}}\sqrt{\frac{V^2\left(\Delta\rho_{qvE}^{A}\right)^2}{c^4}-m_W^2}}\right.\right.$$
$$\left.\left.-\frac{\sqrt{1-\frac{m_W^2c^4}{V^2\left(\Delta\rho_{qvE}^{A}\right)^2}}\left(4\frac{V^4\left(\Delta\rho_{qvE}^{A}\right)^4}{c^8}-4\frac{V^2\left(\Delta\rho_{qvE}^{A}\right)^2}{c^4}m_W^2+3m_W^4\right)\left(48\frac{V^4\left(\Delta\rho_{qvE}^{A}\right)^4}{c^8}-16\frac{V^4\left(\Delta\rho_{qvE}^{A}\right)^2\left(\Delta\rho_{qvE}^{h}\right)^2}{c^8}+\frac{V^4\left(\Delta\rho_{qvE}^{h}\right)^4}{c^8}+\Gamma_h^2\frac{V^2\left(\Delta\rho_{qvE}^{h}\right)^2}{c^4}\right)}{32\pi\frac{V^2\left(\Delta\rho_{qvE}^{A}\right)^2}{c^4}\left(\left(\frac{V^2\left(\Delta\rho_{qvE}^{h}\right)^2}{c^4}-4\frac{V^2\left(\Delta\rho_{qvE}^{A}\right)^2}{c^4}\right)^2+\Gamma_h^2\frac{V^2\left(\Delta\rho_{qvE}^{h}\right)^2}{c^4}\right)}\right)\right] \tag{51}$$

for the W^+W^- final state, and

$$\sigma_{ZZ}v_{rel}\cong\frac{\lambda_{IC}^{\ 2}}{\left(\frac{V^2\left(\Delta\rho_{qvE}^{h}\right)^2}{c^4}-4\frac{V^2\left(\Delta\rho_{qvE}^{A}\right)^2}{c^4}\right)^2+\Gamma_h^2\frac{V^2\left(\Delta\rho_{qvE}^{h}\right)^2}{c^4}}\times$$
$$\left[\frac{\sqrt{1-\frac{m_Z^2c^4}{V^2\left(\Delta\rho_{qvE}^{A}\right)^2}}\left(4\frac{V^4\left(\Delta\rho_{qvE}^{A}\right)^4}{c^8}-4\frac{V^2\left(\Delta\rho_{qvE}^{A}\right)^2}{c^4}m_Z^2+3m_Z^4\right)}{8\pi\frac{V^2\left(\Delta\rho_{qvE}^{A}\right)^2}{c^4}}+v_{rel}^{\ 2}\left(\frac{\left(16\frac{V^6\left(\Delta\rho_{qvE}^{A}\right)^6}{c^{12}}-20\frac{V^4\left(\Delta\rho_{qvE}^{A}\right)^4}{c^8}m_Z^2+4\frac{V^2\left(\Delta\rho_{qvE}^{A}\right)^2}{c^4}m_Z^4+3m_Z^6\right)}{64\pi\frac{V^6\left(\Delta\rho_{qvE}^{A}\right)^6}{c^{12}}\sqrt{\frac{V^2\left(\Delta\rho_{qvE}^{A}\right)^2}{c^4}-m_Z^2}}\right.\right.$$
$$\left.\left.-\frac{\sqrt{1-\frac{m_Z^2c^4}{V^2\left(\Delta\rho_{qvE}^{A}\right)^2}}\left(4\frac{V^4\left(\Delta\rho_{qvE}^{A}\right)^4}{c^8}-4\frac{V^2\left(\Delta\rho_{qvE}^{A}\right)^2}{c^4}m_Z^2+3m_Z^4\right)\left(48\frac{V^4\left(\Delta\rho_{qvE}^{A}\right)^4}{c^8}-16\frac{V^4\left(\Delta\rho_{qvE}^{A}\right)^2\left(\Delta\rho_{qvE}^{h}\right)^2}{c^8}+\frac{V^4\left(\Delta\rho_{qvE}^{h}\right)^4}{c^8}+\Gamma_h^2\frac{V^2\left(\Delta\rho_{qvE}^{h}\right)^2}{c^4}\right)}{32\pi\frac{V^2\left(\Delta\rho_{qvE}^{A}\right)^2}{c^4}\left(\left(\frac{V^2\left(\Delta\rho_{qvE}^{h}\right)^2}{c^4}-4\frac{V^2\left(\Delta\rho_{qvE}^{A}\right)^2}{c^4}\right)^2+\Gamma_h^2\frac{V^2\left(\Delta\rho_{qvE}^{h}\right)^2}{c^4}\right)}\right)\right] \tag{52}$$

for the ZZ final state.

In synthesis, one can say that the model here proposed naturally provides a dark matter candidate in the form of the CP-odd scalar that is stable due to the CP-invariance of the scalar potential (22). This model has the possibility to reproduce the dark matter particle with the correct relic density while fulfilling all experimental constraints on dark matter phenomenology. Today, if detecting the dark matter directly at colliders is very challenging due to the small mixing between the Higgs doublet and the singlet, our framework is potentially testable in the planned dark matter direct detection experiments.

5 About Gravity, Dark Energy, Cosmic Evolution of the Mass and Variability of the Gravitational Constant

It must be emphasized that, contrary to Gabrielli's model, the approach proposed by the authors in this article allows us also to provide a consistent description of gravity explaining the observed cosmological constant value. In the light of equations (5)-(7), the curvature of space-time characteristic of general relativity and similar to the curvature produced by a "dark energy" density may be considered as a mathematical value which emerges from a quantized metric characterizing the underlying microscopic geometry of the 3D quantum vacuum linked with the changes and fluctuations of the quantum vacuum energy density.

Moreover, in virtue of the fluctuations of the quantum vacuum energy density, the interesting perspective emerges that, as a consequence of the evolution of the quantum vacuum energy density, a cosmic evolution of all the masses in the universe occurs, both of the nuclei and of the Dark Matter particles, which can be perfectly compatible with general relativity. In order to preserve the Bianchi identity that is satisfied by the Einstein tensor of the gravitational field equations $\nabla^{\mu}G_{\mu\nu}=0$, the time evolution of the masses can be compensated for by the time variation of one or more fundamental gravitational parameters, typically the gravitational constant G_N, or the cosmological constant Λ, or both [39-43].

By using the Friedmann-Lemaitre-Robertson-Walker (FLRW) metric one finds that the most general local conservation law preserving the Bianchi identity, corresponding to an isotropic and homogeneous dust matter fluid emerging from a change of quantum vacuum energy density $\Delta\rho_{qvE}$, reads

$$\frac{G'_N}{G_N}\left(\frac{\Delta\rho_{qvE}}{c^2}+\frac{35Gc^2}{2\pi\hbar^4V}\left(\frac{V}{c^2}\Delta\rho_{qvE}^{DE}\right)^6\right)+\left(\frac{\Delta\rho_{qvE}}{c^2}\right)^I\left(\frac{35Gc^2}{2\pi\hbar^4V}\left(\frac{V}{c^2}\Delta\rho_{qvE}^{DE}\right)^6\right)^I+\frac{3}{a}\frac{\Delta\rho_{qvE}}{c^2}=0 \tag{53}$$

where a is the scale factor and the primes denote derivatives of the various quantities with respect to it. Equation (53) means physically that Newton's gravitational constant G_N is strictly related to fundamental variations of the quantum vacuum energy density.

From equation (53) one can understand how in the theory here proposed a general evolution of Newton's coupling G_N in combination with the particle masses can emerge. In this regard, many studies motivated the possibility of having variable fundamental constants of Nature and of a time variation of the particle masses, such as, for example, the one regarding the proton mass [44-46]. For example, in Fritzsch's and Solà's chiral gauge theory of quantum haplodynamics, where the weak bosons, quarks, and leptons are bound states of fundamental constituents, called haplons, and their antiparticles, the predicted time evolution of the particle masses can be parameterized as

$$\rho_m \approx a^{-3(1-\nu)} \tag{54}$$

[47], where the presence of $|\nu| << 1$ denotes a very small departure from the standard conservation law $\approx a^{-3}$. Such a departure is not viewed as a loss or an excess in the number of particles in a comoving volume (beyond the normal dilution law), but rather as a change in the value of their masses. Models with anomalous matter conservation laws of the above type have been carefully confronted with the precise cosmological data on distant supernovae, baryonic acoustic oscillations, structure formation, and one finds the upper bound $|\nu| \le O\left(10^{-3}\right)$ [48-50].

In our approach, equation (54) may be written as

$$\Delta\rho_{qvE} \approx c^2 a^{-3(1-\nu)} \tag{55}$$

which means that the predicted time evolution of the particle masses corresponds to a more fundamental time evolution of the quantum vacuum energy density. The conservation law (55) together with equation (53) implies that a dynamical response will be generated from the parameters of the gravitational sector, G_N and $\Delta\rho_{qvE}^{DE}$. In other words, on the basis of equations (55) and (53), one can say that the time evolution of all the masses in the universe as well as of the gravitational constant is related to opportune changes of the quantum vacuum energy density. Conversely, dark energy may be seen as an effect of opportune changes of the quantum vacuum energy density triggered by the time evolution of all the masses in the universe.

The time variation of the proton mass (and in general of all masses) within Fritzsch's and Solà's aforementioned parameterization is expressed as follows:

$$\left|\frac{\dot{m}_p}{m_p}\right| \cong 3|\nu| H \tag{56}$$

and the corresponding change of the vacuum energy density reads

$$\left|\frac{\dot{\rho}_{vac}}{\rho_{vac}}\right| \cong -3|\nu|\frac{\Omega_m^0}{\Omega_{vac}^0}H \tag{57}$$

where Ω_m^0, Ω_{vac}^0 are the current cosmological parameters associated with matter and vacuum energy. In our model, taking account of equation (7), equation (57) becomes:

$$\left| \frac{\left(\frac{35Gc^2}{2\pi\hbar^4 V} \left(\frac{V}{c^2} \Delta\rho_{qvE}^{DE} \right)^6 \right)^I}{\frac{35Gc^2}{2\pi\hbar^4 V} \left(\frac{V}{c^2} \Delta\rho_{qvE}^{DE} \right)^6} \right| \cong -3|v| \frac{\Omega_m^0}{\Omega_{vac}^0} H \quad (58)$$

which indicates that the cosmic evolution of the masses emerges as an effect of a more fundamental evolution of the quantum vacuum energy density. Moreover, as a consequence of the cosmic evolution of the quantum vacuum energy density, one has an analogous evolution of the gravitational constant:

$$\left| \frac{\dot{G}}{G} \right| \le |v| H \quad (59).$$

Using the current value of the Hubble parameter as a reference, $H_0 = 1.0227k \cdot 10^{-10} yr^{-1}$, where $k \cong 0.70$ and the mentioned limit $|v| \le O\left(10^{-3}\right)$, we find that the time variations of the above parameters are at most of the order $\le 10^{-13} yr^{-1}$.

Finally, we should also mention that the approach here developed, which implies that the variable vacuum energy and the gravitational constant can be linked to the variation of the particle masses, are compatible with the primordial nucleosynthesis bounds on the chemical species. The important constraint to be preserved here is that the vacuum energy density remains sufficiently small as compared to the radiation density at the time of nucleosynthesis. At the same time, potential variations of the gravitational constant should also be moderate enough to avoid a significant change in the expansion rate at that time.

6 About the Standard Model Vacuum Stability in the Timeless Three-Dimensional Quantum Vacuum Approach

Another relevant topic to explore is the question about stability of the Standard Model vacuum in the context of the timeless 3D quantum vacuum described by the potential (22) at or below the Planck scale. In analogy to Lalak's, Lewicki's and Olszevski's approach [11], to compute the expected lifetime of a metastable vacuum present in the potential (22) one can use the standard formalism of finding a bounce solution which in the *O*(4) symmetric case depends only of $s = \sqrt{\vec{x}^2 + x_4^2}$. This means solving an equation of motion of the form

$$\ddot{C} + \frac{3}{s}\dot{C} = \frac{\partial V}{\partial C} \quad (60)$$

with a dot denoting a derivative with respect to *s*. The boundary conditions are $\dot{C}(0) = 0$, so that the solution is non-singular at *s*=0, and $C(\infty) = C_{\min}$ so that it corresponds to the decay of the metastable vacuum positioned at $C_{\min}$.

Having found the bounce, we compute its euclidean action given by

$$S_E = \int d^4x \left\{ \frac{1}{2} \sum_{\alpha=1}^{4} \left(\frac{\partial C(\vec{x})}{\partial x^\alpha} \right)^2 + V(C(\vec{x})) \right\} = 2\pi^2 \int dss^3 \left(\frac{1}{2}\dot{C}^2(s) + V(C(s)) \right) \quad (61)$$

which allows us to calculate decay probability of a volume d^3x

$$dp = dtd^3x \frac{S_E^2}{4\pi^2} \left| \frac{\det'\left[-\partial^2 + V''(C)\right]}{\det\left[-\partial^2 + V''(C_{\min})\right]} \right|^{-1/2} e^{-S_E} \quad (62)$$

where S_E is the action for the bounce, $\left[-\partial^2 + V''(C)\right]$ is the fluctuation operator around the bounce (V'' is the second derivative of *V* with respect to the wave function). The prime in the det' means that in the computation of the determinant the zero modes are excluded and $\frac{S_E^2}{4\pi^2}$ comes from the translational zero modes. From equation (62) the following tunnelling time emerges

$$\frac{1}{\tau} = T_U^3 \frac{S_E^2}{4\pi^2} \left| \frac{\det'\left[-\partial^2 + V''(C)\right]}{\det\left[-\partial^2 + V''(C_{\min})\right]} \right|^{-1/2} e^{-S_E} \quad (63)$$

where T_U is the age of the universe. To calculate the expected lifetime we simply assume size of the universe $T_U = 10^{10} yr$ in the spatial directions and define the expected lifetime τ as time at which decay probability is equal to 1. We also approximate the determinant and normalization prefactor by another dimension full quantity encountered in our problem, namely $C_0 = C(0)$. The error associated with (62) is small compared to uncertainty in determination of action, because lifetime depends only on fourth power of C_0 while its dependence on action is exponential,

$$\frac{\tau}{T_U} = \frac{1}{C_0^4 T_U^4} e^{S_E} \quad (64).$$

Equation (64) regarding the lifetime of the vacuum may then be approximated as

$$\frac{\tau}{T_U} = \frac{1}{C\Lambda_B^4 T_U^4} \exp\left(\frac{8\pi^2}{3} \frac{1}{\left|\lambda_{eff}\left(\Lambda_B\right)\right|} \right) \quad (65)$$

where $\lambda_{eff}\left(C\right) = \frac{V\left(C\right)}{C^4}$ and Λ_B denoting a renormalisation scale that minimises λ_{eff}.

Moreover, the euclidean equation of motion (60) for the bounce can be solved analytically and we have

$$C\left(r\right) = \sqrt{\frac{2}{\left|\lambda_{eff}\right|}} \frac{2R}{r^2 + R^2} \quad (66)$$

R being the size of the bounce. The action is degenerate with *R*, $S\left[C\right] = \frac{8\pi^2}{3\left|\lambda_{eff}\right|}$, the degeneracy being lifted by quantum vacuum fluctuations. By computing the electroweak vacuum, the tunnelling rate turns out to be

$$\Gamma = \frac{1}{\tau} = \frac{1}{T_U} \left[\frac{S\left[C\right]^2}{4\pi^2} \frac{T_U^4}{R^4} e^{-S[C]} \right] \times \left[e^{-\Delta S} \right] \quad (67)$$

ΔS being the loop contribution. Inserting the numerical values, for the one-loop contributions one obtains $\tau = 10^{555} T_U$ which indicates that the electroweak lifetime is larger than the age of the universe (one can also remark that the inclusion of the ΔS_i contributions does not modify the results significantly, in fact one obtains $\tau = 10^{588} T_U$). Therefore, if in several completions of the Standard Model existing in the current literature the lifetime of the electroweak vacuum strongly depends on new physics, in the sense that the inclusion of new interactions linked with the Higgs doublet destabilizes the Standard Model electroweak vacuum shortening its lifetime (see for example [11, 51]), instead in our completion of the Standard Model based on the fluctuations of a timeless 3D quantum vacuum this problems seems to be not present: our approach seems to be able to satisfy the "beyond standard model stability test" proposed by Branchina in [51], according to which a beyond standard model theory is acceptable if it provides either a stable electroweak vacuum or a metastable one, with lifetime larger than the age of the universe.

7 Conclusions

Although no clear signal of physics beyond the Standard Model has appeared so far at the LHC, there is no doubt that the Standard Model has to be extended. The Standard Model of particle physics agrees very well with experiment, but many important topics remain unresolved, such as the origin of particles' masses, the interpretation of the Higgs boson, the nature and origin of dark matter and dark energy, as well as the problem to unify the fundamental interactions and to quantize gravity. Other unsatisfactory features of the Standard Model are related to the fact that the Standard Model potential has a global minimum at $\approx 10^{26} GeV$, generating an instability in the electroweak vacuum and thus invalidating the Standard Model as a phenomenologically acceptable model in this energy range.

The framework we have outlined in this paper based on elementary fluctuations of a timeless 3D quantum vacuum suggests interesting perspectives of solution of the problems above mentioned providing a ultraviolet completion of the Standard Model (and thus opening the doors to a new formulation of GUT's) involving gravity *ab initio* (in contrast to more conventional formulations). It also proposes a new candidate for the Dark Matter that is not in conflict with the recent, highly restrictive bounds for the scattering of Dark Matter particles off nuclei. In this picture, the false Standard Model vacuum is avoided because of the modification of the Standard Model Higgs boson quartic coupling Renormalization Group Equations determined by the 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. At the same time, the model here proposed predicts, as a consequence of the changes of the quantum vacuum energy density, a cosmic evolution of all the masses in the universe, both of the nuclei and of the Dark Matter particles, which is perfectly compatible with general relativity, as well as a cosmological variability of the gravitational constant.

The approach of the timeless 3D quantum vacuum is not based on ad hoc assumptions regarding the Higgs boson and it does not lead to a large contribution to the cosmological term. The Dark Energy appears here as the tiny (but observable) dynamical change of the vacuum energy density of the most fundamental background and hence is a part of the generic response of general relativity to the cosmic time variation of the masses of all the stable baryons and Dark Matter particles in the universe. Finally, our proposal of completion of the Standard Model predicts a stable electroweak vacuum, with a lifetime much larger than the age of the universe, thus satisfying the stability test of the vacuum as regards the beyond Standard Model physics.

On the other hand, in particle physics other important topics, such as the neutrino oscillations, which lead to the existence of small (left-handed) neutrino masses, the baryon asymmetry of the universe and the strong CP problem are waiting for a more satisfactory explanation. As regards the baryon asymmetry of the universe, it seems natural to assume that it requires additional dynamics too and here leptogenesis could be considered a plausible candidate mechanism, able to be easily incorporated in our framework together with neutrino masses. As regards the strong CP problem, in the context of particle physics it remains unexplained, and even here a possible solution can be obtained by requiring additional degrees of freedom to be added to the minimal model proposed in this paper. The results and conclusions obtained in this paper remain valid under the assumption that these new degrees of freedom somehow decouple from the relevant degrees of freedom that contribute to our scalar sector.

Finally we want to remark that even if the Planck scale is indeed a physical cutoff for the validity of the Standard Model, the conclusions obtained in the context of the timeless 3D quantum vacuum here proposed remain mostly valid. The extra scalars would still avert the metastability problem of the electroweak vacuum, and the low energy phenomenology of the model, including the dynamical generation of the electroweak scale and the Dark Matter model, remains intact. If our framework turns out to be the right approach for extending the validity of the Standard Model above the Planck scale, there are concrete predictions of our model that could be tested by future Dark Matter and collider experiments.

References

[1] G. Aad et al. [ATLAS Collaboration], *Phys. Lett. B* 716, 1-29 (2012).

[2] S. Chatrchyan et al. [CMS Collaboration], *Phys. Lett. B* 716, 30-61 (2012).

[3] F. Englert and R. Brout, *Phys. Rev. Lett.* 13, 9, 321-323 (1964).

[4] P. W. Higgs, *Phys. Lett.* 12, 2, 132-133 (1964).

[5] P. W. Higgs, *Phys. Rev. Lett.* 13, 16, 508 (1964)

[6] G. S. Guralnik, C. R. Hagen and T. W. B. Kibble, *Phys. Rev. Lett.* 13, 20, 585 (1964).

[7] S. L. Glashow, *Nucl. Phys.* 22, 4, 579-588 (1961).

[8] S. Weinberg, *Phys. Rev. Lett.* 19, 1264-1266 (1967).

[9] A. Salam, *Conf. Proc. C*. 680519, 367-377 (1968).

[10] J. Ellis, *Phil. Trans. Roy. Soc. A*, 370, 818-830 (2012)

[11] Z. Lalak, M. Lewicki and P. Olszevski, "Higher-order scalar interactions and SM vacuum stability", arXiv:1402.3826v3 [hep-th] (2014).

[12] C. G. Callan, S. R. Coleman, J. Wess and B. Zumino, *Phys. Rev.* 177, 2247-2250 (1969).

[13] S. M. Barr and X. Calmet, *Int. J. Mod. Phys.: Conf. Series*, 1-8 (2012).

[14] E. Gabrielli, M. Heikinheimo, K. Kannike, A. Racioppi, M. Raidal and C. Spethmann, "Towards completing the Standard Model: vacuum stability, EWSB and dark matter", arXiv:1309.6632.pdf [hep-th] (2013).

[15] D. Fiscaletti and A. Sorli, *SOP Trans. on Theor. Phys.* 1, 3, 11-38 (2014).

[16] D. Fiscaletti and A. Sorli, *Annales UMCS Sectio AAA: Physica* LXIX, 55-81 (2014).

[17] P. A. M. Dirac, *Principles of Quantum Mechanics*, Oxford University Press, 4th Edition (1982).

[18] G. W. Erickson, *Phys. Rev. Lett.* 27, 780-783 (1971).

[19] G. L. Klimchitskaya, U. Mohideen and V. M. Mostepanenko, *Rev. Mod. Phys.* 81, 1827-1885 (2009).

[20] R. L. Jaffe, *Phys. Rev. D* 72, 021301, 1-5 (2005).

[21] C. Beck, M.C. Mackey, *Fluct. and Noise Lett.* 7, 2, C27-C35 (2007).

[22] A. Bettini, *Introduction to elementary particle Physics*, Cambridge University Press (2008).

[23] V. A. Rubakov, *Phys.–Usp.* 50, 4, 390–396 (2007).

[24] S. M. Carroll, W. H. Press and E. L. Turner, *Annual Review of Astronomy and Astrophysics* 30, 1, 499-542 (1992).

[25] A. D. Chernin, *Phys.–Usp.* 51, 3, 253–282 (2008).

[26] T. Padmanabhan, *29° International Cosmic Ray Conference Pune*, 10, 47-62 (2005).

[27] T. Reichhardt, *Nature* 421, 777 (2003).

[28] V. Sahni, *Lect. Notes Phys.* 653, 141-180 (2004).

[29] Yu. B. Zeldovich, *Phys. – Usp.* 24, 3, 216–230 (1981).

[30] L. Chiatti, "The transaction as a quantum concept", in *Space-time geometry and quantum events*, I. Licata ed., Nova Science Publishers, New York (2014), pp. 11-44

[31] I. Licata, *Eur. Phys. Jour. Web of Conf.* 70, doi:10.1051/epjconf/20147000039 (2013).

[32] I. Licata and L. Chiatti, *Int. J. Theor. Phys.* 48, 4, 1003-1018 (2009).

[33] I. Licata and L. Chiatti, *Int. J. Theor. Phys.* 49, 10, 2379-2402 (2010).

[34] Y. Jack Ng, *Phys. Lett. B* 657, 1, 10-14 (2007).

[35] Y. Jack Ng, *Entropy* 10, 441-461 (2008).

[36] Y. Jack Ng, "Holographic quantum foam", arXiv:1001.0411v1 [gr-qc] (2010).

[37] Y. Jack Ng, "Various facets of spacetime foam", arXiv:1102.4109.v1 [gr-qc] (2011).

[38] T. Hambye and A. Strumia, *Phys. Rev. D* 88, 055022 (2013).

[39] H. Fritzsch and J. Solà, *Class. Quant. Grav.* 29, 21, Article ID 215002, 25 pages (2012).

[40] J. Solà, *Jour. of Phys.: Conf. Series* 453, Article ID 012015 (2013).

[41] J. Solà, *Jour. of Phys.: Conf. Series* 283, 1, Article ID 012033 (2011).

[42] J. Solà, *Jour. of Phys. A: Math. and Theor.* 41, 16, Article ID164066 (2008).

[43] J. Solà, *AIP Conf. Proc.* 1606, 19–37 (2014).

[44] E. Reinhold, R. Buning, U. Hollenstein, A. Ivanchik, P. Petitjean and W. Ubachs, *Phys. Rev. Lett.* 96, 15, Article ID 151101 (2006).

[45] W. Ubachs and E. Reinhold, *Phys. Rev. Lett.* 92, 101302 (2004).

[46] A. Ivanchik, P. Petitjean, D. Varshalovich et al., *Astronomy*

and Astrophysics 440, 1, 45–52 (2005).

[47] H. Fritzsch and J. Solà, *Advances in High Energy Physics* Volume 2014: Article ID 361587, 6 pages (2014).

[48] S. Basilakos, M. Plionis and J. Solà, *Phys. Rev. D* 80, 8, Article ID083511 (2009).

[49] J. Grande, J. Solà, S. Basilakos and M. Plionis, *Journal of Cosmology and Astroparticle Physics* 1108, 007 (2011).

[50] S. Basilakos, D. Polarski and J. Solà, *Phys. Rev. D* 86, Article ID 043010 (2012).

[51] V. Branchina, "Stability of the EW vacuum, Higgs boson and new physics", arXiv: 1405.7864v1 [hep-th] (2014).