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FROM BIG BANG COSMOLOGY TO THE CYCLIC UNIVERSE IN DYNAMIC EQUILIBRIUM

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ABSTRACT. A cyclic model of a timeless universe in dynamic equilibrium is suggested in which the fundamental stage of physical processes is a three-dimensional non-local quantum vacuum defined by reduction-state processes of creation/annihilation of quanta which occur in correspondence to elementary energy fluctuations. It is shown in what sense this model implies the existence of symmetry between the energy of matter and energy of space and, consequently, of a cyclic transformation space-matter-space-matter-... in the active galactic nuclei. It is concluded by demonstrating how this model of the cyclic universe in dynamic equilibrium allows us to resolve some important problems of the Standard Cosmological Model.

Keywords: cyclic universe, timeless universe in dynamic equilibrium, three-dimensional quantum vacuum, fluctuations of the quantum vacuum energy density.

INTRODUCTION

Since the pioneering works of Aleksander Friedmann and Georges-Henry Lemaître almost a century ago, the idea has appeared that the universe emerged from a primordial singularity, a point of zero dimension, where the density of matter and energy density have infinite values. In 1922, by assuming the universe to be homogeneous and isotropic, Friedmann solved Einstein's field equations of general relativity finding equations for the scale factor of the universe which imply that the universe starts from an initial singularity where all physical laws break down (FRIEDMANN, 1922). A few years later Lemaître acknowledged the first evidence of the expansion of the universe in the astronomical data regarding the redshift of galaxies. Lemaître's view of the *atome primitif* is today considered the natural precursor of the big-bang idea, leading to the birth of the Standard Cosmological Model (LEMAÎTRE, 1931, 1934, 1950).

Originally developed by George GAMOW (1948a, 1948b) and then improved by other scientists in the next decades, the Standard Cosmological Model suggests that the universe has evolved from a singularity, about 13,8 billion years ago, and since that moment has been characterized by an expansion which created the big and cold universe of today. Even today the theoretical framework of the Standard Cosmological Model relies on Einstein's general relativity and depends on the assumptions regarding the universality of physical laws and the cosmological principle. Its empirical foundation is based on four crucial independent facts, i.e. the formation of large-scale structures, the recession of the galaxies, the existence of the cosmic background radiation and the nucleosynthesis of light elements. Moreover, the Standard Cosmological Model leads to a peculiar parametrization, known as the Lambda Cold Dark Matter Model (ΛCDM) in which the behaviour of the universe is determined by three fundamental components: a cosmological constant Λ associated with dark energy, cold dark matter and ordinary matter. Nonetheless, the ΛCDM model is based on various parameters, such as baryon density, dark matter density and dark energy density, whose values must be adjusted to the obtained experimental results following fine-tuning procedures (NETCHITAILO, 2021).

Despite its successes, the Standard Cosmological Model meets a certain number of problems (because of its dependence on well-defined initial conditions): in particular, the problem of the origin of the galaxies, the problem of the null curvature of space, the problem of the dimensions of the universe and the problem of the times of the expansion. To face these problems, in 1981 Alan Guth introduced inside the big-bang scenario the idea of inflation, namely the idea that after the initial state the universe is characterised by an extremely rapid expansion (GUTH, 1981). The inflationary model can be certainly considered an important improvement of the standard big-bang model, however, it requires fine-tuning procedures in order to obtain the right values of density variations and today's vacuum energy.

Despite the successes of inflation (the flatness of space, for example, is expected also by the simplest inflationary models (GUTH, 1981; LINDE, 1982), it must be emphasised that cosmology's greatest conundrum, i.e., the initial singularity – the beginning of time and the origin of everything – remains a puzzling dilemma also in the inflation scheme. Although the inflation is explained in terms of the phase transition of the universe due to the decay of a great unified force, in the inflationary model, by invoking ideas such as the no-boundary proposal, it does not seem possible to predict the occurrence of inflation (TUROK and STEINHARDT, 2004). In order to save the theory, some authors have focused their attention on anthropic arguments, but this path meets the issue concerning the question of whether the anthropic selection is great enough to select a universe like ours. On the other hand, it has been recently suggested that the vacuum of superstring theory generates a vast 'discretuum' within an immense landscape and that inflation plus the anthropic principle may determine our observed vacuum. However, by extrapolating back in time, the problem of the big bang singularity remains in the sense that inside the inflationary scenario one cannot explain how and why our region of the universe started out at some point on the landscape. These problems provide strong motivation for searching for a path for cosmology that is an alternative to inflation.

If today's string theory and M theory, by going beyond conventional field theory and gravity, suggest the perspective that there was a universe before the singularity, a new scenario becomes possible in order to explain the evolution of the universe avoiding the problems of the Standard Cosmological Model, namely the view of the cyclic universe, which implies that the big bang cannot be considered as the real origin of the universe, but constitutes only an intermediate phase inside cyclic processes. As regards the paradigm of the cyclic universe, since two germinal papers of 2001, STEINHARDT and TUROK have suggested that the universe is characterised by a periodic sequence of expansions and contractions, which begins with a "big bang" and ends in a "big crunch" thus emerging in a big bang once again (STEINHARDT and TUROK, 2002a, 2002b). The expansion phase of each cycle corresponds to a period of radiation-, matter-, and quintessence-domination, in which the entropy and the density of black holes and any other debris produced since the preceding big bang are watered down. When the acceleration ultimately ends, it is followed by a period of decelerating expansion and then contraction. Thus, a transition from big crunch to big bang occurs, where matter and radiation are created, restoring the universe to the high density required for a new big bang phase. This new cosmology proposed by STEINHARDT and TUROK, therefore, provides a surprisingly complete picture of cosmic history in which high energy inflation is no longer required, exploiting the currently observed dark energy to solve the flatness and homogeneity puzzles, again before the big bang. In this picture, each big bang leads to processes of baryogenesis, dark matter formation, nucleosynthesis and galaxy formation, and ends with an epoch of low energy acceleration of the type we see today. The decay of the dark energy generates both the energy required for the next big bang and the scale-invariant density perturbations required for structure formation in the next cycle. Unlike inflation, the cyclic model of STEINHARDT and TUROK requires the presence of low energy acceleration, in order for the cycles to repeat. Moreover, it allows us to explain the value of today's cosmological constant in physical terms (without invoking the anthropic principle).

The relevance and appeal of cyclic models of the universe lie in the fact that they avoid the issue of initial conditions which characterizes the standard cosmological scenario based on the big bang and the inflation. Based on the FRIEDMANN and TOLMAN original results, the starting point of cyclic cosmological models lies in the assumption that the Friedmann-Robertson-Walker scale factor $a(t)$ oscillates at regularly spaced intervals of time between zero and some large finite value (FRIEDMANN, 1922; TOLMAN and WARD 1932; TOLMAN, 1934). Since the introduction of general relativity, though, various problems with the cyclic concept have emerged. In the 1930s, Tolman discussed cyclic models consisting of a closed universe with zero cosmological constant, underlining that the maximal size of the universe, and the duration of a cycle, increase from bounce to bounce because of the addition of the entropy originating in one cycle with the entropy created in the next. Extrapolating backward, the duration of the bounce converges to zero in a finite time. Consequently, in cyclic models of a closed universe with zero cosmological constant the problem of initial conditions remains. In the 1960s, the singularity theorems of Hawking and Penrose showed that a big crunch necessarily leads to a cosmic singularity where general relativity becomes invalid. Without a theory able to replace general relativity in hand, it was not possible to explore the structure of space and time before the big bang, which thus became synonymous with the beginning of space-time. However, the Hawking-Penrose singularity theorems contain no clues which suggest that cyclic behaviour is forbidden in an improved theory of gravity, such as string theory and M theory, and some people have continued to speculate on this possibility.

In the 1990s, Tolman's cyclic model based on a closed universe was indeed put apart because of the observations that the matter density is significantly less than the critical density and that the scale factor of the universe is accelerating. To face these problems, since 2002, STEINHARDT and TUROK considered a model of cyclic cosmology where the universe is flat, rather than closed. In this model, the transition from expansion to contraction is reproduced by invoking negative potential energy rather than spatial curvature and the cyclic behaviour is linked in an essential way to having a period of accelerated expansion *after* the radiation and matter-dominated phases. During the accelerated expansion phase, the universe approaches a nearly vacuum state, restoring very nearly identical local conditions as existed in the previous cycle prior to the contraction phase. Globally, the total entropy in the universe grows from cycle to cycle, as Tolman suggested. However, the entropy density, which is all any real observer would see, has perfect cyclic behaviour with entropy density being created at each bounce, and subsequently being diminished to negligible levels before the next bounce.

In a recent paper Ijjas and Steinhardt proposed a cyclic theory of the universe in which the Hubble parameter, energy density and temperature are characterised by periodic oscillations, while there is an exponential increase of the scale factor from one cycle to the next (IJJAS and STEINHARDT, 2019). The Ijjas and Steinhardt model allows the resolution of the homogeneity, isotropy and flatness problems as well as the generation of a nearly scale invariant spectrum of density perturbations. At the same time, it faces in a consistent way some old cosmological issues which affect the standard big bang inflationary cosmology. By combining ekpyrotic (ultra-slow) contraction and (non-singular) classical bounces, Ijjas' and Steinhardt's cyclic model considers the possibility that, while the Hubble parameter $H(t) = \frac{\dot{a}}{a}$ (where dot denotes differentiation with respect to time t) oscillates periodically between positive and negative values from cycle to cycle, instead of the Friedmann-Robertson-Walker scale factor $a(t)$ does not, in the sense that $a(t)$ grows during the usual radiation, matter and dark energy dominated expanding phases, but shrinks very little during the contraction phases. In this way, $a(t)$ turns out to have a substantial increase from one cycle to the next.

Ijjas' and Steinhardt's cyclic model considers the perspective that, according to the Friedmann equations, the Friedmann-Robertson-Walker scale factor has the behaviour $a(t) \approx |t|^{1/\varepsilon}$ while the Hubble parameter $|H(t)|$ is proportional to $a^{-\varepsilon}$ during a phase with equation-of-state ε. In this picture, the equation-of-state is

$$\varepsilon_{\pm} = \frac{3}{2}\left(1 + \frac{p}{\rho}\right) \tag{1}$$

where p is the pressure and ρ is the energy density, the subscript – refers to the value of ε during the contracting phase (which is characterised by $H < 0$) and the subscript + indicates the value during the expanding phase (which is characterised by $H > 0$).

Ijjas' and Steinhardt's cyclic model predicts that, during the expanding phase of a cycle, at the beginning, the Hubble parameter $H(t)$ is large and positive and then decreases. In the expanding phase, the evolution of the universe is thus characterised by different periods corresponding to the different values of ε_+: when $\varepsilon_+ = 2$ the dominant form of energy density is radiation, when $\varepsilon_+ = 3/2$ the dominant form of energy density is matter, when $\varepsilon_+ \approx 0$ the dominant form of energy density is dark energy. In particular, Ijjas and Steinhardt suggest that, since $\varepsilon_+ = O(1)$ and the expansion phase lasts a long time, the scale factor $a(t) \approx |t|^{1/\varepsilon_+}$ can increase and the Hubble parameter $H(t) \approx a^{-\varepsilon_+}$ can decrease by large exponential factors by the time the expansion phase ends.

When the expansion phase ends, in Ijjas' and Steinhardt's model, one has the beginning of a ekpyrotic contracting phase which is associated to $\varepsilon_- \gg 1$. In this situation the magnitude of $H(t)$, which is proportional to $a^{-\varepsilon_-}$, can increase by an exponential factor. Then, one deals with a (non-singular) classical bounce phase, which is characterised by a rapid increase of the Hubble parameter $H(t)$ from a large negative value to a large positive value of approximately the same magnitude while $a(t)$ remains the same. In this situation, the universe enters the next expansion phase, and a new cycle begins.

In summary, in the cyclic universe proposed by Ijjas and Steinhardt, at the end of a full cycle, one has the following important results: on one hand, the Hubble parameter $H(t)$ is characterised by an oscillation between exponentially large positive and negative values; on the other hand, the Friedmann-Robertson-Walker scale factor $a(t)$ grows exponentially during the expansion phase but decreases very little during the contraction and bounce phases. These facts lead to a general exponential increase in $a(t)$ by the end of the cycle (IJJAS and STEINHARDT, 2019).

In this paper, our purpose is to go beyond the results of Ijjas and Steinhardt, by exploring the possibility that a more fundamental background rules the behaviour of the universe. By starting from a fundamental non-local quantum vacuum as the ultimate stage of physical processes, we will introduce a new cyclic model of the universe in dynamic equilibrium, in which the universe can be seen as a timeless system which had no beginning and will have no end, as a system which can create itself. In this picture, the view of the big bang theory according to which the universe expands in time intended as a primary physical reality cannot be considered appropriate. The universe is timeless in the sense that time is not a physical dimension in which the universe exists but exists only as a mathematical parameter measuring the numerical order of material changes. We will call this new cosmological model the "cyclic model of the timeless universe in dynamic equilibrium" (TUDE). We will see how our model of TUDE allows us to provide a new suggestive and more general interpretation of the results obtained recently by Ijjas and Steinhardt. The paper is structured in the following manner. In section 2, after reviewing the interpretation of matter and gravity in the model of the three-dimensional non-local quantum vacuum, we will discuss how some fundamental concepts of this model lead to the idea of the cyclic universe in dynamic equilibrium and then, we will analyse the foundations and main features of the model of TUDE. In section 3, we will explore the predictions of our model of TUDE. In section 4, we will summarise the results of the paper.

FROM THE THREE-DIMENSIONAL NON-LOCAL QUANTUM VACUUM ... TO THE FOUNDATIONS AND MAIN FEATURES OF THE CYCLIC MODEL OF THE TIMELESS UNIVERSE IN DYNAMIC EQUILIBRIUM

As I have shown in a series of recent papers (FISCALETTI and SORLI, 2014, 2016a, 2016b, 2017, 2018; FISCALETTI, 2015), subatomic particles and macroscopic bodies can be seen as opportune excitations of a fundamental background medium represented by a three-dimensional (3D) non-local quantum vacuum defined by reduction-state (RS) processes of creation/annihilation of quanta which occur in correspondence to elementary energy fluctuations.

The 3D quantum vacuum is characterised by a ground state which is defined by the Planck energy density

$$\rho_{PE} = \frac{m_p \cdot c^2}{l_p^3} \tag{2}$$

where m_P is Planck's mass, c is the light speed and l_p is Planck's length. The quantity (2) is the maximum value of the energy density of space and physically corresponds to the total average volumetric energy density, owed to all the frequency modes possible within the visible size of the universe, expressed by

$$\rho_{PE} = \frac{c^7}{\hbar G^2} \approx 4{,}641266 \cdot 10^{113}\, J/m^3 \tag{3}$$

$\hbar$ being Planck's reduced constant, G the universal gravitation constant. Out of the ground state of the 3D quantum vacuum defined by the Planck energy density (2), particles and antiparticles continuously appear and disappear. In other words, the appearance of material objects corresponds to excited states of the 3D quantum vacuum which are associated with opportune diminutions of the quantum vacuum energy density given by the relation

$$\rho_{qvE} = \rho_{PE} - \frac{m \cdot c^2}{V} \tag{4}$$

where ρ_{qvE} is the energy density of quantum vacuum inside the physical object, ρ_{PE} is the Planck energy density (given by (3)) and V is the volume of the physical object. Equation (4) may be opportunely rearranged as

$$m = \frac{\Delta\rho_{qvE} V}{c^2} \tag{5}$$

where $\Delta\rho_{qvE} = (\rho_{PE} - \rho_{qvE})$ is the change of the quantum vacuum energy density (FISCALETTI, and SORLI, 2014, 2016a, 2016b, 2017, 2018; FISCALETTI, 2015). The fundamental physical meaning of equation (5) lies in the fact that a fundamental symmetry between the property of mass and the changes of the quantum vacuum energy density exists: the property of mass is nothing more than an opportune diminishing of the quantum vacuum energy density of the fundamental background of the universe.

In this approach, both the dark energy and the matter density can be seen as different aspects of the same energy of the 3D quantum vacuum. By considering a quantized metric of the 3D quantum vacuum condensate given by the relation

$$d\hat{s}^2 = \hat{g}_{\mu\nu} dx^\mu dx^\nu \tag{6}$$

where here the (quantum operators) coefficients of the metric are defined (in polar coordinates) as

$$\hat{g}_{00} = -1 + \hat{h}_{00},\ \hat{g}_{11} = 1 + \hat{h}_{11},\ \hat{g}_{22} = r^2\left(1 + \hat{h}_{22}\right),\ \hat{g}_{33} = r^2 \sin^2 \vartheta\left(1 + \hat{h}_{33}\right),\ \hat{g}_{\mu\nu} = \hat{h}_{\mu\nu} \text{ for } \mu \neq \nu \tag{7}$$

where

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

and

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

the metric (6) is assumed to be close to the Minkowski metric and $\Delta\rho_{qvE}^{DE}$ are opportune fluctuations of the quantum vacuum energy density which determine the dark energy density based on relation

$$\rho_{DE} \cong \frac{35Gc^2}{2\pi\hbar^4 V}\left(\frac{V}{c^2}\Delta\rho_{qvE}^{DE}\right)^6 \tag{9}$$

one finds that the changes and fluctuations of the energy density of the 3D quantum vacuum can be considered the fundamental origin of the curvature of space-time characteristic of general relativity (FISCALETTI, and SORLI, 2014, 2016a, 2016b, 2017, 2018; FISCALETTI, 2015). In this picture, gravitational interaction is an immediate physical phenomenon that derives directly from a variable energy density of the 3D quantum vacuum, in the sense that no movement of particle-wave is needed for its acting. Gravity is transmitted directly by a variable gravitational energy density characterising the region under consideration given by the following relation

$$\rho_{grav} c^2 = -G\left(\frac{V}{c^2}\Delta\rho_{qvE} + \frac{35Gc^2}{2\pi\hbar^4}\left(\frac{V}{c^2}\Delta\rho_{qvE}^{DE}\right)^6\right)^2 \frac{1}{l}\cdot\frac{1}{l^3} \tag{10}$$

where

$$l = \frac{\hbar}{\left(\frac{V}{c^2}\Delta\rho_{qvE}^{DE}\right)c} \tag{11}$$

The gravitational energy density (10), associated with opportune quantum vacuum energy density fluctuations, acts as a direct medium of gravity, in the sense that it acts as a two-point correlation function based on the relation

$$4\pi\int_0^\infty C(r_{12})r_{12}dr_{12} = \left(\frac{V}{c^2}\Delta\rho_{qvE} + \frac{35Gc^2}{2\pi\hbar^4}\left(\frac{V}{c^2}\Delta\rho_{qvE}^{DE}\right)^6\right)^2 \frac{1}{l}\cdot\frac{1}{l^3} \tag{12}$$

As regards the interpretation of subatomic particles, in epistemological affinity with the models of SBITNEV (2015a, 2015b, 2015c, 2016) and FEDI (2017a, 2017b, 2017c), in my approach (FISCALETTI and SORLI, 2014, 2016a, 2016b, 2017, 2018; FISCALETTI, 2015) the 3D quantum vacuum is described as an organised timeless Bose-Einstein condensate of virtual particle/antiparticle pairs, where the real elementary particles of the Standard Model emerge from opportune RS processes of creation/annihilation of these virtual particle/antiparticle pairs, which give rise to an opportune excited state of the 3D quantum vacuum. The RS processes of creation/annihilation of virtual particles of the 3D quantum vacuum are somewhat similar to the transactional processes, corresponding to a peculiar reduction of a state vector, invoked by Chiatti and Licata in their interpretation of an archaic, atemporal vacuum as the fundamental arena in which the only truly existent "things" in the physical world are the events of creation and destruction (or, in other words, physical manifestation and demanifestation) of certain qualities and all the other constructions of physics are "emergent" concerning the network of events (CHIATTI, 2014; LICATA, 2013; LICATA and CHIATTI, 2009, 2010, 2015; CHIATTI and LICATA, 2016). In virtue of the physical correspondence between opportune diminishing of the quantum vacuum energy density and opportune RS processes of creation/annihilation of particle/antiparticle pairs, the excited state of the quantum vacuum can be described by a wave function $C = \begin{pmatrix}\psi\\ \phi\end{pmatrix}$ at two components satisfying a time-symmetric extension of the Klein-Gordon quantum relativistic equation

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

where $H = \left(-\hbar^2\partial^\mu\partial_\mu + \frac{V^2}{c^2}(\Delta\rho_{qvE})^2\right)$. Equation (13) corresponds to the following two equations:

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

for creation events and

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

for destruction events. The RS processes of creation and annihilation of virtual particles turn out to be choreographed by a quantum potential of the vacuum, generating the fundamental non-local features of the vacuum, given by relation

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

In this picture, ordinary matter represented by the material particles of the Standard Model emerges as the result of opportune diminutions of the quantum vacuum energy density corresponding to opportune elementary RS processes of creation/annihilation of virtual particles with mass satisfying equation

$$mc^2 = n'\frac{\hbar c^2}{V^2 \vartheta_0} \tag{17}$$

inside the length scale $c\vartheta_0 \approx 10^{-13}$cm . Equation (17), where n'=0, ½, 1, 3/2, ... is an integer for odd solutions and a half-integer for even solutions, provides the condition that links the geometry of the 3D quantum vacuum characterised by virtual particle/antiparticle pairs with the quantum jumps characteristically of an elementary particle of the Standard Model described by the scale $c\vartheta_0 \approx 10^{-13}$cm and ruled by the ordinary quantum laws.

Now, in the second part of this section, we will discuss how the 3D non-local quantum vacuum where ordinary matter emerges as the result of reduction-state (RS) processes of creation/annihilation of quanta which occur in correspondence to elementary energy fluctuations, directly lead, from the cosmological point of view to the idea of a timeless universe in dynamic equilibrium. In our cosmological model of TUDE, before all, in the light of the fundamental symmetry between mass and quantum vacuum energy density, the turning key is represented by the fact that there is a symmetry between the energy of matter (associated with a diminishing of the quantum vacuum energy density) and energy of space (associated with the ground state of the quantum vacuum energy density defined by the Planck energy density (2)). Moreover, since gravity and the behaviour of material particles are directly associated with elementary fluctuations of the quantum vacuum energy density based on equations (10) and (16) which imply the action of the 3D quantum vacuum as a non-local direct medium of information, it follows that energy of matter and energy of space can be seen themselves as two aspects of the same coin. The symmetry between matter and quantum vacuum energy density, expressed by equation (5), as well as the gravitational energy density (10) and the quantum potential (16), can be considered as the fundamental entities which can provide a unifying treatment of energy of matter and energy of space leading to the concept of the timeless universe in dynamic equilibrium.

Based on the first law of thermodynamics, the total energy of the universe is always constant, namely, in each phase of the evolution the sum of the energy of matter E_m and of the energy of the empty space E_s is always constant:

$$E_m + E_s = E_k \tag{18}$$

In the light of the fundamental symmetry between matter and variations of the quantum vacuum energy density, equation (18) may be conveniently written in terms of the energy density of the 3D quantum vacuum, as:

$$\left(\rho_{PE} - \rho_{qvE}\right) + \frac{E_S}{V} = \frac{E_k}{V} \tag{19}$$

The stability of atoms and subatomic particles requires that the energy density of quantum vacuum has a certain critical value. In other words, we can say that a certain critical value of the quantum vacuum energy density exists which assures the stability of atoms and subatomic particles. Inside of Schwarzschild radius

$$r_s = \frac{2Gm}{c^2} \tag{20}$$

where G is the gravitational constant and m is the mass of a stellar object, the energy density of quantum vacuum is at its minimum which, in the light of equations (4) and (20), turns out to be expressed by relation:

$$\rho_{qvE} = \rho_{pE} - \frac{3c^8}{32\pi G^3 m^2} \tag{21}$$

In light of these considerations, by virtue of the fundamental role of the gravitational energy density (10) and the quantum potential (16) in determining a unifying treatment of energy of matter and energy of space, in our cosmological model of TUDE, we consider the possibility that the standard Friedmann equation

$$\frac{\dot{a}^2}{a^2} + \frac{c^2 k}{a^2} - \frac{\lambda}{3} = \frac{8}{3}\frac{\pi G \rho}{c^2} \tag{22}$$

where a is the scale factor of the universe, the symbol dot indicates differentiation with respect to time, ρ is the matter-energy density, λ is the cosmological constant and must be replaced by a more general equation ruling a cycling behaviour of the universe. Taking account of Siong's, Radiman's and Nikouravan's derivation of the Friedmann equation with quantum potential (SIONG *et al.*, 2014) and the fact that, in our approach, the cosmological constant is assimilated to specific fluctuations of the quantum vacuum energy density, we consider the following generalised Friedmann equations for the cyclic universe

$$\frac{\dot{a}^2}{a^2} + \frac{c^2 k}{a^2} + \frac{\rho_{grav} c^2}{3} = \frac{8}{3}\frac{\pi G}{c^2}\left(\rho_{PE} - \rho_{qvE} + \frac{Q}{a^3}\right)\left[\left(1 - \frac{\rho_{PE} - \rho_{qvE}}{\rho_{PE}}\right)\left(1 - \frac{E_S}{V\rho_{PE}}\right)\right] \tag{23}$$

where Q is the quantum potential, ρ_{grav} is the gravitational energy density (linked with the variable quantum vacuum energy density and the specific fluctuations of the energy density mimicking the effects of dark energy). Equation (23) allows us to draw the following important consequences as regards the evolution of the universe. When the energy density of the quantum vacuum reaches its minimum value (21), this means that in black holes energy density of the 3D quantum vacuum is at its minimum and under its value which is required for the stability of elementary particles. Inside Schwarzschild radius, low energy density of quantum vacuum does not provide a necessary quantum vacuum "background" for the stability of elementary particles and stability of atoms (FISCALETTI and SORLI, 2016b, 2018; SORLI *et al.*, 2016). When the quantum vacuum energy density reaches this minimum value, inside Schwarzschild radius matter transforms back into electromagnetic energy and this back into non-structured energy of quantum vacuum: in fact, based on equation (23), $\frac{\rho_{PE}-\rho_{qvE}}{\rho_{PE}}$ assumes the maximum value and thus ρ_{qvE} increases, $\rho_{PE} - \rho_{qvE}$ diminishes tending to 0, E_s increases tending to E_k, in such a way that equation (19) holds. Matter which is the structured energy of quantum vacuum is disintegrating back into the energy of the empty quantum vacuum, thus approaching to its ground state. In this phase of the evolution of the universe, we will therefore have a decrease in entropy. In this phase, as a consequence of the increased energy density of the quantum vacuum within the Schwarzschild radius, the gravitational forces between the galaxies become more intense. This process results in a decrease in the expansion rate of the universe. The decreasing of expansion will stop just when, in the active galactic nuclei, the energy of the matter has become null and the energy of space has reached its maximum value, that is when $E_m = 0$ e $E_s = E_k$ which means that the entropy has reached its minimum value (zero). In this configuration, in the intergalactic areas the quantum vacuum energy density ρ_{qvE} turns out to be maximum and so it begins to decrease, transforming itself into cosmic rays and subsequently into elementary particles. Based on equation (23), $\frac{\rho_{PE}-\rho_{qvE}}{\rho_{PE}}$ increases and, in correspondence, $\frac{E_S}{V\rho_{PE}}$ diminishes. Thus, the process of emission of fresh gas by the active galactic nuclei takes place, space is transformed into matter, that is E_s is transformed into E_m. In this phase, the quantum vacuum energy density ρ_{qvE} in the region within the Schwarzschild radius decreases. Consequently, we have the formation of nuclei, atoms, molecules, stars and planets and in correspondence the entropy increases. At this stage, the expansion of the universe also tends to increase.

Based on our cosmological model, one deals with a continuous flow of energy "matter - space – matter ..." which is in permanent dynamic equilibrium. In other words, in the light of the generalised Friedmann equation (23), a cyclic transformation "space-matter-space-matter ..." is generated, through which the universe is maintained in dynamic equilibrium, receiving a process of renewal with the continuous formation of new systems of space and matter. And as regards these processes, one can identify neither a beginning nor an end. In the singularities that characterise black holes, "old matter" is transformed into fundamental "fresh" energy of the quantum vacuum, based on a process in which energy cannot be created and cannot be destroyed. The growth of the entropy of matter that we observe in the universe does not increase the total entropy of the universe. In this regard, a crucial function is played by black holes. In fact, in the model of TUDE, black holes have the role of rejuvenating the universe, making it ageless, in the sense that they lead to processes in which old matter transforms into space which then generate elementary particles and cosmic rays and thus new fresh gas which results in the formation of new stellar objects, and so on in a cyclic way (see also SORLI, 2020). This view of black holes as the primary structures which rejuvenate the universe by leading to the creation of new systems of space and the fresh matter is supported by the fact that, according to astronomical observations (see for example KARDASHEV, 2001), supermassive black holes existing in the centre of galaxies have the role to generate elementary particles and cosmic rays. According to the TUDE model, in virtue of this crucial role of black holes, the universe is a non-created system, in which galaxies, stars and planets appear and disappear, but the universe as a whole is eternal.

The TUDE model also allows us to resolve the information-loss problem for black holes approaching the Planck scale. As is known, based on the Hawking effect predicted by quantum field theory in a curved spacetime, a stationary black hole has a temperature

$$T_{BH} = \frac{\hbar\kappa}{2\pi k_B c} \tag{24}$$

where κ is the surface gravity of a stationary black hole (HAWKING, 1975) and, as a consequence of this, it also has an entropy, the so-called "Bekenstein-Hawking entropy", which is given by the universal expression

$$S_{BH} = \frac{k_B A}{4 l_p^2} \tag{25}$$

where A is the surface of the event horizon. Many of the open questions which must be addressed in any theory of quantum gravity and cosmology are related to the temperature and the entropy of black holes (STROMINGER, 2009). In particular, 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. In fact, according to Hawking's calculation leading to (25), if when effects of quantum gravity (Planck scale) assume a role, 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, namely a state where 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 (HAWKING, 1976). Now, in the picture of the TUDE, 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 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 agree with standard quantum theory. Therefore, the TUDE cosmology allows us to resolve in a simple and elegant way also the information-loss problem (FISCALETTI, 2018).

THE FRIEDMANN-ROBERTSON-WALKER SCALE FACTOR AND PREDICTIONS IN THE MODEL OF THE CYCLIC UNIVERSE IN DYNAMIC EQUILIBRIUM

In the TUDE model here suggested, the equation of state (1) and the Friedmann-Robertson-Walker scale factor $a(t) \approx |t|^{1/\varepsilon}$ invoked by Ijjas and Steinhardt continue to be valid but are formulated in a different, more general, way and therefore can receive a new interpretation.

Since the fundamental arena of the universe is a 3D non-local quantum vacuum, the pressure p and the energy density ρ appearing in equation (1) are ultimately associated with the elementary properties of a three-dimensional (3D) quantum vacuum defined by RS processes of creation/annihilation of quanta corresponding to elementary fluctuations of the quantum vacuum energy density with respect to the ground state. As shown in (FISCALETTI, and SORLI, 2016a, 2018), in the 3D quantum vacuum the quantum processes are ruled and choreographed by a quantum potential of the vacuum of the form which, for creation events, has the expression

$$Q = V\frac{p_1 + p_2}{n} = -\frac{\hbar^2 c^2 n^2}{4\Delta\rho_{qvE}{}^2 V^2}\left[\nabla^2\Delta\rho_{qvE} - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\Delta\rho_{qvE}\right] + \frac{\hbar^2 c^2 n^2}{8\Delta\rho_{qvE}{}^3 V^2}\left[\left(\nabla\Delta\rho_{qvE}\right)^2 - \frac{1}{c^2}\left(\frac{\partial}{\partial t}\Delta\rho_{qvE}\right)^2\right] \quad (26)$$

where n is the number of virtual particles-antiparticles of the RS processes in the volume V of the 3D quantum vacuum into consideration, p_1 and p_2 are pressures that arise by the collisions between the virtual particles-antiparticles populating the vacuum and corresponding to the RS processes. Consequently, in the TUDE model, we consider that the pressure p appearing in equation (1) is ultimately generated by the quantum potential of the vacuum and thus by the changes of the quantum vacuum energy density $\Delta\rho_{qvE} = (\rho_{PE} - \rho_{qvE})$. In analogous way, the energy density ρ appearing in equation (1) may be assimilated to the quantum vacuum energy density (4).

This implies that, in our approach, equation (1) may be formulated as

$$\varepsilon_{\pm} = \frac{3}{2}\left(1 + \frac{Qn}{\rho_{qvE}V}\right) \quad (27)$$

where Q is the quantum potential (26), n is the number of virtual particles-antiparticles of the RS processes in the volume V of the 3D quantum vacuum into consideration, ρ_{qvE} is the quantum vacuum energy density given by (4). Therefore, the Friedmann-Robertson-Walker scale factor $a(t)$ has a behaviour of the form

$$a(t) \approx |t|^{\frac{2}{3\left(1+\frac{Qn}{\rho_{qvE}V}\right)}} \quad (28)$$

On the basis of equations (27) and (28), we can say that, in our model, the periods of the universe when there is a domination of radiation occur in the condition $\frac{Qn}{\rho_{qvE}V}=\frac{1}{3}$, a domination of matter occurs when $Q=0$, a domination of dark energy occurs when $\frac{Qn}{\rho_{qvE}V}=-1$, while the ekpyrotic contracting phase correspond to the condition $\frac{Qn}{\rho_{qvE}V}\gg-\frac{1}{3}$.

Equations (27) and (28) here become the fundamental laws that allow us to discriminate between the different phases of the evolution of the universe, in other words, to describe what happens in the different phases of the cyclic universe in dynamic equilibrium. When inside the Schwarzschild radius the quantum vacuum energy density goes under the minimum value required to provide stability of elementary particles, then inside the Schwarzschild radius matter transforms back into electromagnetic energy and this back into non-structured energy of quantum vacuum (namely into the energy of empty space E_s). This means that in this phase the Friedmann-Robertson-Walker scale factor $a(t)$ given by (28) tends to decrease (but very little) with respect to the phase of the transformation of space into matter (because domination of radiation occurs in the condition $\frac{Qn}{\rho_{qvE}V}=\frac{1}{3}$, while domination of matter occurs when $Q=0$). Therefore, if in Ijjas' and Steinhardt's cyclic model, in the phase of domination of radiation there is a little decreasing of $a(t)$, now this physical situation can receive a new suggestive interpretation and explanation. The decreasing of the Friedmann-Robertson-Walker scale factor $a(t)$ concerns the transformation of matter into non-structured energy of quantum vacuum which occurs in the active galactic nuclei when inside Schwarzschild radius the quantum vacuum energy density goes under the minimum value required to provide stability of elementary particles, and it is due to opportune corresponding properties of the 3D quantum vacuum, expressed by the condition $\frac{Qn}{\rho_{qvE}V}=\frac{1}{3}$ between quantum vacuum energy density and quantum potential.

Then, as a consequence of this little decreasing of $a(t)$, the evolution of the universe continues in the following way: matter disintegrates itself back into primordial non-structured energy of the quantum vacuum, which therefore tends to increase (with a corresponding decrease of the entropy). The decreasing of $a(t)$ provokes therefore also a more intense action of the gravitational forces between the galaxies. When in the active galactic nuclei the energy of the matter has become null and the energy of space has reached its maximum value, that is when $E_m=0$ and $E_s=E_k$, in this physical situation in the intergalactic areas the quantum vacuum energy density ρ_{qvE} turns out to be maximum and thus the quantum potential (26) associated with the RS processes of creation/annihilation of virtual particles/antiparticles of the 3D quantum vacuum reaches its minimum value, namely zero. Because of this, the universe enters a critical point where the Friedmann-Robertson-Walker scale factor $a(t)$ begins to grow exponentially and this is the phase of the transformation of quantum vacuum energy into cosmic rays and subsequently into elementary particles, namely into the new fresh matter. In other words, we can say that the phase of the cyclic universe represented by the formation of nuclei, atoms, molecules, stars and planets in the active galactic nuclei (with the corresponding increase of the entropy) begins when the quantum potential (26) reaches its minimum value (zero) and thus the Friedmann-Robertson-Walker scale factor $a(t)$ begins to grow exponentially.

The flow of energy "matter - space – matter-..." which takes place in the active galactic nuclei and is in permanent dynamic equilibrium, can therefore be associated with the different behaviour of the Friedmann-Robertson-Walker scale factor $a(t)$ which derives from the equation of state (27) and thus which ultimately derives from opportune more fundamental properties of the 3D quantum vacuum, namely from opportune values of the quantum vacuum energy density and of the quantum potential (26) of the 3D quantum vacuum. In other words, the cyclic transformation "space-matter-space-matter ..." may be indeed seen as a consequence of the different values of the Friedmann-Robertson-Walker scale factor $a(t)$ which emerge as solutions of the equation of state (27) in the different phases of evolution, which ultimately depend on the changes of the quantum vacuum energy density and on the quantum potential (26) of the 3D quantum vacuum. In summary, quantum vacuum energy density and quantum potential of the 3D quantum vacuum can be considered as the ultimate visiting cards whose values and variations allow us to realise what happens in the different phases of the evolution of the universe, in the context of a cyclic picture.

In our approach, the net result determined by the changes of the quantum vacuum energy density as well as the quantum potential of the 3D quantum vacuum (26) is that the Friedmann-Robertson-Walker scale factor $a(t)$ grows from cycle to cycle and thus that the universe can be seen as a timeless phenomenon in dynamic equilibrium where each cycle of evolution leads to the creation of new systems of space and matter which have no end. In the TUDE model, as a consequence of the processes above described, also the Hubble parameter $H(t)$ has a cyclic behaviour.

In order to show the coherence of the prediction of the TUDE model with the current values of astronomical parameters, we can consider here the following illustrative example which satisfies the known quantitative constraints. The minimum value of the Hubble radius r_H is fixed as $\sim 10^{-25} cm$, corresponding to a maximum value of the Hubble parameter of $|H| \sim 10^{10} GeV$. Then, we assume that the temperature is $T \sim 10^{15} GeV$ at the start of the process of transformation of space into the matter. Because of these assumptions, the fundamental equations (19), (27) and (28) of the TUDE model imply that the scale factor $a(t)$ increases by a factor $e^{120/\varepsilon_+} \sim e^{60}$ by the time the temperature reaches today's cosmic microwave background temperature. In correspondence, one deals with an increase of the Hubble radius by a factor of $a^{\varepsilon_+} \sim e^{120}$ from a microscopic size of $10^{-25}\ cm$ to the current value of the Hubble radius $10^{28}\ cm$.

If the present epoch is characterised by domination of dark energy, however, the TUDE model implies that, in a cyclic universe, the dark energy-dominated phase cannot last forever but must eventually terminate. In our theory, as we have said before, dark energy is nothing other than a special aspect of the 3D quantum vacuum fluctuations associated with opportune quantum vacuum energy density fluctuations. In particular, based on the results obtained in (FISCALETTI, and SORLI, 2014, 2016b; FISCALETTI, 2018), the dark energy density is given by the equation

$$\rho_{DE} \cong \frac{35Gc^2}{2\pi\hbar^4 V}\left(\frac{V}{c^2}\Delta\rho_{qvE}^{DE}\right)^6 \tag{9}$$

The dark energy density ρ_{DE} can be associated with opportune fluctuations $\Delta\rho_{qvE}^{DE}$ of the 3D quantum vacuum energy density defined by relation

$$\Delta\rho^{DE}{}_{qvE} = \frac{m_{DE} \cdot c^2}{V} \tag{29}$$

m_{DE} being the mass corresponding to the dark energy ρ_{DE} in the volume V and thus

$$\rho_{DE} = \frac{\Delta\rho_{qvE}^{DE}}{c^2} \tag{30}$$

On the other hand, the idea that dark energy represents peculiar energy of the excited state of the quantum state of the universe is supported by current research (see, for example, FEOLI *et al.*, 2017). In our theory, the dark energy density (9) is the appropriate energy of specific excited states of the 3D quantum vacuum in the sense that may be associated with a scalar field potential of the 3D quantum vacuum $V(\Delta\rho_{qvE}^{DE})$. During the radiation- and matter-dominated phases, $\Delta\rho_{qvE}^{DE}$ satisfies the condition $V\left(\Delta\rho_{qvE}^{DE}\right) > 0$. As a consequence of opportune quantum vacuum energy density fluctuations, the accelerated expansion phase ends and contraction begins when $\Delta\rho_{qvE}^{DE}$ changes from $V\left(\Delta\rho_{qvE}^{DE}\right) > 0$ to $V\left(\Delta\rho_{qvE}^{DE}\right) < 0$. In this situation, the quantum vacuum energy density fluctuations become a sort of ekpyrotic field that rules the following phase of ultraslow contraction (similar to the one invoked by Ijjas' and Steinhardt's model).

It must be underlined here that the scalar field potential $V\left(\Delta\rho_{qvE}^{DE}\right)$ of the fluctuations of the quantum vacuum energy density which generates the action of dark energy, is important in the TUDE because it determines the time when the domination of dark energy begins and it fixes the characteristic time scale for the duration of the expanding phase, the contracting phase as well as the total period of a cycle. Moreover, taking account of Ijjas' and Steinhardt's results, the quantum vacuum energy density fluctuations and the scalar field potential $V\left(\Delta\rho_{qvE}^{DE}\right)$, associated with the action of the dark energy, satisfy the following equation-of-state

$$\varepsilon_{-} = 3 \cdot \frac{\frac{1}{2}\Delta\dot{\rho}_{qvE}^{DE}}{\frac{1}{2}\Delta\dot{\rho}_{qvE}^{DE} + V\left(\Delta\rho_{qvE}^{DE}\right)} \tag{31}$$

Equation (31) leads to important consequences as regards the physical processes occurring during the contraction phase, which occurs when in the active galactic nuclei there is a transformation of matter into non-structured energy of the quantum vacuum, into the energy of empty space. Before all, it implies that, if one considers the potential $V = -V_0 e^{\Delta\rho_{qvE}^{DE}/M}$ (where $V_0 > 0$ is constant and we utilize reduced Planck units $8\pi G_N = 1$ for Newton's gravitational constant G_N), the solution for ε_{-} in the contracting phase is nearly constant about the expression $\varepsilon_{-} = 1/2M^2$ and therefore reaches big values even for short masses. Moreover, the contraction phase turns out to be characterised by a shrinking of the scale factor $a(t)$ and an even bigger shrinking of the Hubble parameter $H(t)$. In the light of equation (31), the homogeneous ekpyrotic field energy (which is associated with a value $\varepsilon_{-} \gg 1$) grows much faster, during the contracting phase, than all other components (matter, radiation, dark energy, gradient energy, spatial curvature, anisotropy). As a consequence of this peculiar behaviour, the universe is guided towards an ultra-uniform, ultra-flat state as the end of a cycle is approached and the beginning of a new cycle occurs. In these processes, the crucial fact is that the opportune fluctuations of the quantum vacuum energy density are the fundamental physical entities that determine the large value of ε_{-} and, in correspondence, the smoothing and flattening effect in space.

Our model – based on equations (18)-(23) and (26)-(31) – predicts that each cycle of transformation "matter-space-..." ends with a non-singular bounce, where the value of the Hubble parameter $H(t)$ and of the density of matter and radiation have returned to the values they had a cycle ago and therefore a new period of oscillation in $H(t)$ begins. Compatibly with Ijias' and Steinhardt's approach, our model predicts that the large energy density generated in the ekpyrotic scalar field is transformed into new fresh matter and radiation providing results that are coherent to that assumed in inflationary approaches.

In summary, we can say that the essential feature of the TUDE model is that it predicts that the evolution of the universe through all phases is dominantly associated with opportune elementary properties of the 3D quantum vacuum, in particular with opportune values and variations of the quantum vacuum energy density and of the quantum potential of the vacuum. The appealing aspect of the TUDE model is that here one deals with a natural sequence of different phases, in a cyclic picture, determined by the continuous opportune variations of the quantum vacuum energy density, which indeed can be considered as the real forces which guide the cosmological evolution. Here there is no need to invoke the idea of the big bang, no need to specific ad hoc initial conditions and no need to consider runaways that lead to the multiverse. In this approach, all properties of the universe are deterministically fixed by opportune properties of the energy density of the 3D quantum vacuum. Moreover, the TUDE model allows us to face the causal horizon problem by replacing the big bang with the cycles of transformations space-matter-space-matter which occur in the active galactic nuclei in correspondence to the opportune variations of the quantum vacuum energy density. The homogeneity, isotropy and flatness problems are resolved by invoking ultra-slow contraction in the phase of the transformation of matter into non-structured energy of quantum vacuum, where the Hubble parameter $H(t)$ shrinks a lot while the Friedmann-Robertson-Walker scale factor $a(t)$ shrinks comparatively less. The idea of dynamic equilibrium can be considered a solution to the cosmic singularity problem.

CONCLUSIONS AND PERSPECTIVES

Some of the current cosmology models existing in the literature, in particular those by Steinhardt, consider the idea of a cyclic universe, in which the universe undergoes an endless sequence of cosmic epochs which begin with the universe expanding from a 'big bang' and end with the universe contracting to a 'big crunch', on the basis of the concept of ekpyrotic scenario and M-theory. The model of the cyclic universe in dynamic equilibrium introduced in this paper throws new light on the interpretation of several important properties of the universe. In the light of the treatment made in this paper, the suggestive perspective is opened that the different stages of the evolution of the universe are related to the continuous variations of the energy density and of the quantum potential of a 3D non-local quantum vacuum defined by elementary RS processes of creation/annihilation of quanta. The changes in the quantum vacuum energy density and the corresponding changes in the quantum potential of the vacuum produce a cyclic flow of energy "matter-space-matter-space-..." which is in permanent dynamic equilibrium. The model of the cyclic universe in dynamic equilibrium allows us to provide a new re-reading, inside a more general picture, of the equations of the Ijjas' and Steinhardt's cyclic model developed in (IJJAS and STEINHARDT, 2019). Moreover, it has the merit to resolve some problems of the Standard Cosmological Model, because it does not present the initial cosmic singularity, it resolves the causal horizon problem, the homogeneity, isotropy and flatness problems.

On the other hand, in order to provide future developments and improvements of this new cyclic model, important topics must be faced: the search for the link of this approach with aspects of fundamental physics, the explanation of why the quantitative conditions here introduced are possible and are likely to occur as well as the analysis of the links with other current cosmological approaches (alternative to inflation) such as the archaic universe based on de Sitter projective relativity and an event-based reading of quantum mechanics, developed by Chiatti and Licata (LICATA and CHIATTI, 2009, 2010; CHIATTI, 2011; LICATA, 2006), or the model of the cyclic entropy developed by FRAMPTON (2015, 2018), where the universe is a cyclic phenomenon whose entropy is reset to zero in each cycle expansion-turnaround-contraction-bounce-etc…. In this regard, further research will give you more information.

References:

[1] Chiatti, L. (2011): De Sitter relativity and cosmological principle. *Total Open Access Astronomy Journal* **4**: 27–37. doi: 10.2174/1874381101104010027

[2] Chiatti, L. (2014): The transaction as a quantum concept. *In* Licata, I. (ed) *Space-time geometry and quantum events* (Nova Science Publishers, New York), 11–44; e-print arXiv.org/pdf/1204.6636 (2012).

[3] Chiatti, L., Licata, I. (2016): Particle model from quantum foundations. *Quantum Studies: Mathematics and Foundations* **4**: 181–204. doi: 10.1007/s40509-016-0094-6

[4] Fedi, M. (2017a): Hydrodynamics of the dark superfluid: I. Genesis of fundamental particles. HAL-archives, CCSD, France, https://hal.archives-ouvertes.fr/hal-01549082

[5] Fedi, M. (2017b): *Hydrodynamics of the dark superfluid: II. photon-phonon analogy*. HAL-archives, CCSD, France. https://hal.archivesouvertes.fr/hal-01532718

[6] Fedi, M. (2017c): *A Superfluid Theory of Everything?* HALarchives, CCSD, France. https://hal.archives-ouvertes.fr/hal01312579

[7] Feoli, A., Benedetto, E., Capriolo, M., Feleppa, F. (2017): Is dark energy due to an excited quantum state of the universe? *The European Physical Journal Plus* **132** (5): 211, 7 pp. doi: 10.1140/epjp/i2017-11478-8

[8] Fiscaletti, D. (2015): *The timeless approach. Frontier perspectives in 21st century physics*, World Scientific, Singapore.

[9] Fiscaletti, D. (2018): Towards a non-local timeless cosmology for the beyond Standard Model physics. *Bulgarian Journal of Physics* **45** (4): 334–356.

[10] Fiscaletti, D., Sorli, A. (2014): Space-time curvature of general relativity and energy density of a three-dimensional quantum vacuum. *Annales UMCS Sectio AAA: Physica* **LXIX**: 53–78. doi: 10.1515/physica-2015-0004

[11] Fiscaletti, D., Sorli, A. (2016a): About a three-dimensional quantum vacuum as the ultimate origin of gravity, electromagnetic field, dark energy … and quantum behaveour. *Ukrainian Journal of Physics* **61** (5): 413–431. doi: 10.15407/ujpe61.05.0413

[12] Fiscaletti, D., Sorli, A. (2016b): Dynamic quantum vacuum and relativity. *Annales UMCS Sectio AAA: Physica* **LXXI**: 11–52. doi: 10.17951/aaa.2016.71.11

[13] Fiscaletti, D., Sorli, A. (2017): Quantum vacuum energy density and unifying perspectives between gravity and quantum behaviour of matter. *Annales de la Fondation Louis de Broglie* **42** (2): 251–297.

[14] Fiscaletti, D., Sorli, A. (2018): Quantum relativity: variable energy density of quantum vacuum as the origin of mass, gravity and the quantum behaviour. *Ukrainian Journal of Physics* **63** (7): 623–644. doi: 10.15407/ujpe63.7.623

[15] Frampton, P.H. (2015): Cyclic entropy: an alternative to inflationary cosmology. *International Journal of Modern Physics* A **30** (21): 1550129-125. doi: 10.1142/S0217751X15501298

[16] Frampton, P.H. (2018): Holographic entanglement entropy and cyclic cosmology. *Physics of the Dark Universe* **20**: 28. doi: 10.1016/j.dark.2018.02.003

[17] FRIEDMANN, A. (1922): Über die Krümmung des Raumes. *Zeitschrift für Physik* **10**: 377-386; English translation: On the curvature of space. *General Relativity and Gravitation* **31** (12): 1991–2000 (1999). doi: 10.1007/BF01332580

[18] GAMOW, G. (1948a): The Origin of Elements and the Separation of Galaxies. *Physical Review* **74**: 505–506. doi: 10.1103/PhysRev.74.505.2

[19] GAMOW, G. (1948b): The Evolution of the Universe. *Nature* **162**: 680–682. doi: 10.1038 /162680a0

[20] GUTH, A.H. (1981): Inflationary universe: a possible solution to the horizon and flatness problem. *Physical Review D* **23**: 347–356. doi: 10.1103/PhysRevD.23.347

[21] HAWKING, S.W. (1975): Particle creation by black holes. *Communications in Mathematical Physics* **43** (3): 199–220; Erratum ibid, **46**, 206 (1976). doi: 10.1007/BF0 2345020

[22] HAWKING, S.W. (1976): Breakdown of predictability in gravitational collapse. *Physical Review D* **14** (10): 2460–2473. doi: 10.1103/PhysRevD.14.2460

[23] IJJAS, A., STEINHARDT, P.J. (2019): A new kind of cyclic universe. *Physics Letters B* **795**: 666–672. doi: 10.1016/j.physletb.2019.06.056

[24] KARDASHEV, N.S. (2001): *MNRAS* **326** (3): 1122–1126. doi: 10.1046/j.1365-8711.2001. 04643.x

[25] LEMAÎTRE, G. (1931): The expanding universe. *M.N.R.A.S.* **41**: 490–501. doi: 10.1093/ mnras/91.5.490

[26] LEMAÎTRE, G. (1934): Evolution of the expanding universe. *Proc. Nat. Acad. Sci.* **20** (1): 12–17. doi: 10.1073/pnas.20.1.12

[27] LEMAÎTRE, G. (1950): *The primeval atom: An essay on cosmogony*, Van Nostrand Company.

[28] LINDE, A.D. (1982): A new inflationary universe scenario: a possible solution of the horizon, flatness, homogeneity, isotropy and primordial monopole problems. *Physics Letters B* **108** (6): 389–393. doi: 10.1016/0370-2693(82)91219-9

[29] LICATA, I. (2006): Universe without singularities. A group approach to de Sitter cosmology. *Electronic Journal of Theoretical Physics* **3** (10): 211–224.

[30] LICATA, I. (2013): Transaction and non-locality in quantum field theory. *European Physical Journal Web of Conferences* **70**: 00039. doi: 10.1051/epjconf/20147000039

[31] LICATA, I., CHIATTI, L. (2009): The archaic universe: big bang, cosmological term and the quantum origin of time in projective cosmology. *International Journal of Theoretical Physics* **48** (4): 1003–1018. doi: 10.1007/s10773-008-9874-z

[32] LICATA, I., CHIATTI, L. (2010): Archaic universe and cosmological model: "big-bang" as nucleation by vacuum. *International Journal of Theoretical Physics* **49** (10): 2379–2402. doi: 10.1007/s10773-010-0424-0

[33] LICATA, I., CHIATTI, L. (2015): Timeless approach to quantum jumps. *Quanta* **4**: 10–26. doi: 10.12743/quanta.v4i1.31

[34] NETCHITAILO, V.S. (2021): *Paradigm shift in cosmology*. 22 pp. https://vixra.org/pdf/2107.0020v2.pdf – Accessed 21 June 2022.

[35] SBITNEV, V. (2015a): *Navier-Stokes equation describes the movement of a special superfluid medium*. arXiv:1504.07497v1 [quant-ph].

[36] SBITNEV, V. (2015b): Physical vacuum is a special superfluid medium. *In:* Pahlavani, M.R. (ed) *Selected Topics in Applications of Quantum Mechanics*. (InTech, Rijeka), pp. 345–373.

[37] SBITNEV, V. (2015c): Hydrodynamics of the physical vacuum: dark matter is an illusion. *Modern Physics Letters A* **30** (35): 1550184.
doi: 10.1142/S0217732315501849

[38] SBITNEV, V. (2016): Hydrodynamics of the physical vacuum: I. Scalar quantum sector. *Foundations of Physics* **46** (5): 606-619. doi: 10.1007/s10701-015-9980-8

[39] SIONG, C.H., RADIMAN, S., NIKOURAVAN, B. (2014): Friedmann equation with quantum potential. *A.I.P. Conference Proceedings* **1571**: 35–41. doi: 10.1063/1.4858626

[40] SORLI, A., KOROLI, V., NISTREANU, A., FISCALETTI, D. (2016): Cosmology of Einstein's NOW. *American Journal of Modern Physics* **5** (4–1): 1–5.

[41] SORLI, A.S. (2020): Black holes are rejuvenating systems of the universe. *Journal of Advances in Physics* **17**: 23–31. doi: 10.24297/jap.v17i

[42] STEINHARDT, P.J., TUROK, N. (2002a): A cyclic model of the universe. *Science* **296** (5572): 1436–1439. doi: 10.1126/science.1070462

[43] STEINHARDT, P.J., TUROK, N. (2002b): Cosmic evolution in cyclic universe. *Physical Review D* **65**: 126003. doi: 10.1103/PhysRevD.65.126003

[44] STROMINGER, A. (2009): Five problems in quantum gravity. *Nuclear Physics B* **192-193**: 119–125. doi: 10.1016/j.nuclphysbps.2007.07.049

[45] TOLMAN, R.C. (1934): *Relativity, thermodynamics and cosmology*, Oxford University Press.

[46] TOLMAN, R.C., WARD, M. (1932): On the behavior of non-static models of the universe when the cosmological term is omitted. *Physical Review* **39**: 835–843.
doi: 10.1103/PhysRev.39.835

[47] TUROK, N., STEINHARDT, P.J. (2004): Beyond inflation: a cyclic universe scenario. *Talk given at the Nobel Symposium 'String Theory and Cosmology', Sigtuna, August 14–19 2003*. doi: 10.48550/arXiv:hep-th/0403020v1