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The Interactions between Universes and its Effect on the Cosmological Constant in a Multiverse with Regularized Big Bangs

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Abstract:

The total universe is made up of many universes like our own. These different universes can interact in many different ways. These collisions are essential for the development of each of the many universes. Because of this interaction, a process is started so that the landscape structure where the universes develop leads us to different practical values of the cosmological constant. So then, quantum tunneling plays a vital role in the rise of the new areas created by the Universal interacts. This leads to the values of their vacuum state. The interacting universes and the new areas that they create depend on just small regions of Spacetime. The quantum effects are significant only in this Spacetime. These new areas that develop help to develop different areas of a continuous process.

Keywords: Many Universes, Cosmological Constant, and Quantum Tunneling.

The total universe is made up of many universes like our own. These different universes can interact in many different ways. These collisions are essential for the development of each of the many universes. Because of this interaction, a process is started so that the landscape structure where the universes develop leads us to different practical values of the cosmological constant. So then, quantum tunneling plays an essential role in the rise of the new areas created by the Universal interacts. This leads to the values of their vacuum state. The interacting universes and the new areas that they create depend on just small regions of Spacetime. The quantum effects are significant only in this Spacetime. These new areas that develop help to develop different areas of a continuous process. In this paper, we shall be studying the process of vacuum decay in the context of interacting universes that exist in the Multiverse. The interacting Multiverse entails a new and deeper structure for all the universes that make up the total Multiverse. More than two universes can interact with each other. The area that is affected can be small or large. We shall use the Wheeler-DeWitt equation for the wave function of Spacetime. For many cases of interest, Spacetime can be described by a homogeneous and isotropic geometry. Using a homogeneous and isotropic geometry, we can define the spatial section volumes scale as $z^3(t)$. Then scale factor z(t) is a function of cosmic time t of a given universe within the Multiverse. The wave function of each of the universes within the Multiverse simplifies. The process lets the values of the scale factor and the matter fields become a set of scalar fields. If this is the case, then these scalar fields can be considered a field that propagates in the space spanned by the variables {z, $^{\varsigma}$ t}. Interactions and collective behavior occur among the many universes that exist in the Multiverse. In quantum theory, physical elements are connected to their environments. If one considers the state of the particle, then this means every interaction entangles each of the many universes. Spacetime says that every state in the many universes exists in the total universe that makes up the Multiverse from a quantum perspective. Also, the Multiverse has regularized big bangs. In each of the many individual universes, many constants have different values. Each time the scale factor a(t) attains a singular value, the gravitational coupling becomes infinite. [1][2].

Let us start with a connected piece of a homogeneous and isotropic spacetime manifold with a scalar field ς representing the matter content in an individual universe. We spit the whole manifold into connected pieces of Spacetime, each of which is quantum mechanically described by a wave function. $\varphi = \varphi(z,\varsigma)$. This is the wave function that is the solution of the Wheeler-DeWitt equation,

$$\ddot{\varphi} + \frac{1}{z}\dot{\varphi} - \frac{1}{z^2}\varphi'' + \omega^2(z,\varsigma)\varphi = 0 \tag{1}$$

where the scalar fields have been changed according to

$$\varsigma \to \frac{2}{m_p}\sqrt{\frac{\pi}{3}}\varsigma \, , \tag{2}$$

where m_p is the Plank mass. The function in equation (1) contains the potential terms. So then the case of a closed spacetime is given as

$$\omega^2(z,\varsigma) \equiv \sigma^2(H^2 z^4 - z^2) \, , \tag{3}$$

where

$$\sigma \equiv \frac{3\pi m_p^2}{2} \, , \tag{4}$$

and $H \equiv H(\varsigma)$ is the Hubble function. The frequency ω has units of mass. Let us look at two contributions to the Hubble function [3]. The first contribution is due to the existence of a cosmological constant,

$$H_0^2 = \frac{\Lambda_0}{3m_p^2} \, , \tag{5}$$

which can vary in the Multiverse. The second contribution comes from the potential of the scalar field,

$$H_1^2 = \frac{8\pi}{3m_p^2}V(\varsigma). \tag{6}$$

We can now start to work on a Quantum field theory for the wave function φ . This wave function is in curved minisuperspace spammed by (z, ς) with a minisuperspace metric which is given by

$$K_{RS} = \begin{pmatrix} -z & 0 \\ 0 & z^3 \end{pmatrix} , \tag{7}$$

where R, S stands for {z, ς }. The line element of the minisuperspace metric can then be written as

$$ds^2 = -zdz^2 + z^3 d\varsigma^2 . \quad (8)$$

The scale factor, z, is the time variable and the matter field in the two-dimensional Lorentzian minisuperspace metric [4]. Let us follow the general procedure of a Quantum field theory for the scalar field $\varphi(z,\varsigma)$, so then

$$F = \int dz d\varsigma \; S£ \, (\varphi \dot{\varphi} \varphi') , \quad (9)$$

where the Lagrangian density is given, as

$$£ = \frac{1}{2} \sqrt{-K} \; \{ K^{RS} \partial_R \varphi \; \partial_S \varphi - \upsilon(\varphi)\} \quad (10)$$

$$£ = \frac{1}{2} \left(-z \dot{\varphi}^2 + \frac{1}{z} \varphi'^2 \right) + \frac{z\omega^2}{2} \varphi^2 , \quad (11)$$

where K = det(K_{RS}). Then the Euler-Lagrange equation can be written like,

$$\frac{1}{\sqrt{-K}} \partial_R (\sqrt{-K} \; K^{RS} \partial_S) \varphi + \frac{1}{2} \frac{\partial \upsilon}{\partial \varphi} = 0 , \quad (12)$$

This is just the Wheeler-DeWitt equation (1). So then we can write,

$$H = -\frac{1}{2} \left(\frac{1}{a} P_\varphi^2 + \frac{1}{a} \varphi'^2 + a\omega^2 \varphi^2 \right), \quad (13)$$

where,

$$P_\varphi = a\dot{\varphi} , \quad (14)$$

This is the momentum conjugate to the field φ. We can now discuss a set of N universes by looking at a total Hamiltonian density like equation (13),

$$H = \sum_{n=1}^{n} H_n^{(0)} + H_n^{(i)} , \quad (15)$$

where $H_n^{(0)}$ is the unperturbed Hamiltonian density of the n-universes [5]. $H_n^{(i)}$ is the Hamiltonian density of the interaction for each n-universes that exist in the Multiverse, we will now consider a simple quadratic interaction between any two universes,

$$H_n^{(i)} = \frac{a\gamma^2(a)}{8} (\varphi_{n+1} - \varphi_n)^2 , \quad (16)$$

where γ (a) is a coupling function that depends on the value of the scale factor. Also, we have the periodic boundary conditions so that, $\varphi_{n+1} \approx \varphi_n$. Now let us consider the Hamiltonian density from equation (14). This equation represents the evolution of a set of n-universes that are interacting with each other. Each internal observer does not see any interaction in each of these universes but only its Hamiltonian density. We can then take a new representation given in terms of the normal modes using the Fourier transform φ P_φ .

$$\tilde{\varphi}_j = \frac{1}{\sqrt{N}} \sum_{n=1}^{n} e^{-(2\pi ijn/N)} \varphi_n \,, \tag{17}$$

$$\tilde{P}_j = \frac{1}{\sqrt{N}} \sum_{n=1}^{n} e^{(2\pi ijn/N)} P_n \,. \tag{18}$$

We then have the Hamiltonian density,

$$H = -\frac{1}{2} \sum_{j=1}^{n} \left(\frac{1}{a} \tilde{P}_j^2 + \frac{1}{a} \tilde{\varphi}_j^2 + a\omega_j^2 \varphi_j^2 \right). \tag{19}$$

The new quantum states oscillate with a frequency given by,

$$\omega_j^2(a,\psi) = \omega^2(a,\psi) + \gamma^2(a) \sin^2\left(\frac{\pi j}{N}\right). \tag{20}$$

For a single-mode j, the oscillation of the wave function $\tilde{\varphi}_j$ is given by

$$\ddot{\tilde{\varphi}}_j + \frac{1}{a} \dot{\tilde{\varphi}}_j - \frac{1}{a^2} \tilde{\varphi}_j'' + \omega_j^2(a,\psi) \tilde{\varphi}_j = 0, \tag{21}$$

This equation is the Wheeler-DeWitt equation of the new wave function of the j-universes. The j-universes in the $\tilde{\varphi}$ representation appear as an isolated non-interacting universe [6]. The practical value of the potential term of the scalar field in the j-universes can be modified due to the interaction with other universes. So we can rewrite equation (18) as

$$\omega_j^2(a,\psi) = \sigma^2 (\tilde{H}_{1j}^2 a^4 + H_0^2 a^4 - a^2), \tag{22}$$

where

$$H_0 = 3 \;\; \Lambda_0 \tag{23}$$

and

$$\tilde{H}_{1j}^2 = \frac{8\pi}{3m_p^2} \tilde{K}_j(\psi, a) \quad \text{with} \tag{24}$$

$$\tilde{K}_j(\psi, a) = K(\psi) + \frac{\lambda^2(a)}{4\pi^2 a^4} \sin^2\left(\frac{\pi j}{N}\right) \tag{25}$$

We now need to look at the term in equation (23) in terms of the j-universes. Our interest is in the area where the wave function of the j-universe is generally best described by

$$\phi_j = e^{\pm \frac{i}{\hbar} I_0(a)} \Delta_j(a,\psi) \,. \tag{26}$$

I_0 is just the gravitational component with no interaction, so then

$$I_0(a) = \sigma \int daa \sqrt{H_0^2 a^2 - 1} = \frac{\sigma}{3H_0^2}(H_0^2 a^2 - 1)^{\frac{3}{2}} \qquad (27)$$

The positive and negative signs in equation (26) are contracting and expanding the equation ϕ_j [7]. If the wave function $\Delta_j(a,\psi)$ satisfies the first order $\hbar$, then we have,

$$-i\hbar \frac{\partial}{\partial t}\Delta_j = \frac{1}{2}(\frac{1}{a}\frac{\partial}{\partial \psi^2} + a\tilde{K}_j(\psi,a)\Delta_j \ . \qquad (28)$$

The term $H_{1,j}$ is the term K_j in equation (28). Then we can see that the Schrodinger equation for the scalar field ψ with a Hamiltonian is given by

$$h = \frac{1}{2}p_{\psi}^2 + K(\psi). \qquad (29)$$

The new field equation for the scalar field is then

$$\ddot{\psi} + 3\frac{\dot{a}}{a}\dot{\psi} + \frac{d\tilde{K}_j}{d\psi} = \ddot{\psi} + 3\frac{\dot{a}}{a}\dot{\psi} + \frac{dK}{d\psi} = 0 \qquad (30)$$

The dots stand for derivatives concerning the Friedmann time t. The additional term in the potential modifies the vacuum state that needs to be accounted for by any vacuum decay of any of the universes in the Multiverse. The process has an important influence on the structure of Spacetime. This quantum interaction among distant regions of the whole spacetime manifold does modify the vacuum state of the matter fields. For a chain of interacting universes, the wave function of each universe depends on the value r of the mode. Different universes remain in other mode states, so observers feel their universes filled with a scalar field whose vacuum state is different for each mode state. The universes can then suffer a process of vacuum decay between two different values of their vacua. Vacuum decay is the existence of other local minima in the potential of the matter field. The minimum of these local minima can be called the actual vacuum, and the remaining are false vacuum [8]. These vacuum states can then decay. This leads to the state of true vacuum with a probability given by

$$\Gamma / K = Ae^{-B/\hbar} \qquad (31)$$

A and B are quantities to be determined. The result is the materialization of different sizes of true vacuum separated by a thin wall from the surrounding false vacuum. The total picture of this process is then a vast spacetime in the false vacuum splattered by different sizes of areas within a true vacuum. So then, the actual vacuum is continuously forming and expanding until they finally collide and fill the whole Spacetime. Indeed, many Multiverse universes hit, merge, and fill the entire Spacetime [9]. We can now discuss a potential $K(\psi)$ that has two minima ψ_+ and ψ_-. The values of their vacuum energy are given by

$$\Lambda_+ = K(\psi_+) \qquad (32)$$

and

$$\Lambda_- = \mathrm{K}(\psi_-). \tag{33}$$

The additional term of the potential of the j-universe is a constant that depends on the value of j of the mode of each universe. The overall practical value of the potential is then given by a set of curves separated by j units, with j = 0….., N/2. The comprehensive view is a landscape structure with N different vacua: N = 1 is the false vacua states. The actual vacuum state is $\mathrm{K}(\psi_+, j=0)$. this vacuum decay process due to the many universes in the Multiverse interacting with each other. The many universes in the Multiverse are created from Quantum fluctuations of Spacetime. At small values of the scale factor, the changes of the scalar field and the effects of the interaction among the many universes in the Multiverse are dominant, so the newborn universes are expected to have a high value of j [10]. The quantum fluctuations of the Spacetime of large regions with false or true vacuum states would supply the new universes with a continuous process where big bangs occur continuously. Let us consider the following potential,

$$V(\psi) = \frac{m^4}{4\lambda_\psi^2} - \frac{1}{2}m^2\psi^2 + \frac{\lambda_\psi^2}{4}\psi^4, \tag{34}$$

where m is the mass, and this equation λ_ψ is the self-coupling of the scalar field. It has two minima located at

$$\psi_\pm = \pm\frac{m}{\lambda_\psi}, \tag{35}$$

Both with the e value of the potential are given by $V(\Psi_\pm) = 0$. So then, instead of us having equation (31), we have

$$\tilde{V}_j(\psi_+) - \tilde{V}_{j-1}(\psi_+) = \varepsilon_j. \tag{36}$$

We now have,

$$\varepsilon_j = \frac{\lambda^2(a)}{4\pi^2 a^4}\left[\sin^2(\frac{\pi j}{N}) - \sin^2(\frac{\pi(j-1)}{N})\right). \tag{37}$$

which is given by

$$\mathrm{B} = 2\pi^2\bar{\rho}^3 S_1 - \frac{1}{2}\pi^2\bar{\rho}^4\varepsilon_j, \tag{38}$$

where

$$\bar{\rho} = 3S_1/\varepsilon_j, \tag{39}$$

$$S_1 = 2\int d\rho\left[\tilde{V}_0(\psi) - \tilde{V}_0(\psi_+)\right] \tag{40}$$

If we know that $\tilde{V}(\psi)$ is a function then,

$$\widetilde{V}_0(\psi_+) = \widetilde{V}_0(\psi_-), \tag{41}$$

so then we have

$$\frac{d\widetilde{V}_0}{d\psi}(\psi_\pm) = 0. \tag{42}$$

Then, $\widetilde{V}_0(\psi) = V(\psi)$ which is given in equation (34). If we choose $\bar{\rho}$ as the point at which Ψ is the average of its two extreme valves, we have

$$\phi_{1/2} = \frac{1}{2}(\widetilde{V}(\psi_+, j) + \widetilde{V}(\psi_+ j-1)), \tag{43}$$

$$\phi_{1/2} = \frac{\lambda^2(a)}{4\pi^2 a^4}\left[\sin^2(\frac{\pi j}{N}) + \sin^2(\frac{\pi(j-1)}{N})\right]. \tag{44}$$

If we assume $\bar{\rho}$ to be large compared to the length scale on which Ψ varies significantly, then we can write Ψ in terms of ρ :

$$\rho - \bar{\rho} = \int_{\phi_{1/2}}^{\phi} d\psi\left[2\widetilde{V}_0(\psi) - \widetilde{V}_0(\psi_\pm)^2\right]^{-1/2}, \tag{45}$$

then,

$$\phi(\rho) = \frac{m}{\lambda\psi} + \tanh\left[\frac{m}{2\sqrt{2}}(\rho - \bar{\rho}) + \tanh^{-1}\frac{\lambda_\psi}{m}\phi_{1/2}\right]. \tag{47}$$

If we now evaluate S_1 in the thin wall approximation,

$$S_1 = 2\int_{-\infty}^{+\infty} d\rho\left[\widetilde{V}_0(\psi) - \widetilde{V}_0(\psi_+)\right] = \frac{2\sqrt{2}}{3}\frac{m^3}{\lambda_\psi^2}, \tag{48}$$

and so the probability factor B for a vacuum decay can be written,

$$B = \frac{10}{3}\pi^2\frac{m^{12}}{\lambda_\psi^8}\left(\frac{4\pi^2 a^4}{\lambda^2(a)}\right)^3\frac{1}{\left[\sin^2(\frac{\pi j}{N}) - \sin^2(\frac{\pi(j-1)}{N})\right]^3}. \tag{49}$$

By looking at equation (49), we notice this equation restricts the value of the coupling function $\lambda(a)$ [11]. This function suppresses the vacuum decay at large values of the scale function. For example, with a polynomial value $\lambda(a) \propto a^n$, n must be less than or equal to 2 to satisfy the vacuum decay cannot grow with the scale factor. In our universe, $\lambda(a) \propto a^2$ this leads to the following value,

$$\lambda^2(a) = \frac{9\pi M_p^2}{2}\Lambda a^4, \tag{50}$$

which can be written as follows,

$$\omega_j^2(a,\psi) = \sigma^2(H_{0,j}^2 a^4 - a^2) + \sigma^2 H_1^2 a^4. \tag{51}$$

In the last equation, we can write H, as

$$H_1 = \frac{8\pi}{3M_p^2}V(\psi), \tag{52}$$

and

$$H_{0,j} = 3\Lambda_j^{eff}, \tag{53}$$

with

$$\Lambda_j^{eff} = \Lambda_0 + \Lambda \sin^2 \frac{\pi j}{N}. \tag{54}$$

So then, equation (19) represents the Quantum state of our universe with a compelling value of the cosmological constant of the background spacetime given by equation (54) [12]. For a positive value of Λ and a small value of Λ_0, then at the beginning of our universe, there would be an enormous value for the r mode. As our universe decayed into lower modes, the value of the cosmological constant would get less and less until it would reach the value Λ_0 that we are currently observing in our universe. In the Multiverse, many interactions occur between the many universes. This interaction idea opens up the possibility of new and exciting processes of vacuum decay. For the case of vacuum decay of the Spacetime, it would result in the dev elopement of two areas of true vacuum, whose quantum states would be entangled,

$$\phi = \phi^+(\psi_-)\phi^+(\psi_+) \pm \phi^-(\psi_-)\phi^-(\psi_+), \tag{55}$$

$\phi^\pm(\psi_\pm)$ In equation (55), the v is equal to,

$$V(\psi_\pm) \approx V(\psi_\pm) + \frac{1}{2}V''(\psi_\pm)\psi^2. \tag{56}$$

In the Multiverse, more than two universes can become entangled, so then.

$$\phi = \phi^+(\psi_-)\phi^+(\psi_+) \pm \phi^-(\psi_-)\phi^-(\psi_+) \pm .....\phi_n^+(\psi_-)_n\phi_n^+(\psi_+)_n \pm \phi_n^-(\psi_-)_n\phi_n^-(\psi_+)_n. \tag{57}$$

The properties of the Spacetime inside the many entangled areas that interact with each other would be the same for observers in each universe. For example, the value of the cosmological constant would be the same, given by, Λ_0 and the mass scale field would be in all areas of interaction provided by

$$V''(\psi_{\pm}) = m^2(\frac{1}{\lambda_\psi} - 1) \quad (58)$$

So the inner areas of the interacting universes would be very similar at large scales. If the two entangled areas came out from a double instanton, then the reduced matrix would give one of the areas the quantum state. We can then obtain it by tracing out the degrees of freedom of the partner area of the entangled pair; the probability of this would be given by

$$\Gamma / V \propto e^{-21}, \quad (59)$$

With

$$I = \frac{a+H}{3}[(a_+^2 + a_-^2)F(q) - 2a_-^2 J(q)], \quad (60)$$

J(q) and F(a) are the complete elliptic integrals of the first and second kind; the resulting state is a thermal state indistinguishable from a classical state. So that inhabiting these interacting areas would see their universes in a thermal state, and they would ultimately be unaware of the entanglement properties of their interacting regions. There would also be time-reversal symmetry between the time variables of the entangled parts. This would make the regions inside the interacting areas present opposite symmetry assignments; some examples could be baryon asymmetry or other discrete symmetries that would be the consequences of the global symmetries of the entangled pair of interacting areas between the many universes. The symmetry assignments and asymmetries would disappear for anyone external to these interacting areas when considering that the whole entangled pair would be properties. The process would fix many of the apparent symmetries of our universe [13][14]. In the Multiverse, many constants can vary in each universe. For example, the gravitational constant G can be a different value in each universe. If we start with Friedmann universes with varying speed of light c and varying gravitational constant G, we have

$$\varsigma(t) = \frac{3}{8\pi G(t)}\left(\frac{\dot{a}^2}{a} + \frac{kc^2(t)}{a^2}\right) \quad (61)$$

$$p(t) = -\frac{c^2(t)}{8\pi G(t)}\left(2\frac{\ddot{a}}{a} + \frac{\dot{a}^2}{a^2} + \frac{kc^2(t)}{a^2}\right) \quad (62)$$

The field equations are then,

$$\frac{\dot{a}^2}{a^2} = \frac{8\pi G(t)}{3}\varsigma - \frac{kc^2(t)}{a^2} \quad (63)$$

$$\frac{\ddot{a}}{a} = \frac{-4\pi G(t)}{3}\left(\varsigma + \frac{3p}{c^2(t)}\right) \quad (64)$$

where p is the pressure and ς is the mass density, then

$$\dot{\varsigma}(t) + 3\frac{\dot{a}}{a}\left(\varsigma(t) + \frac{p(t)}{c^2(t)}\right) = -\varsigma(t)\frac{\dot{G}(t)}{G(t)} + 3\frac{kc(t)\dot{c}(t)}{4\pi G a^2} . \quad (65)$$

In this equation, a= a(t) is the scale factor, a dot means a derivative concerning time t, G = G(t) is the time-varying gravitational constant, c= c(t) is the time-varying speed of light, and the curvature index k = 0, $\pm$ 1. We can then try and understand how new universes are being created in the Multiverse. Let us start by setting k = +1 and $\dot{c}$ = 0. The scale factor in the Multiverse takes on the form

$$a(t) = a_0 \left|\tan(\pi\frac{t}{t_s})\right| . \quad (66)$$

The gravitational constant can be written,

$$G(t) = \frac{4G_s}{\sin^2(2\pi\frac{t}{t_s})} \quad (67)$$

Which then gives the mass density and pressure as

$$\varsigma(t) = \frac{3}{8\pi G_s}\left[\frac{\pi^2}{t_s^2} + \frac{3c^2\cos^4(\pi\frac{t}{t_s})}{a_0^2}\right], \quad (68)$$

$$p(t) = -\frac{c^2}{8\pi G_s}\left[\frac{\pi^2}{t_s^2} + 4\frac{\pi^2\sin^2(\pi\frac{t}{t_s})}{t_s^2} + \frac{c^2\cos^4(\pi\frac{t}{t_s})}{a_0^2}\right] \quad (69)$$

In the Multiverse, if t = mt_s, with m= 0,1,2,….., then we have regularized big bangs. Each time the scale factor a(t) attains a singular value, like vanishes or reaches infinity, the gravitational coupling becomes infinite (G $\to \infty$). Then one can calculate the equation of state from equations (61) and (62),

$$p(\varsigma) = -c^2\left[\frac{\pi}{2G_s t_s^2} + \frac{\varsigma}{3} - \frac{\pi^{\frac{3}{2}} a_0}{c t_s^2}\sqrt{\frac{2\varsigma}{3G_s}} - \frac{\pi}{4G_s^2 t_s^2}\right] \quad (70)$$

with

$$\varsigma \geq \frac{3\pi}{8G_s t_s^2}, \quad (71)$$

which agrees with equation (61) for t= m/2 and m = 0,1,2,…… [15, 16].

In conclusion, we have discussed the idea of interacting universes and the issue of interacting areas. Interacting universes open necessary implications for the global structure of the Multiverse. Because of these interactions, a system appears where the universes are created with different practical cosmological constant values. So then, quantum tunneling transitions between other universal states give rise to new interacting areas with similar values. The interaction between universes gives rise to a new generation of the interacting regions dominant only for small length scales of the parent spacetime. However, the quantum effects of Spacetime are significant in these interacting universes. These newborn interacting areas may expand and start new interacting areas in a self-reproducing process. The vacuum decay between the quantum state of two or more universes will be cut off for large values of their scale factors. This explains the minimal value of the cosmological constant of our universe. In the Multiverse, the vacuum decay can have larger values of their scale factors. So, then equation (49) can be written,

$$B = \frac{10}{3}\pi^2 \frac{m^{12}}{\lambda_\psi^8}\left(\frac{4\pi^2 a^4}{\lambda^2(a)}\right). \tag{71}$$

The process leads us to larger values of the cosmological constant in the Multiverse. The practical value of the cosmological constant is not changing in the Multiverse. We can then write,

$$\Lambda_j^{eff} = \Lambda, \tag{72}$$

The value of the cosmological constant would be larger than the individual universes that make up the Multiverse. Finally, the Multiverse has regularized big bangs. Each time the scale factor attains a singular value, the gravitational coupling becomes infinite. Hopefully, soon we will be able to show the interacting universes using current observational data [17][18][19].

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