Cosmological Constant from Rotating Universe Interpretation of Time and Energy

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The cosmological constant (Λ) problem is resolved within the framework of a new interpretation of time and energy with a second Planck size time dimension T_2 where Energy is a vector quantity in combined space and time T_2 dimension. This Rotating Universe interpretation of Time and Energy (RUTE) as proposed in this paper, describes a cylindrical brane Universe rotating along its time dimension $T_{1,}$ while also oscillating between two asymmetric vacuum states a and b along its second time dimension T_2. Where vacuum states a and b for T_2 are analogous to particle and antiparticle states for T_1 time dimension. In RUTE, a non-zero and running Λ essentially arises from an asymmetry in Planck density of vacuum states a and b coupled with a general energy-momentum conservation principle in spacetime. It constrains the energy density and speed of a reference frame in spacetime, to always equal the upper limit of the Planck density and c respectively. The asymmetry is fundamentally in the form of difference in speed limit c for vacuum states a and b with a relativistic relationship that is described by a cosmological factor Γ asymptotically approaching zero as a function of orbital radius r. A curious measure of entropy emerge as the surface area of the two time dimensions $2\pi r$ in Planck units raising a question as to the relationship between our model Universe and blackhole Physics. Prospects of Λ driven inflation with a reheating mechanism, light speed oscillation and matter-antimatter transmutation among other predictions are briefly discussed.

1. Introduction

In 1998, Riess et al.[1] published their supernova observations of the accelerated expansion of our Universe. This was followed in 1999 by Perlmutter et al., [2] corroborating the earlier findings. Since then, several independent lines of evidence have led to the conclusion that there is a mysterious negative pressure dark energy component driving the accelerated expansion of our Universe. Results published by the Planck collaboration (Planck 2013) [3], shows that dark energy density constitutes about 68.3% of the total energy density of our Universe, while ordinary baryonic matter constitutes 4.9%. The invisible dark matter component makes up 26.8%.

Dark Energy, according to the standard model of cosmology known as the ΛCDM (Lambda Cold Dark Matter) model, is in the form of Einstein's cosmological constant (Λ). Λ in turn, is known to arise from vacuum energy, an intrinsic energy associated with empty space. But quantum field theory estimated a vacuum energy density 10^{120} times more than the observed dark energy density. This is the cosmological constant problem. It is also not known what the connection of Λ if any, is to inflation [4], a brief period of exponential expansion of the early Universe.

Supper Symmetry (SUSY) provides an elegant frame work for the cancellation of large Λ to a very small value. In unbroken SUSY, every bosonic particle has its own fermionic superpartner with same mass but with each contributing opposite signs thereby cancelling vacuum energy. Null search result for SUSY partners of the standard model particles shows that SUSY, if at all describes our universe, must be broken. Even with SUSY breaking around 10^3 GeV, it's still very far from the observed dark energy density. There are a number of other cancellation models such as that from string theory which cancels the bare Λ down to a small effective value [5]. There are also relaxation models where the value of the vacuum energy density is relaxed [6] including anthropic considerations [7] and even an approach that makes the space-time metric insensitive to the cosmological constant [8]. There are several other alternative approaches which avoid the thorny problem of Λ such as quintessence, unification of dark energy and dark matter [9] and modification of gravity [10]. For detailed review see Ref. [11, 12].

On appreciating the seriousness of the Λ Problem, It becomes more apparent that a satisfactory solution requires drastic revolution in our understanding of the Universe. Such a solution should provide at least some clues to problems like the Physics of inflation, baryogenesis, the nature of time and may be even result in a quantum theory of gravity.

In this paper, we resolve the Λ problem using a rotating cylindrical space time structure with an asymptotically vanishing asymmetry between two opposite vacuum energy states. Vacuum energy is basically interpreted as resulting from vacuum oscillation at Planck frequency along a second Planck size time dimension T_2. This model is not a cancellation model par se. In This framework energy is interpreted as a vector quantity in space time T_2 ($S+T_2$) as illustrated in figure 4 in section 3. With the bulk of vacuum energy being directed along the time dimension T_2, the space-time metric is insensitive to it. It is only sensitive to energy/momentum component directed along the spatial dimensions S. This includes a very small component of vacuum energy (dark energy) directed along the spatial dimension due to a deficit in the Planck density of one of the 2 vacuum states, coupled with an energy conservation principle which constrains the energy density of a spacetime reference frame to always equal the upper limit of the Planck density. That is, the magnitude of the vector sum of spatial dimension and time dimension T_2 components of energy must always equal the upper limit of the Planck density. A deficit vacuum density for a vacuum state along T_2 simply manifests as a non-zero spatial component which we observe as dark energy or small effective Λ. However the resulting Λ has inflationary energy scale in the early Universe since the asymmetry between the 2 vacuum states was large before asymptotically falling to its current value. It is also well known however, that a Λ driven inflation usually suffer from the graceful exit and reheating problems as attempted in [13]. But this can be resolved with an asymptotically falling Λ and a reheating mechanism provided by this framework for converting or directing vacuum energy from the T_2 dimension into the spatial dimensions as standard model particles, obviating the need for a scalar field driven inflation.

Generally speaking, in this model like in most extra dimensional models, the Universe is seen as a spacetime brane like in the DGP model [14] (Though in a different context of cosmic acceleration without dark energy) operating in a multiverse environment with a higher dimensional spacetime structure of its own. Indeed a two dimensional Universe provides literally, a new degree of freedom in understanding our universe such as in Ref. [15], though in an apparently different context of standard model of particles and forces.

In the next section, we interprete the time dimension T_1 in the context of our rotating cylindrical space time structure while reproducing relativistic effects. We also explore in subsection 2.1 an emergent effect of particle antiparticle transmutation and its implications for baryon asymmetry in subsection 2.2. In section 3 we introduce a second time dimension T_2 as vacuum energy driven where energy is interpreted as a vector quantity in spacetime T_2. We also develop relativistic relationship in the form of energy momentum conservation between the spatial dimensions S, the time dimension T_1 and the second time dimension T_2. This is in regards to speed limit c and energy or frequency of oscillation as illustrated in figure 4. In section 4, we achieve an asymptotically vanishing asymmetry between the two vacuum states along time dimension T_2. In section 5, we describe how the deficit in Planck density of one of the vacuum states results in a non-zero cosmological constant. Discussion follows in section 6.

2. Nature of Time

The actual nature of time has been a puzzle for both physicists and philosophers alike [16]. In what follows, we interpret the nature of time as an irreversible progressive effect of motion of a spatial reference frame along a time dimension. We start by exploring, as shown in figure 1, how the rotation of a cylindrical brane Universe along its time dimension drives time and produces relativistic effects if there is speed deficit along such time dimension.

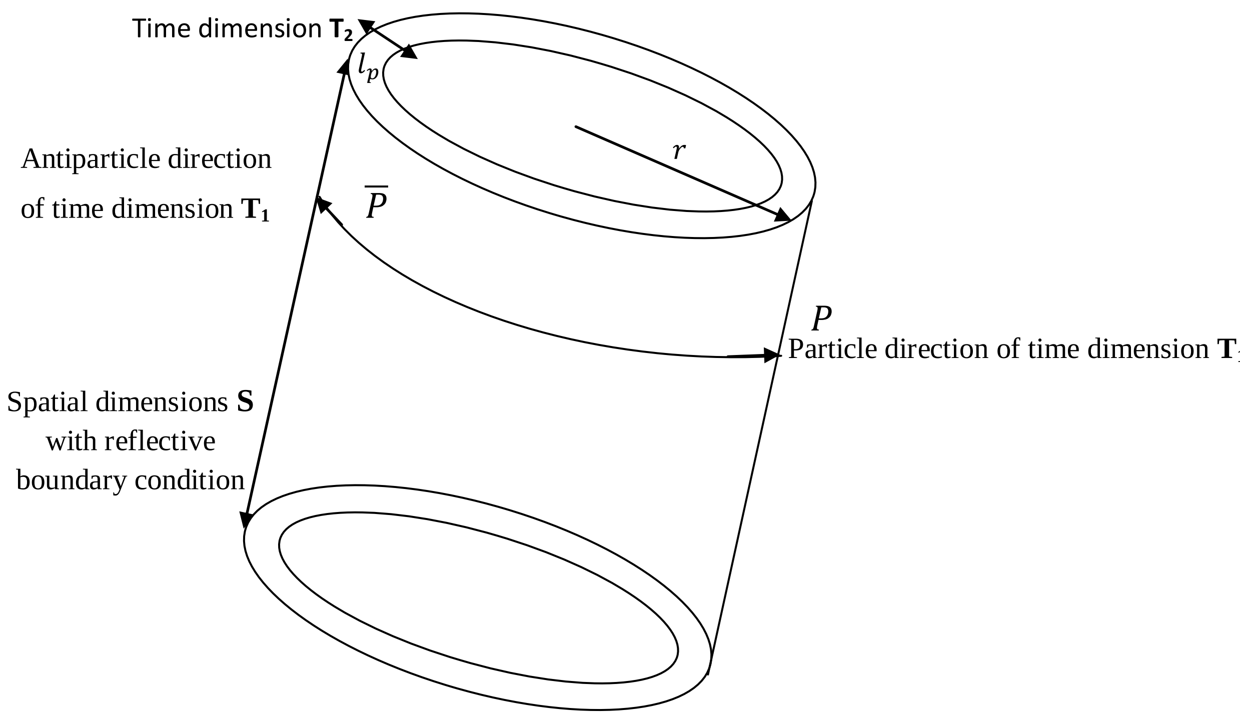

Figure 1: A cylindrical brane universe. The circumferential dimension represents time dimension T_1, while the spatial dimensions are represented by the flat vertical side. The brane thickness which is Planck length l_p in size represents a second time dimension T_2 which we shall discuss in section 3. All the dimensions in this model have reflective boundary condition. That is, a reference frame is reflected back on reaching the dimensional boundary. If there is such a boundary along T_1, a particle transmutes into an antiparticle and vice versa.

In line with the Feynman-Stueckelberge interpretation, massive particles and antiparticles are modeled as rotating along opposite directions of time dimension T_1. Massless particles such as photons having zero orbital speed travel at maximum speed c along the spatial dimensions S. In this framework, time as an irreversible entropic progression is driven by motion in either direction through a time dimension. Given the speed constraint from special relativity, an initial reference frame must always travel at c in combined spacetime dimensions. That is the vector sum of its velocity $\mathbf{V_T}$ along time dimension T_1 and velocity **V**, along the spatial dimensions S must always equal **C**.

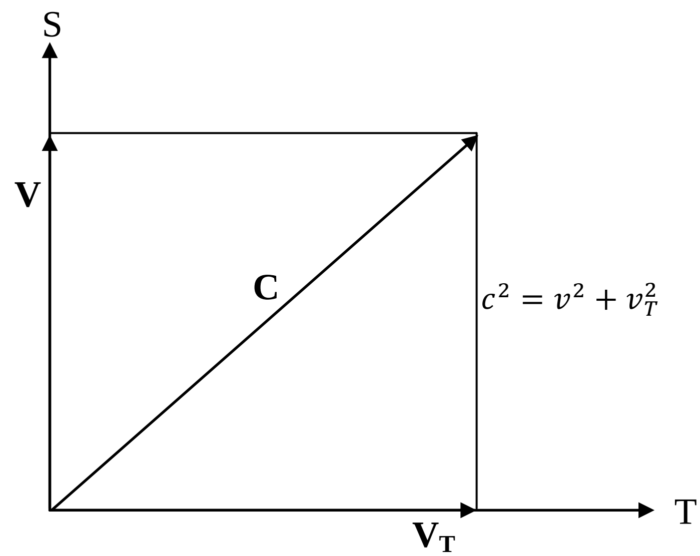

Figure 2: The speed constraint. The magnitude of the vector sum of the spatial and time dimension components of velocity must always equal c.

$$C = V + V_T \tag{1}$$

$$c = \sqrt{v^2 + v_T^2} \tag{2}$$

For a spatial reference frame or massive particle X with spatial velocity V (relative to an observer), its velocity v_T component along the time dimension T_1 becomes

$$v_T = \sqrt{c^2 - v^2} \tag{3}$$

Given the clock rate factor Γ

$$\Gamma = \sqrt{1 - \frac{v^2}{c^2}} \tag{4}$$

Its relative clock rate will be

$$\Gamma = \sqrt{1 - \frac{v^2}{c^2}} \times 100 \tag{5}$$

relative to the reference observer who's clock ticks at

$$\Gamma = \sqrt{1 - \frac{0^2}{c^2}} \times 100\% \tag{6}$$

hundred percent relative to itself. The inverse of the clock rate factor gives the Lorentz factor

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \,. \tag{7}$$

2.1 Particle-antiparticle Transmutation

As earlier noted, in line with the Feynman-Stueckelberge interpretation, particles and antiparticles rotate in opposite directions along the time dimension T_1, as illustrated earlier in figure 1. Massless particles with maximum spatial velocity c have zero orbital speed along T_1. Thus the speed limit c, serves as a barrier between particle and antiparticle states. As a massive particle or antiparticle asymptotically approach maximum spatial speed c, or zero orbital speed v_T, in an analogous quantum mechanical way, there is in this scenario, a non zero probability of it tunneling into the opposite antiparticle or particle state. The probability P of such particle-antiparticle transmutations can be expressed as

$$P \approx \frac{v^2}{c^2} \tag{8}$$

So the question of exceeding c, tachyons and time travel doesn't even arise as a massive particle on approaching c, simply tunnels into an antiparticle state effectively travelling backward in this case, along time dimension T_1 (not in time) without exceeding c.

2.2 Baryon Asymmetry

Let's consider the consequence of particle-antiparticle transmutation in regards to the Sakharov conditions. See Ref. [17] for a review on baryogenesis. In a high energy thermal equilibrium with Planck scale energies such as that obtainable in the early Universe with $t{\sim}t_{reheating}$, and given equal number of particles and antiparticles created according to the standard model, they should freely transmute equally. This creates baryon number violation (condition 1). If the Universe has a net spin along the time dimension T_1, the probability of a particle type transmuting into the opposite type along the net spin direction is favoured. This creates thermal inequilibrium (condition 2). And finally the type of baryon favoured depends on the net spin direction (condition 3), where the asymmetry parameter η is proportion to the net spin.

3. Second Time Dimension T_2

As noted in the previous section, the speed constraint limits a reference frame to always move at resultant velocity c through space and time dimension T_1, in what follows, we identify a second time dimension T_2 along the Planck size brane thickness with which this speed constraint equally applies. Its Planck size and reflective boundary condition makes it an oscillatory time dimension.

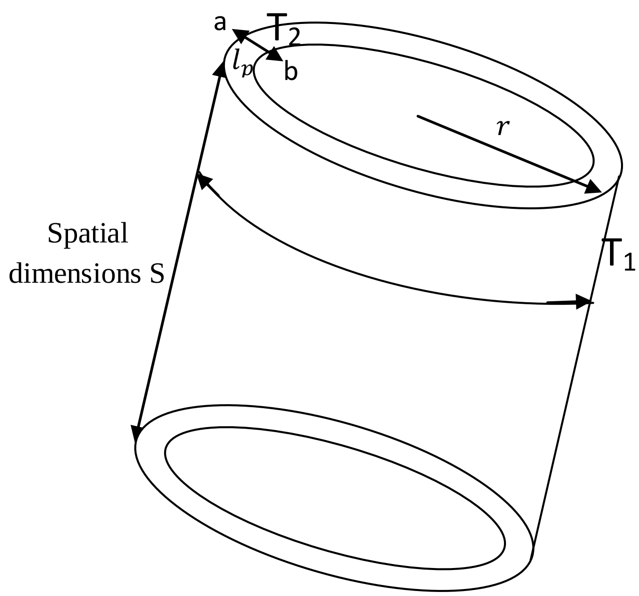

Figure 3: The inner and outer bane surfaces (vacuum states) oscillate in and out, flipping sides at the Planck frequency f_{Planck}.

Applying the speed constraint to time dimension $T_{2,}$ a vacuum reference frame (empty brane surface) must travel at c along T_2 dimension, but with the Planck size of T_2 and its reflective boundary condition, such a vacuum state must oscillate at $f_{\text{Planck}} = c/l_p$. The speed constraint in eq.(2) results in the frequency constraint.

$$f_{\text{Planck}} = \sqrt{f^2 + f_{vac}^2} \quad . \tag{9}$$

Where f_{vac} is the oscillation frequency along T_2 dimension and f is the oscillation frequency along the spatial dimension. It follows that a vacuum with no spatial oscillation (i.e devoid of energy or $f = 0$) must oscillate at the Planck frequency along T_2 dimension. i.e

$$f_{\text{Planck}} = \sqrt{f_{vac}^2 + 0}\ . \qquad (10)$$

Any deficit in oscillation along the time dimension T_2 must be compensated for with spatial oscillation manifesting as a particle with frequency

$$f = \sqrt{f_{Planck}^2 - f_{vac}^2}\ . \qquad (11)$$

This oscillate or ticks with a frequency

$$f_{vac} = \sqrt{f_{Planck}^2 - f^2} \qquad (12)$$

along T_2 dimension. So a Planck frequency particle is literally frozen along T_2 dimension, while a vacuum oscillates at the Planck frequency between the 2 opposite vacuum states. The 2 opposite vacuum states a and b for time dimension T_2 are analogous to the particle and antiparticles states for time dimension T_1. These oscillations translate to energy as $E = hf$. where h is the Planck constant, leading to the Planck energy and Planck energy density constraints.

$$E_{\text{Planck}} = \sqrt{E^2 + E_{vac}^2} \qquad (13)$$

$$\rho_{\text{Planck}} = \sqrt{\rho^2 + \rho_{vac}^2} \qquad (14)$$

Where E and E_{vac} are the energy of a particle and its associated vacuum energy along the time dimension T_2. ρ and ρ_{vac} are the spatial component of energy density and component vaccum energy density along T_2 dimension respectively. In essence, the magnitude of the vector sum of spatially observable energy density ρ of a given reference and its component vacuum energy density ρ_{vac} along time dimension T_2 must always equal to the upper limit of the Planck density ρ_{Planck}. Note the reference to upper limit here as there is an intrinsic asymmetry between the 2 vacuum states along T_2 dimension which we shall discuss in section 4.

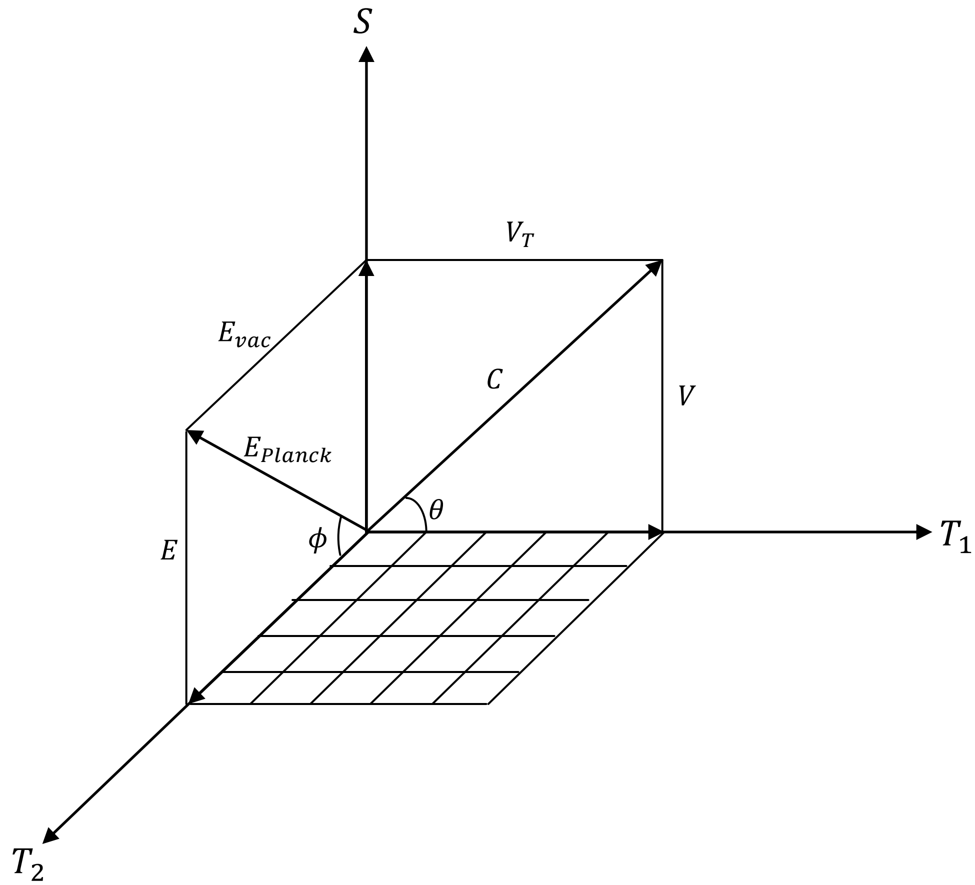

Figure4: Relativistic relationship between the spatial dimensions and the 2 time dimensions in terms of speed and frequency or energy constraints. The surface area of the 2 time dimensions gives the entropy of the universe in an analogous way ¼ of a black hole's (event horizon) surface area gives its entropy.

The energy density constraint eliminates infinite energy densities such as black hole singularity and big bang singularity, while predicting the existence of Planck stars also described by [18]. It also obviates the need for renormalization of vacuum energy density. The surface area of the 2 time dimensions in Planck unit gives the entropy of the Universe as S$= A = 2\pi r$. Where r is the orbital radius of the cylindrical space time structured Universe. Given the relatively constant Planck size of T_2 dimension, only T_1 dimension expands freely. Gravity in this scenario, essentially contracts the spatial dimensions to expand time dimension T_1 there by driving entropy while increase the orbital radius r. Just like in the case of T_1 dimension, if a particle or a reference frames in space time oscillates with a frequency f along the spatial dimensions S, its clock rate along T_2 will tick at

$$\sqrt{1-\frac{f^2}{f_{Planck}^2}} \times 100\% \qquad (15)$$

percent relatively to a vacuum (non spatially oscillating reference frame) with clock rate ticking at

$$\sqrt{1-\frac{0^2}{f_{Planck}^2}} \times 100\% \tag{16}$$

hundred percent of the Planck frequency along T_2.

Given the factor Γ

$$\Gamma^2 = 1-\frac{f^2}{f_{Planck}^2} \tag{17}$$

$$\Gamma = \sqrt{1-\frac{f^2}{f_{Planck}^2}} \tag{18}$$

Where $\frac{1}{\Gamma}$ equals the Lorentz factor γ for 2nd time dimension T_2

$$\gamma = \frac{1}{\sqrt{1-\frac{f^2}{f_{Planck}^2}}} \tag{19}$$

4. Vacuum State Asymmetry

With the oscillation of space time between 2 opposite vacuum states a and b along a second time dimension T_2, as illustrated in figure 6 below, we examine the resulting asymmetry.

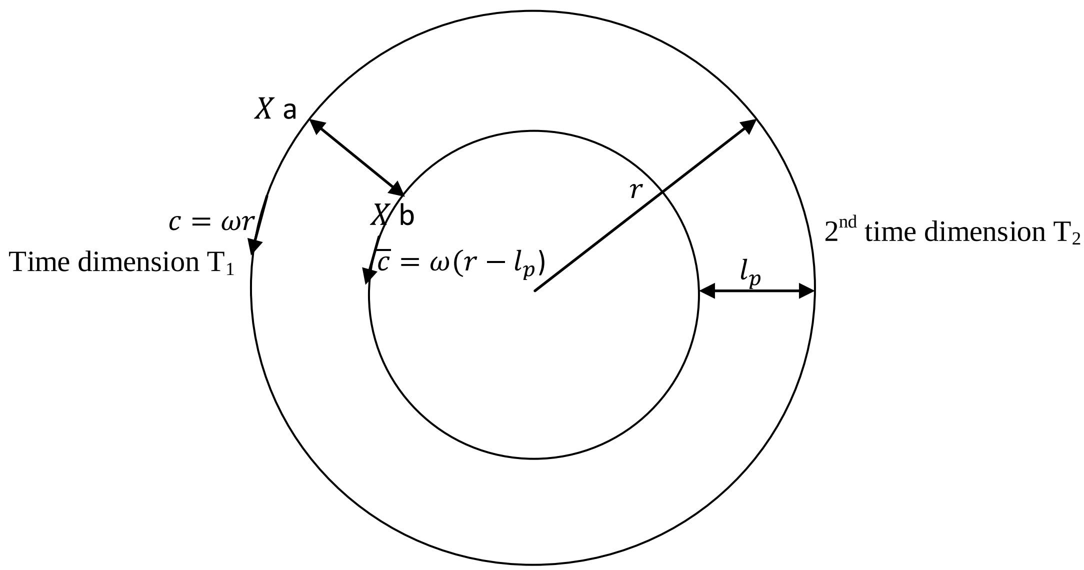

Figure 5: A massless particle x oscillating between two vacuum states a and b along time dimension T_2

As illustrated in figure 6, a massless photon x with energy less than the Planck scale, oscillates between the 2 vacuum states (brane surface states) a and b which has different orbital speeds (or speed limits $c = \omega r$ and $\overline{c} = \omega(r - l_p)$. At vacuum state a, photon x must have a spatial velocity $c = \omega r$ in order to have zero orbital speed. At vacuum state b, it must have a spatial velocity $\overline{c} = \omega(r - l_p)$. Where Planck length l_p is the brane thickness. The difference in speed ($c - \overline{c}$) between the vacuum states can be described by the cosmological factor Γ.

$$\Gamma = 1 - \frac{\overline{c}}{c} \tag{20}$$

$$\Gamma = 1 - \frac{\omega(r - l_p)}{\omega r} \tag{21}$$

$$\Gamma = \frac{l_p}{r} \tag{22}$$

The reduced cosmological factor $\frac{\Gamma}{2\pi}$ is the relative size of the two time dimensions T_1 and T_2.

$$\gamma = \frac{1}{1-\Gamma} \tag{23}$$

Where γ is the Lorentz factor associated with this relativistic asymmetry.

$$\gamma = \frac{r}{r-l_p} \tag{24}$$

This asymmetry Lorentz factor describes the asymmetry between the 2 vacuum states with different speed limits and clock rates. It is also the ratio of the orbital radius of the two vacuum states. Since the cosmological factor as expressed in eq. (22) is a function of orbital radius r, it evolves asymptotically with the growth of orbital radius with $0 < \Gamma < 1$. The growth of orbital radius r is in turn driven by gravity as it expands the size of the entropic time dimension T_1 ($2\pi r$).

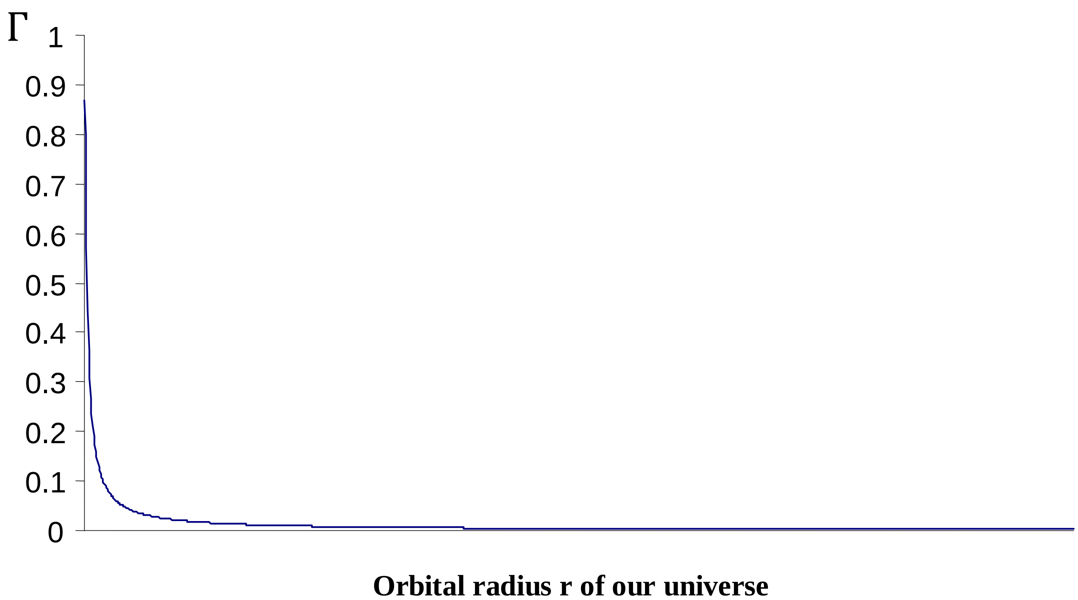

Figure 6: The asymptotic vanishing of Γ with the growth of orbital radius r.

5. Non-Zero and Running Cosmological Constant

The state asymmetry discussed in the previous section results in the following relativistic relationship between the 2 vacuum states.

$$\rho_{planck} - \overline{\rho}_{planck} = \Gamma^2 \rho_{planck} \tag{25}$$

Where ρ_{planck} is the maximum vacuum energy of vacuum state a with a maximum speed limit c as illustrated in figure 7 below. $\overline{\rho}_{planck}$ is the deficit vacuum energy density of vacuum state b with deficit speed limit $\overline{c}$. $\Gamma \sim 10^{-60}$ is the cosmological factor, now asymptotically approaching zero as a function of orbital radius r.

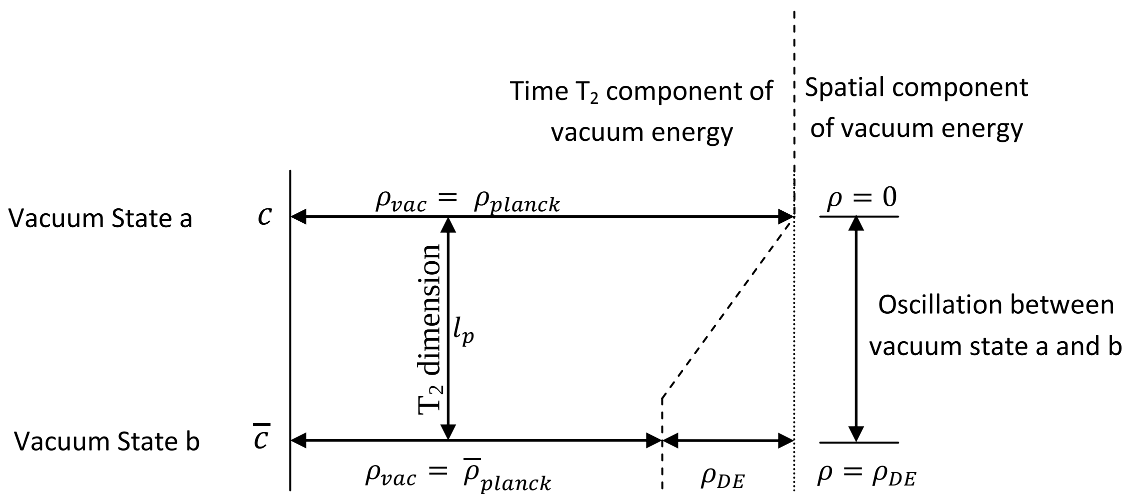

Figure 7: Asymmetry between vacuum states a and b with densities $\rho_{planck} > \overline{\rho}_{planck}$. The vacuum oscillates between states a and b. While at vacuum state a, the time dimension T_2 Component has the maximum value of energy density $\rho_{vac} = \rho_{planck}$ and zero spatial value $\rho = 0$. When at vacuum state b, the T_2 dimension component has a deficit value of energy density $\rho_{vac} = \overline{\rho}_{planck}$ and therefore the spatial component $\rho = \rho_{DE} \neq 0$ to satisfy the energy conservation constraint $\rho^2_{Planck} = \rho^2 + \rho^2_{vac}$.

Given the energy density conservation constraint earlier arrived at in section 3, the energy density in spacetime must always equal the upper limit of the Planck density ρ_{planck}. Any deficite in vacuum energy density along T_2 dimension must be compensated for with a corresponding amount of energy density being projected along the spatial dimension S. Therefore, as the vacuum oscillates at f_{planck}, moving from state a to state b as shown in figure7, the resulting deficit along T_2 as the energy density change from ρ_{planck} to $\overline{\rho}_{planck}$ has to be compensated for with the emergence of dark energy ρ_{DE} along the spatial dimensions where

$$\rho_{DE} = \Gamma^2 \, \rho_{planck} \tag{26}$$

With equation of state $\omega = {}^{-p}/_{\rho}$ = -1, it results as a negative pressure cosmological constant

$$\Lambda = \frac{8\pi G}{c^4} \rho_{DE} \tag{27}$$

With Γ evolving asymptolically with gravity driven growth of orbital radius r, Λ runs in a step wise manner. The possible running of Λ was explored in [18]. In the early universe, with $r \sim l_p$ and $\Gamma \sim 1$, $\Lambda \sim \mathrm{M}^4_{\mathrm{Planck}}$ in reduced Planck unit ($\rho_{DE} \sim 10^{73}\ GeV^4$), enough to power the inflation of the early Universe. However the energy scale here asymptotically falls from the Planck scale with increasing orbital radius r as $r \gg l_p$, $\Gamma \rightarrow 0$ and with reheating effectively ending inflation and leaving a residual asymptotically vanishing cosmological constant now driving the late time acceleration of our Universe.

6. Discussion

Using a rotating and oscillating cylindrical space time model of our Universe which we have developed, we have provided an elegant resolution of the cosmological constant problem in this paper. In achieving this, we define the nature of time as an irreversible progression driven by motion of a spatial reference frame along a time dimension and also identified a second Planck size, oscillatory time dimension T_2 driven by vacuum energy. Thus time T_2 is a progressive vacuum oscillation between 2 vacuum states a and b (analogous to particle- antiparticle states for T_1 time dimension) along time dimension T_2. Time and time dimension are different in this scenario with the former being a progressive effect of moving along the later like the motion of a train on a track.

Another important milestone within this frame work, is the interpretation of energy as a vector quantity in space time T_2 (i.e Spatial + T_2 time dimension) and only appear locally as a scalar quantity in spatial dimensions. The magnitude of the vector sum of it spatial component and its T_2 dimension component must always equal the Planck energy E_{plank} for a reference frame. Also the space-time metric is only sensitive to the spatial component of energy because gravity is associated in this scenario to the slowing down of time T_2 or T_1 which is coincident with spatial availability of energy and momentum. Since the bulk of vacuum energy here is directed along T_2 dimension, it is gravitational inert like in [8]. But with a deficit in the vacuum energy density of one of the vacuum states coupled with the spacetime energy conservation principle which limits energy density just like speed limit c of a reference frame, a small non-zero component of vacuum energy (the deficit) is projected into the spatial dimensions S appearing as dark energy. The gravitationally inert nature of vacuum energy along T_2 dimension may however be accounted for if vacuum states a and b provides opposite terms to cancel each other. Despite the asymmetry, vacuum contributions from vacuum states a and b gives:

$$\Lambda_a - \Lambda_b = 0 \tag{28}$$

i.e,

$$\frac{8\pi G}{c^4}\rho_{Planck} - \frac{8\pi \overline{G}}{\overline{c}^{\,4}}\overline{\rho}_{Planck} = 0 \tag{29}$$

Since

$$\frac{G}{c^2} = \frac{\overline{G}}{\overline{c}^{\,2}} \tag{30}$$

and

$$\frac{\rho_{Planck}}{c^2} = \frac{\overline{\rho}_{Planck}}{\overline{c}^{\,2}} \tag{31}$$

Where G and $\overline{G}$ are the gravitational constant for vacuum states a and b respectively. The asymptotically evolving nature of the deficit vacuum energy which emerge as dark energy, is described by the cosmological factor Γ. Γ~1 in the early Universe provided a Planck scale Λ that likely powered inflation before falling asymptotically to its present small value coupled with reheating effectively ending inflation.

One major difference between T_1 and T_2 time dimensions apart from the Planck size and oscillatory nature of T_2, is that its 2 vacuum states are not coupled like particle and antiparticle states for T_1 dimension, so the annihilation cross section is zero, else an annihilation of vacuum states a and b along T_2 for a reference frame will project all the vacuum energy into the spatial dimensions S appearing as Planck energy scale particles. Such particle creation mechanism can reheat the Universe during and after inflation. Reheating can also be achieved by any process that dampens vacuum oscillation along T_2, (like measured increase in Planck length l_p, deficit in speed limit c, or other associated constants) and the deficit is automatically projected spatially as standard model particles. This framework potentially obviates the need for scalar field driven inflation. Detailed analysis of this deficit reheat mechanism is expected in future work.

The energy density constrain in this model, rules out all forms of infinite energy densities since exceeding the Planck density limit for T_2 time dimension is analogous to exceeding speed limit c for T_1 time dimension. It therefore rules out big bang singularity and replaces black hole singularity with Planck stars like in [19]. Moreover, the vacuum energy density in such a Planck star must be zero, since the spatial component is already at the maximum Planck value.

It is also interesting, how the surface area A of the 2 time dimensions describe the entropy S of our Universe (with $S = 2\,\pi r$) in an analogous way the surface area A of the event horizon of a black hole describes its entropy S (with $s = {}^{1}\!/_{4}\,A$). This raises the question: Is our Universe a holographic black hole in a much bigger and older Universe as also suggested in [20]? We also discussed in subsection 2.1 about particles–antiparticle transmutation at high energies, and how disequilibrium from a net spinning Universe can give rise to baryon asymmetry.

Another major prediction of this RUTE model is light speed oscillation. A photon with frequency f less than the Planck frequency will oscillate its speed between c and $\overline{c}$ (Where $\overline{c}$ is the deficit speed) at a frequency $f_{vac} = \sqrt{f_{Planck}^2 - f^2}$. Again this asymmetry is a function of the cosmological factor Γ and therefore asymptotically vanishes with the growth of orbital radius. However, with this speed asymmetry more pronounced in the early universe, it is hoped that some relic evidence is imprinted in the CMB photons. With the 2 vacuum states of T_2 time dimension not coupled, the oscillation of particles (only particles with $E < E_{Planck}$) between the 2 vacuum states produces the effect of appearance and disappearance of particles in a wave like manner contributing to probabilistic nature of its position and momentum.

If there is discontinuity along T_1 time dimension, the reflective boundary condition in this RUTE model ensures a reflection, but in this case, a cyclic particle-antiparticle transmutation with momentum reversal and with a progressively growing wavelength of $2\pi r$. Given that $r = \frac{l_p}{\Gamma}$ and $\Gamma \sim 10^{-60}$, we have a present cycle period $t_{p\leftrightarrow\overline{p}} = \frac{2\pi r}{c} \sim\ 10^{17} s$ though progressively more frequent in the earlier Universe with smaller r.

In this model, the contraction of a dimension inevitably leads to the expansion of another and vice versa. So the contraction of the spatial dimensions in this case, expands the time dimension T_1 as $2\pi r$. Therefore, the expansion of the spatial dimensions must be balanced by the contraction of another dimension(s). Since the size of T_1 and T_2 dimensions is associated with entropy, they can't be contracted without interacting with the external Multiverse environment. Thus at least an extra dimension is required to contract as the 3 spatial dimensions expand. If spacetime is quantized according to loop quantum gravity [21], then as the extra spatial dimension(s) reach the minimum quantized size, the expansion of the 3 macroscopic spatial dimensions stops, leading to the contraction of our Universe as gravity reigns. The exact number of extra spatial dimensions then determines the lifetime of the expansion phase. As the Universe reaches the Planck density during the contraction phase, the density constraint (or Planck degeneracy pressure) stops the contraction, effectively preventing a singularity. With the Universe effectively frozen, neither able to contract further, nor expand, this may be the entropic end.

Looking at the big picture, it is interesting how an attempt to resolve the Λ problem is providing viable insights into a number of other unsolved problems in physics. With work still in progress, it remains to be seen how far we are from a quantum theory of gravity.

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