A universe from nothing or big bounce?

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Abstract : The beginning of the universe is explained by many theoretical aspects. The cosmological evolution begins with the singularity. Such singularities predict the initial conditions of the universe. To deal the singularity there are lots of mathematical models have been proposed. In particular universe from nothing model, that deals the beginning of the universe as nonsingular and initiated out of nothing scenario. Similarly loop quantum cosmology resolves the initial singularity with quantum geometry. That resolution replaces the big bang with big bounce. Initial conditions of the universe in vacuum dominated states and loop quantum cosmological bouncing solutions is analyzed in this work. Minimal scale factor and critical density is analyzed to scrutinize the formation of universe from nothing. It is been interpreted that the universe from vacuum solutions replicate the dark energy dominated final stages of the universe , which leads to cyclic cosmology

***Index Terms* - Universe from nothing, Loop quantum cosmology, Quantum gravity, Cosmological singularities, Big bang , Scale factor**

I. INTRODUCTION

The beginning of the universe and initial stages of the universe is a long standing problem for mathematical and physical theories. There are numerous theoretical models has been carried out to analyze and scrutinize the initial conditions of the universe. The initial conditions of the universe suffers with classical singularities, where energy density, curvature and pressure diverges. The classical singularities also face geodesic divergence. The universe has begin with such singularities. Many mathematical models have been proposed to explore the singularity, and state of the universe just before, at and after singularities. Cosmological models like big bang model[1], Ekpyrotic model [2], string model[3], cycle model[4] and quantum cosmological scenarios [5] were introduced to study the initial stages of the universe. Among these models the universe from quantum vacuum [16] [18], is a quiet important model which suggests the universe has been created spontaneously from nothing. Loop quantum cosmological approach solves many cosmological problems. The loop quantum cosmology implements loop quantum gravitational formalism. The loop quantum cosmology resolves the classical singularities. At classical singularity the universe will bounce back as an extension of conformal cyclic cosmology. Such resolution quantum mechanically solves the singularity and explains the discreteness of the space at Planck scales. As from cyclic cosmology the universe evolves like cycles. Such as end of a universe cycle will be the initial state of the future cycle of the universe. The final stages of the universe will also face singularities. But the vacuum models propose that the universe will be initiated out of quantum vacuum. The equation of state parameter determines the character of the constituents of the universe. The matter has $\omega < \frac{-1}{3}$. In the accelerated universe and dark energy has ω=−1. The cosmological constant is smaller than the value that is expected for that quantum gravitational calculations. Even though the technical conflicts between the theory and experiment the term is added in the Einstein field equations. In this work we discuss about the solutions of universe from nothing, dark energy dominated universe scenarios and resolution of singularity using loop quantum cosmology. In section II we discuss about quantum vacuum and dark energy. In section III we discuss about the singularity resolution in loop quantum cosmology. In later section formation of universe from quantum vacuum is discussed. The paper concludes with formation of universe out of quantum vacuum.

II QUANTUM VACUUM ENERGY

Dark energy is the mysterious component of the universe. The dark energy is referred as component for accelerated expansion of the universe. The dark energy is initially found from Einstein cosmological model. In Einstein’s field equations the cosmological constant was included in order to explain the expansion of the universe. the model previously set up with steady state universe. Such as

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} = \frac{8\pi G}{c^2}T_{\mu\nu} \tag{1}$$

Where $R_{\mu\nu}$ curvature tensor , *R* Ricci scalar, $T_{\mu\nu}$ stress energy tensor. The equation balances as the gravity is manifestation of spacetime. But this equation could not explain the expansion of the universe. Then Einstein included the cosmological constant term in his field equations [7]. This term contains time independent homogeneous matter density ρ_m and positive constant curvature. The cosmological constant Λ is often referred as energy density of vacuum. The dark energy is translated as vacuum energy. It has been theoretically approached as the cosmological constant [17]. The cosmological constant has the magnitude of

$$\Lambda\frac{G\hbar^3}{c^3} \sim 10^{-123} \tag{2}$$

From Einstein's field equations

$$R_i^k - \frac{1}{2}\delta_k^i R - \delta_k^i \Lambda = 8\pi G T_k^i \tag{3}$$

even in the absence of matter $T_k^i = 0$. Then

$$R_i^k - \frac{1}{2}\delta_k^i R - \delta_k^i \Lambda = 0 \tag{4}$$

The solution does not admit the flat space time as a solution. The quantum vacuum is related to the Casimir force. The Casimir force is the force between two material plates. The force is attractive and independent of materials [19].

$$F = \hbar c \frac{\pi^2}{240}\frac{1}{a^4} \tag{5}$$

$$\frac{\delta E}{L^2} = \frac{-\hbar c \pi^2}{720}\frac{1}{a^3} \tag{6}$$

The dark matter and dark energy are the dominant constituents of the universe. They occupy 95−96% of the energy content of the universe. Remaining of the universe itself contains Baryonic matter. Thus universe is dominated by dark matter and dark energy [25]. The total energy density of dark energy will be $\Omega_{DE} \sim 0.70$. The cosmological constant is referred as vacuum energy. The energy density of vacuum and pressure is related as

$$\rho_\Lambda = \frac{-p_\Lambda}{c^2} = \frac{\Lambda c^2}{8\pi G} \tag{7}$$

The order of cosmological constant is $\Lambda \sim 3x10^{-56} cm^{-2}$. The compact stellar objects are modified by the cosmological constant. The dark energy has the equations of state parameter as ω=−1 . Where $\omega = \frac{p}{\rho}$. Without the presence of dark energy the extra electric universe will not have any special scenarios rather than the darkness. As the galaxies are bounded by the gravitational potential they will not be ripped off by the late time evolution of the universe. these structures will be safe for the equation of state parameter $-1 \leq \omega \leq \frac{-1}{3}$. [28]. The universe will be ripped off ∼22*Gyr* from current time [27]. In such, scenarios the galactic clusters, galaxies, planets of solar system, atoms and even the atomic nuclei will be ripped off. The phantom energy increases over time. Hence any gravitation system will be ripped off. This is the significance of dark energy dominated feature stages of the universe. The vacuum energy will be dominated in the future evolution states of the universe. The quantum vacuum energy of Desitter space remain unperturbed even in the expansion of the universe. The early universe in quantum vacuum constant of nonlinear inflation [8][9]. The quantum vacuum fluctuations leave the imprints of matter distribution while inflation stops. The expanding universe will not disturb the quantum vacuum and that will be a consequence for creation of particles.

III LOOP QUANTUM COSMOLOGY

Loop quantum cosmology implements the solutions of loop quantum gravity, where the spacetime metric is attempted to quantize to harvest the quantum gravitational theory. Quantum cosmology results the Big bang singularity at the quantum level [26]. The spacetime and metric is

$$ds^2 = -dt^2 + a(t)^2 \mathring{q}_{ab} dx^a dx^b \tag{8}$$

The holonomies of symmetry reduce the connection along edge e_k^a will be

$$h_k^\mu = cos\left(\frac{\mu c}{2}\right) I + 2sin\left(\frac{\mu c}{2}\right) T_k \tag{9}$$

With μ - fiducial length *I* - 2*x*2 unitary matrix ,$T_k = -i\frac{\sigma_k}{2}$, and σ_k Pauli matrices. Hubble rate from modified Friedmann equation will be

$$H^2 = \frac{8\pi G\rho}{3}(1 - \frac{\rho}{\rho_{max}}) \tag{10}$$

with

$$\rho_{max} = \frac{3}{8\pi G\gamma^2\lambda^2} \tag{11}$$

where γ - Barbero Immirzi parameter λ area parameter.
Then the modified Raychaudhuri equation will be

$$\frac{\ddot{a}}{a} = -\frac{4\pi G\rho}{3}(1-\rho\frac{\rho}{\rho_{max}}) - 4\pi G\rho(1-\rho\frac{\rho}{\rho_{max}}) \tag{12}$$

where $\rho_{max} \sim 0.41\rho_{pl}$

. The universe will bounce off when energy density approached to ρ_{max}. The loop quantum cosmology is mathematically consistent theory [32] [33]. The effective Hamiltonian in loop quantum cosmology will be

$$\mathcal{H}_{eff} = \frac{-3}{8\pi G\gamma^2}\frac{sin^2(\lambda\beta)}{\lambda^2}V + \mathcal{H}_{matt} \tag{13}$$

The quantum dynamics are described by effective Hamiltonian. the minimal area eigenvalue operator of loop quantum cosmology is determined by λ. The difference of quantum geometry is provided by the parameter λ [34]. This has been denoted as

$$\lambda = 2(\sqrt{3}\pi\gamma)^{\frac{1}{2}} l_{pl} \tag{14}$$

where γ - Barbero Immirizi parameter has the values as γ=0.2308 . Interesting features of low quantum cosmology can be found in [30] [31].

IV UNIVERSE FROM NOTHING

The initial stages of the universe is considered as quantum vacuum. Quantum tunneling is a key to understanding the creation of the universe from nothing. The quantum tunneling let the universe be created from nothing into a Desitter space [12]. The model does not require big bang singularity for the formation of the universe. Any initial boundary conditions also does not required for such scenarios. The Higgs potential approaches to the absolute minimum stage φ=ξ , then the Coleman potential is free from curvatures for small values of φ. (φ<<ξ) .The quantum universe will grow until it reaches the minimum value ξ. During this dynamical process of the universe has greater roll over time τ over expansion from H^{-1}. The universe looks homogeneous isotropic and flat at large scales. To explain such behaviors the inflation models have been proposed [8].The inflation scenarios stipulated the solutions for problems of big bang. For such consequences the parameters to be at the magnitude of

$$exp(H\tau) \geq 10^{+28} \tag{15}$$

As from quantum electrodynamics the quantum vacuum produce virtual particles spontaneously. , and γ are created and annihilated from quantum vacuum fluctuations. The earlier quantum universe also stands in same scenario. Quantum tunnelling ascertains the initial radius of the universe. The initial radius is determined by the energy density of the vacuum.

$$R = c\left(\frac{3}{8\pi G\rho_v}\right) \tag{16}$$

No consequences are required to form the universe to be emerged out of nothing. It happens as like a radioactive decay. The radioactive decay is a random process. Such a way that the probability of universe emerging out of nothing is also exists [10]. Even at vacuum like solutions the fundamental physics remain unperturbed. The universe conserves all quantities at beginning as it appears from nothing [11]. At the scenarios the discrete quantities such as Lepton number, Baryon number, electric charge, strangeness etc., are conserved. The universe starts from matter antimatter symmetry. The net energy is also constant at this stage. Owing to the universe has enormous amount of mass energy, it creates universe out of nothing. The universe may be originated as closed universe at early stages of the universe. The vacuum universe consists critical energy density as

$$E_g \sim \frac{-mc^2}{2} \tag{17}$$

The gravitational energy is nullified by the existence of cosmological constant, that cancels out the positive mass energy density. Than the universe appears with zero net energy density as the universe has zero net values of all conserved qualities. It might have appeared as vacuum without valuations of any conservation laws. From the inflation scenarios it has been shown the scale factor growth is proportional to

$$a(t) \propto exp[H\tau] \tag{18}$$

At the Higgs potential when φ become ξ the universe is thermalised by vacuum energy and it enters radiation dominated initial conditions. These density fluctuations are generated by the vacuum strings [13]. The temperature of the earlier universes cooled down to $\sim 10^{14} GeV$ to attain the critical density values. the RW metric is

$$ds^2 = dt^2 - a^2(t)[\frac{dr^2}{(1-r^2)} + r^2 d\Omega^2] \tag{19}$$

The solutions of their radius will be

$$a^2 H = \frac{8\pi G}{3}\rho_v a^2 \tag{20}$$

$$a(t) = H^{-1} cosh(Ht) \tag{21}$$

with

$$H^{-1} = (\frac{8\pi G}{3}\rho_v)^{\frac{1}{2}} \tag{22}$$

As from the cyclic cosmology [14] the universe contracts in the region $t<0$ attains minimum at $t=0$ and expands at $t>0$. Where

$$a_{min} = H^{-1} \tag{23}$$

The universe emerges out of quantum vacuum as the consequences of quantum tunnelling. The quantum tunnelling is analyzed even as semi classical behavior[15]. Equations 19,21 refers Desitter instanton.

V DISCUSSION

The tunneling of the universe from nothing exhibits a tunneling probability as $\exp(\frac{-3}{8}G^2\rho_v)$, with ρ_v vacuum density. The vacuum energy thermal thermalises the universe. Hence the universe is heated up with temperatures of order

$$T \sim \rho_v^{\frac{1}{4}} \tag{24}$$

Such model avoids the big bang like initial conditions. Also this models does not require any initial boundary conditions. For cyclic scenarios the wave functions of the universe from nothing will be

$$\psi(g,\phi) = \int [dg_{\mu\nu} d\phi exp(is(g_{\mu\nu},\phi))] \tag{25}$$

Such a wave functions are satisfied by Wheeler Dewitt equation.

Thus at Planck scales the universe will tunnel out of nothing. For the universe to be created from nothing the quantum potential plays a key role as a cosmological constant, that energize the exponential expansion [18]. The Wheeler Dewitt equation can be written [21], [23] as

$$(\frac{1}{a^p}\frac{\partial}{\partial a} - ka^2)\psi(a) = 0 \tag{26}$$

Where $k=0,-1,+1$ for spatially flat, open and close bubbles respectively. The quantum trajectory can be obtained from the Wheeler Dewitt equation [22], [24].

$$\frac{\partial a}{\partial \dot{a}} = -a\dot{a} = \frac{\partial s}{\partial a} \tag{27}$$

$$\dot{a} = -\frac{1}{a}\frac{\partial s}{\partial a} \tag{28}$$

For the values $p=-2 or 4$ in equation 26 the universe will expand exponentially, once the metastable vacuum is created. In loop quantum cosmology in the universe bounces at minimum radius $a \sim a_{min}$. The LQC suggest that the cyclic universe will bounce at the critical density $\rho \rightarrow \rho cric$. Where $\rho cric \sim 0.41 \rho pl$. From equations 23 it has been found that at minimum radii the universe will have the energy density as $\rho cric$.

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6 CONCLUSION

With the presence of cosmological constant the Poincare relativity is replaced by Desitter relativity. At final stages of the cyclic cosmology the universe will remain with the empty space and dark energy. The dark energy will not disintegrate over time. The loop quantum cosmology suggests that the universe behaves without singularity, as the big bang model suggests. The universe avoids any classical singularities at the beginning. At *t*=0 the universe appears to be nothing and it bounce back another evolution cycles. From modified Friedmann equations it has been analyzed that

$$H^2 = \frac{8\pi G\rho}{3}(1 - \frac{\rho}{\rho_{crit}}) \tag{29}$$

at $\rho \to \rho_c$ the universe bounce back to future evolutions. The classical singularity is resolved using loop quantum cosmology. It suggests that at the quantum level the gravity behaves as repulsive instead of attractive. This repulsion is due to quantum nature of the spacetime. Loop quantum cosmology renormalizes the cosmological constant as

$$\Lambda' = \Lambda\left(1 - \frac{\Lambda}{8\pi G\rho_{crit}}\right) \tag{30}$$

The FRW equation is modified with this resolution as

$$H^2 = \frac{\Lambda'}{3} \tag{31}$$

$$\frac{\ddot{a}}{a} = \frac{\Lambda'}{3} \tag{32}$$

In classical universe the cosmological constant is proposed for repulsive gravitational behavior. The quantum nature of gravity at earlier times of the universe behaves like a cosmological constant. The loop quantum cosmology replaces the big bang as big bounce. The energy density of vacuum is more dominant form of the universe. The vacuum energy adds phase transition for the universe. From the initial stage there is also possibility for quantum multiverses. The quantum vacuum consists virtual gravitational dipoles. The quantum vacuum is considered as a new state of matter energy composed of short living particles anti particles. Thus it is known that the universe is created out of quantum vacuum.

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