Cosmological Constant from Rotating Universe Interpretation of Time and Energy

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Abstract

The cosmological constant (Λ) problem is resolved within the framework of a new interpretation of time and energy with a dimensional symmetry in which every macroscopic spacetime dimension has a microscopic dimensional partner doubling the number of functional spacetime dimensions to 8d. This Rotating Universe interpretation of Time and Energy (RUTE) as proposed in this paper, describes a brane Universe with 2dimensional ring time structure, 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 with the growth of time dimension T_1 as $2\pi r$ where r is the orbital radius. Tantalizing prospects of a Λ driven inflation with gravitational wave 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).

Supersymmetry (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 and resulting in zero Λ. 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 above 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 other problems like the Physics of inflation, baryogenesis, the nature of time and even quantum gravity. In this paper, we resolve the Λ problem using a rotating and oscillating 2 dimensional ring structure of time with an asymptotically vanishing asymmetry between two opposite vacuum energy states. The required dimensional symmetry which doubled the time dimension also doubled the spatial dimensions resulting in 8 spacetime dimensions. Vacuum energy is basically interpreted as resulting from vacuum oscillation at Planck frequency along the second Planck size time dimension T_2. This model is not a cancellation model per se but a sort of spill model. In This framework, energy is interpreted as a vector quantity in space time T_2 (S_1+T_2) as illustrated in figure 6 in section 4. 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 macroscopic spatial dimensions S_1. This includes a very small component of vacuum energy (dark energy) directed into (spilled) the spatial dimension due to a deficit in the Planck density (energy capacity) 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 gravitational wave 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, in this model like in most extra dimensional models, the Universe is seen as a spacetime brane like in the DGP model [14] (Though DGP is modeled 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 time 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 discuss the key dimensional symmetry in RUTE. In section 3, we interpret the nature of time dimension T_1 in the context of our rotating space time structure while reproducing relativistic effects. We also explore in subsection 3.1 an emergent effect of particle antiparticle transmutation and its implications for baryon asymmetry in subsection 3.2. In section 4 we discuss the 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_1, 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 figures 5 and 6. In subsection 4.1, we introduce the DIGIT (Digital Gramophone Interpretation of Time) analogy for pedagogical purpose. In section 5, we achieve an asymptotically vanishing asymmetry between the two vacuum states along time dimension T_2. Then in section 6, we describe how the deficit in Planck density of one of the vacuum states results in a non-zero cosmological constant while in subsection 6.1, a resulting gravitational wave reheating mechanism is examined and discussion follows in section 7.

2. Dimensional Symmetry

Dimensional Symmetry (DIMSY) in RUTE requires that for every macroscopic spacetime dimension, there is a microscopic dimensional partner, doubling the number of functional spacetime dimensions of our universe to 8d [(3+3) + (1+1)]. In this case, the dimensional partner of the macroscopic time dimension T_1, is the Planck size T_2 dimension while for the macroscopic set of spatial dimensions $S_1 = 3d,$ the microscopic counterpart is $S_2 = 3d.$ A key element of RUTE's dimensional symmetry is that the contraction or expansion of a dimension must be balanced by the expansion or contraction of another dimension as the case may be. Since the area A of the two time dimensions T_1 and T_2 is equal to entropy $S = 2\pi r - 1$ (see section 4), T_1 can only expand and T_2 maintains its Planck size which defines the Planck constant and therefore gravitationally inert. T_2 however can oscillate with T_1 to mirror the gravitational wave oscillation of the spatial dimensions provided the surface area of T_1-T_2 remains irreducible due to the entropy constraint (see subsection 6.1). The gravitational contraction of $S_1 = 3$ by positive pressure and energy drives the expansion of time T_1 dimension as shown in figure 1. The expansion of the 3 macroscopic spatial dimensions S_1 driven by negative pressure is required to be fed by the contraction of its microscopic dimensional partner $S_2 = 3d.$

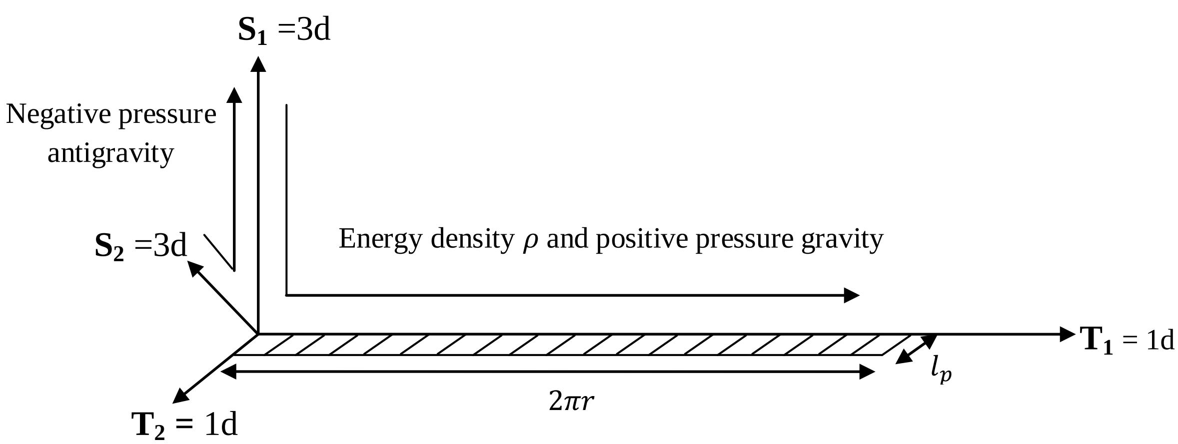

Figure 1: Gravitational traffic across the 7 dimensions of $T1 = 1d, S_1 = 3d$ and $S_2 = 3d$. T_2 is gravitationally inert.

In what follows, we analyze the equation of state constraint of $S_2 = 3$ consistent with $T_1 = 1$ based on the gravitational traffic across the $S_1 \xrightarrow{\rho,+P} T_1$ and $S_2 \xrightarrow{-P} S_1$ dimensions with T_2 being gravitationally inert as illustrated in figure 1.

The number of a dimension N, interacting gravitationally with the 3 spatial dimensions S_1 is given by

$$N = 3/\omega/ \tag{1}$$

Where $/\omega/$ is the absolute value of the equation of state of the most gravitationally attractive or repulsive component existing, which is radiation for $S_1 \xrightarrow{\rho,+P} T_1$ gravitational interaction and Λ for $S_2 \xrightarrow{-P} S_1$.

For the $S_1 \xrightarrow{\rho,+P} T_1$ gravitational interaction, radiation equation of state $\omega_r = 1/3$.

$$T_1 = 3/\omega_r/. \tag{2}$$

Therefore, $T_1 = 1d$ consistent with observation.

For the $S_2 \xrightarrow{-P} S_1$ gravitational interaction, Λ equation of state $\omega_\Lambda = -1$.

$$S_2 = 3/\omega_r/. \tag{3}$$

Therefore $S_2 = 3d,$ giving a total of 8 functional spacetime dimensions [(3+3) + (1+1)]. If however, there exists components with $\omega < -1$, then $S_2 > 3d$ which is observationally ruled out. This further constrains the maximum or minimum ω to be an integral multiple of 1/3 with the maximum being 1/3 for radiation and -1 for Λ.

$$-1 < \omega < 1/3 \quad (4|)$$

3. Nature of Time

The actual nature of time has been a puzzle for both physicists and philosophers [16]. In what follows, we interpret the nature of time as an irreversible progressive effect of motion of a spatial reference frame along either direction of a time dimension. We start by exploring, as shown in figure 2, how the rotation of the brane Universe along its macroscopic time dimension drives time and produces relativistic effects if there is speed deficit along such time dimension.

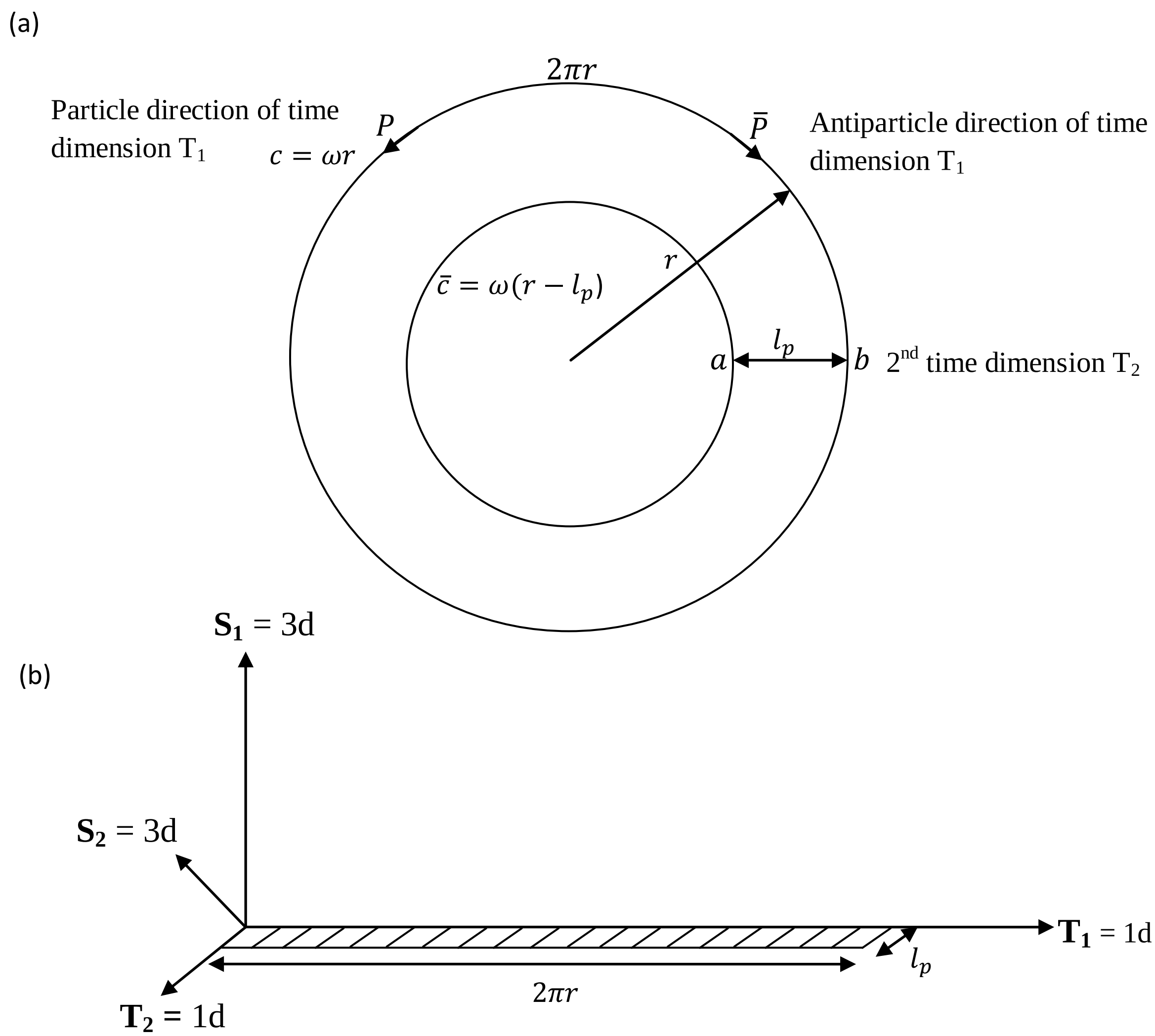

Figure 2: (a) The 2d ring structure of time in RUTE brane universe. The ring thickness (also the brane thickness) which is Planck length l_p in size represents a second time dimension T_2 which we shall discuss in section 4. (b) The 3 macroscopic spatial dimensions S_1, the macroscopic time dimension T_1 and their microscopic dimensional partners S_2 and T_2 respectively.

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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 including spatial momentum reversal. In line with the Feynman-Stueckelberge interpretation, massive particles and antiparticles are modeled as travelling 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_1. 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 inertial 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 $\mathbf{V}$, along the spatial dimensions S_1 must always equal $\mathbf{C}$.

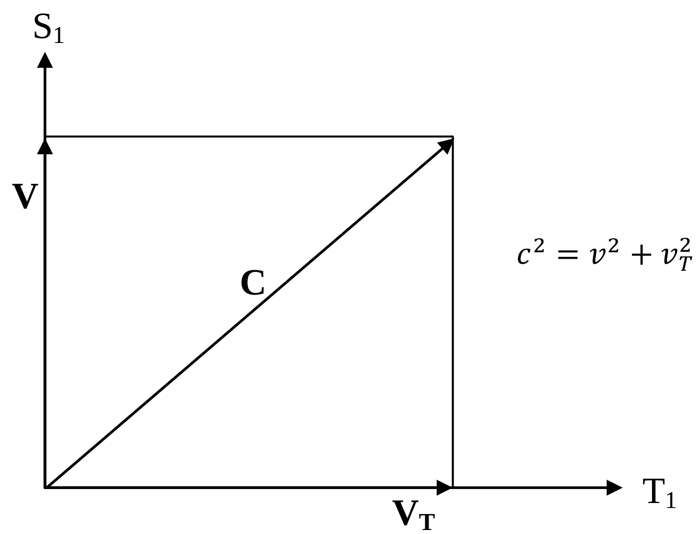

Figure 3: The speed constraint. The magnitude of the vector sum of the spatial and time dimension components of velocity must always equal c.

$$C = V + V_T \tag{5}$$

$$c = \sqrt{v^2 + v_T^2} \tag{6}$$

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

$$v_T = \sqrt{c^2 - v^2} \tag{7}$$

Given the clock rate factor Γ

$$\Gamma = \sqrt{1 - \frac{v^2}{c^2}} \tag{8}$$

Its relative clock rate will be

$$\Gamma = \sqrt{1 - \frac{v^2}{c^2}} \times 100 \tag{9}$$

relative to the reference observer who's clock ticks at

$$\Gamma = \sqrt{1 - \frac{0^2}{c^2}} \times 100\% \tag{10}$$

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

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}. \tag{11}$$

3.1 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

$$P = \frac{v^2}{c^2} \tag{12}$$

With $v = 0$, $P = 0$ for non-relativistic massive particles. But for photons, $p = 1$ making it essentially a superposition of particle and antiparticle state or majorana particle.

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. It is hoped that higher energy run of the LHC, more powerful accelerators or high energy cosmic ray particles will show evidence of such energy dependent transmutation which is more probable at higher energies and with time.

3.2 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.

4. 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 discuss the second time dimension T_2 in this scenario which exists 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.

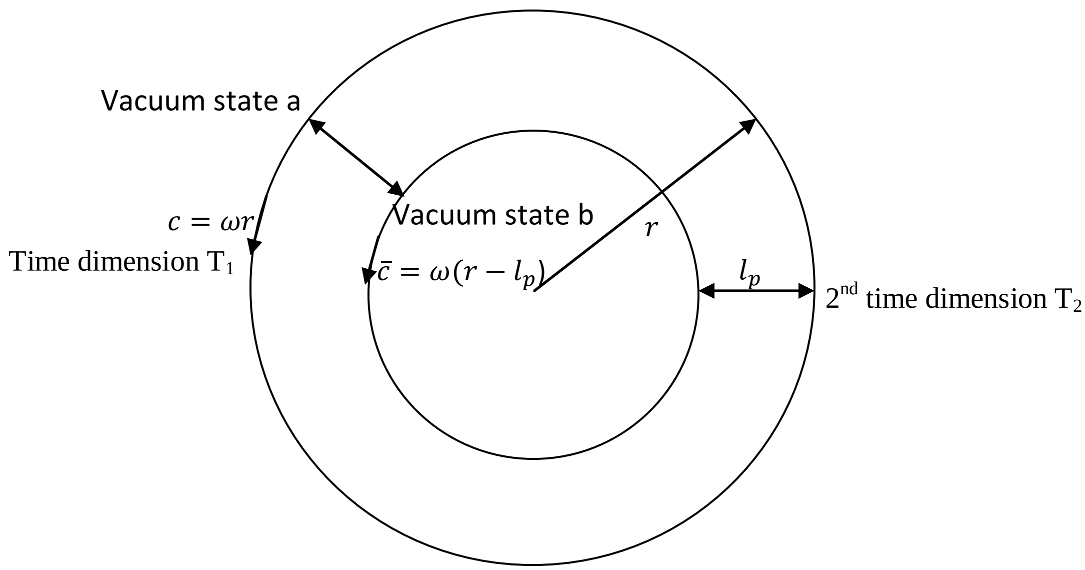

Figure 4: A vacuum reference frame oscillates between the 2 vacuum states a and b along T_2 dimension at the Planck frequency f_{Planck}

Applying the speed constraint to time dimension T_2, a vacuum reference frame (empty space) 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. (6) results in the frequency constraint.

$$f_{\text{Planck}} = \sqrt{f^2 + f_{vac}^2} \quad . \tag{13}$$

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 along T_2 dimension at the Planck frequency

$$f_{\text{Planck}} = \sqrt{f_{vac}^2 + 0}\,. \tag{14}$$

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

$$f = \sqrt{f_{Planck}^2 - f_{vac}^2}\,. \tag{15}$$

This oscillates or ticks with a frequency

$$f_{vac} = \sqrt{f_{Planck}^2 - f^2} \tag{16}$$

along T_2 dimension.

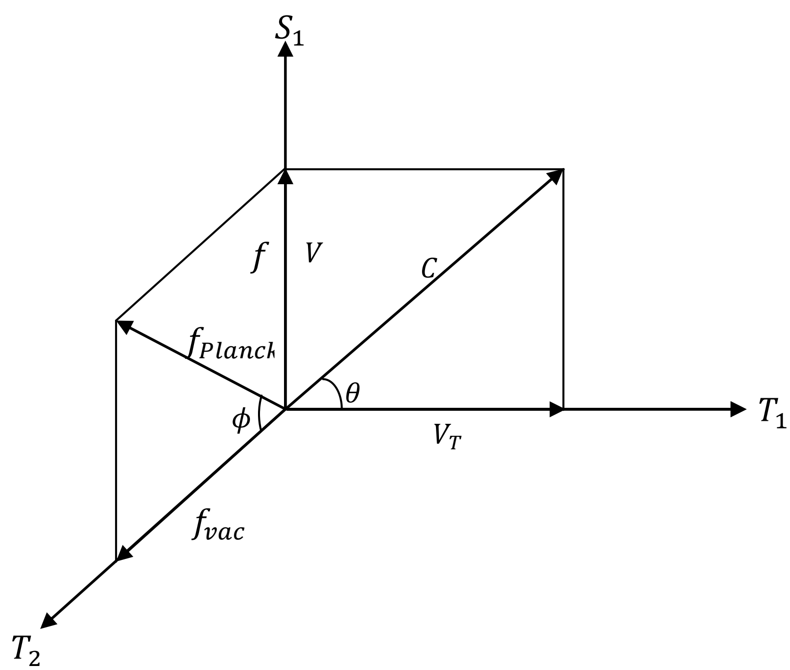

Figure 5: The oscillatory and speed time dimensions T_2 and T_1 in relation to the spatial dimensions S_1.

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.

$$E_{\text{Planck}} = \sqrt{E^2 + E_{vac}^2} \tag{17}$$

$$\rho_{\text{Planck}} = \sqrt{\rho^2 + \rho_{vac}^2} \tag{18}$$

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.

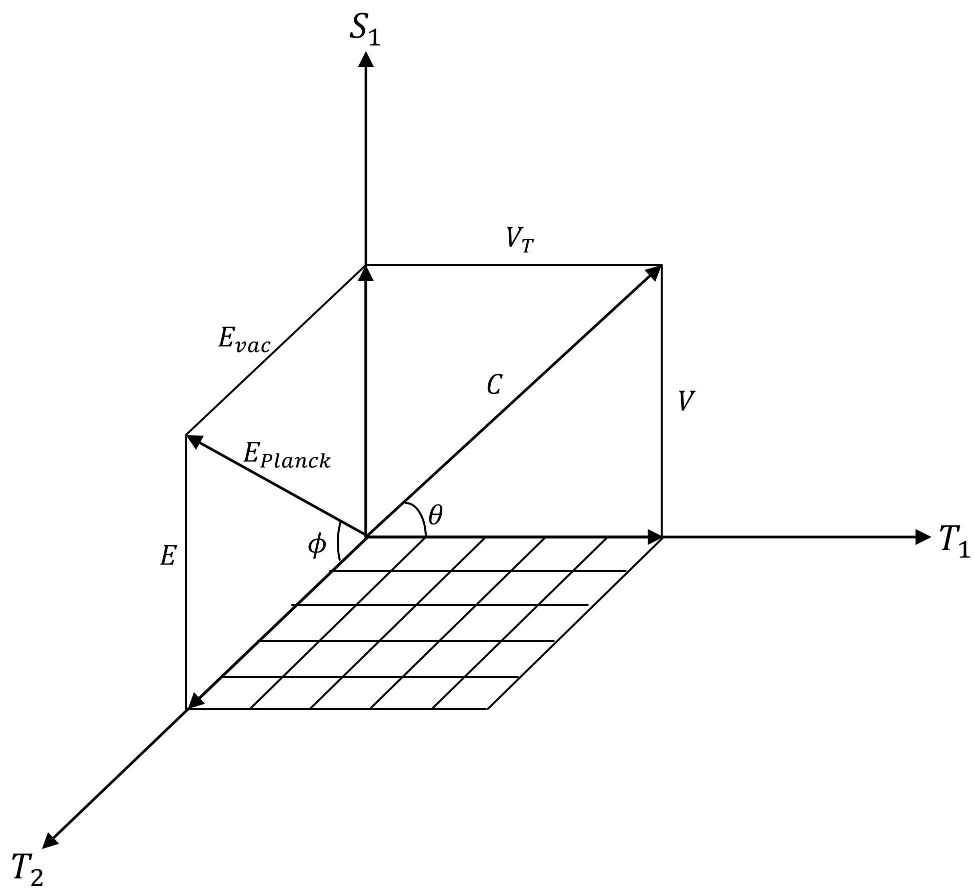

Figure 6: Relativistic relationship between the spatial dimensions S_1 and the 2 time dimensions in terms of speed and frequency or energy constraints. The surface area of the 2 time dimensions gives the entropy of the universe in an analogous way ¼ of a black hole's (event horizon) surface area gives 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 is given by $A = 2\pi r l_p - l_p$. In Planck unit, A gives the entropy S of the Universe as $S = A = 2\pi r - 1$. Where r is the orbital radius of the rotating 2d 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 as discussed in section 1.

Just like in the case of T_1 dimension, if a particle or a reference frame in space time oscillates with a frequency f along the spatial dimensions S, its clock rate along T_2 will tick at

$$\sqrt{1-\frac{f^2}{f_{Planck}^2}}\ \times 100\% \tag{19}$$

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

$$\sqrt{1-\frac{0^2}{f_{Planck}^2}}\ \ \times 100\% \tag{12}$$

hundred percent of the Planck frequency along T_2.

Given the factor Γ

$$\Gamma^2\ = 1-\frac{f^2}{f_{Planck}^2} \tag{21}$$

$$\Gamma = \sqrt{1-\frac{f^2}{f_{Planck}^2}} \tag{22}$$

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

$$\gamma = \frac{1}{\sqrt{1-\frac{f^2}{f_{Planck}^2}}} \tag{23}$$

4.1 Digital Gramophone Interpretation of Time.

Essentially, while T_1 dimension can be described as relatively analogue due to its scale, the T_2 dimension being Planck size can be described as discrete or digital and defines quantum mechanics. In what follows, we introduce the DIGIT analogy (Digital Gramophone Interpretation of Time) within the RUTE framework.

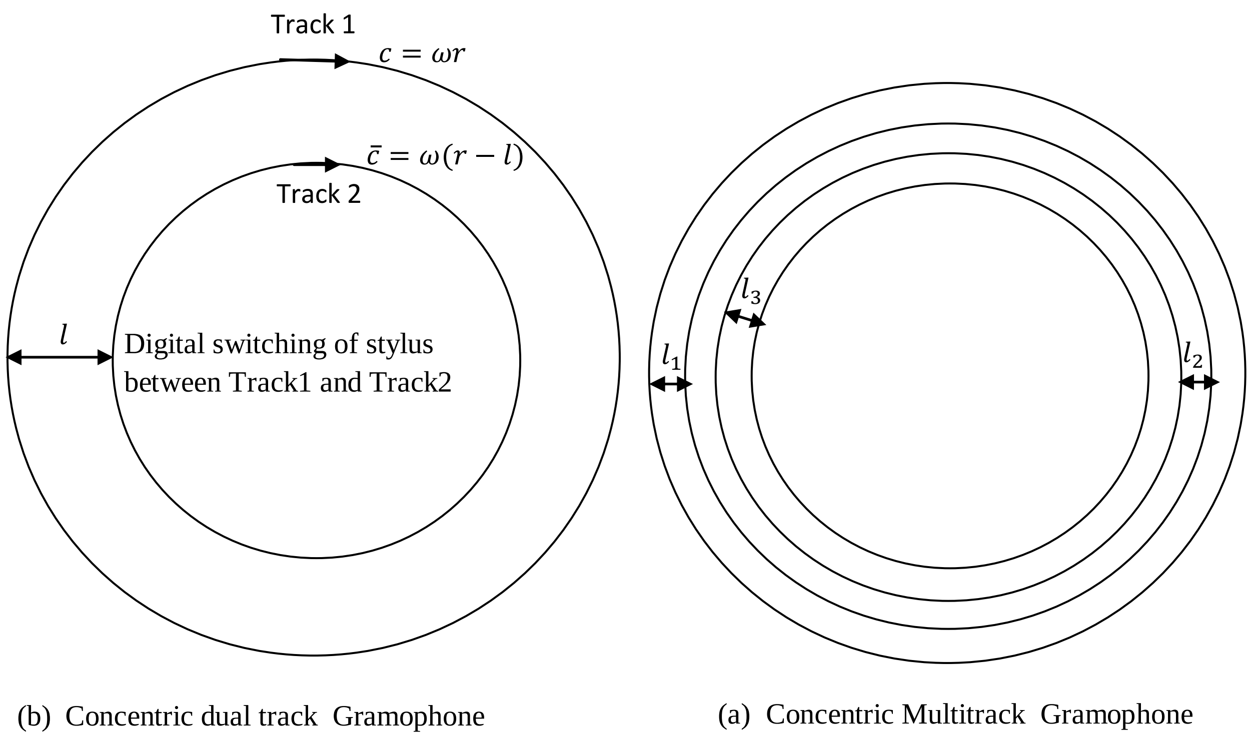

Figure 7: The DIGIT analogy. (a) A dual track gramophone system. While time T_1 for the gramophone system is driven by the analogue rotation of the gramophone record, T_2 is analogously driven by the digital switching of the stylus between two concentric and identical tracks with different rpm c and $\bar{c}$. l is the inter track distance. (b) Multitrack gramophone system.

In figure 5, we used a gramophone record with only 2 identical tracks and a stylus switching between the two, to describe our two dimensional time model. The analogue rotation of the record which drives the progression (play) of the record is analogous to the rotation of the Universe along its T_1 dimension to drive time T_1. The digital switching between the 2 identical but different speed tracks is analogous to the 2^{nd} time progression T_2 which is discrete, while the surface area $A = 2r\pi l - l$ of the record is proportional to its entropy. As illustrated in Fig. 7b, if our universe is part of a multibrane system like this gramophone analogy, then we can have spatially parallel but time concentric universes. Gravitational influence of matter and energy in such spatially parallel universes then manifests as a dark matter component in our universe.

5. 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.

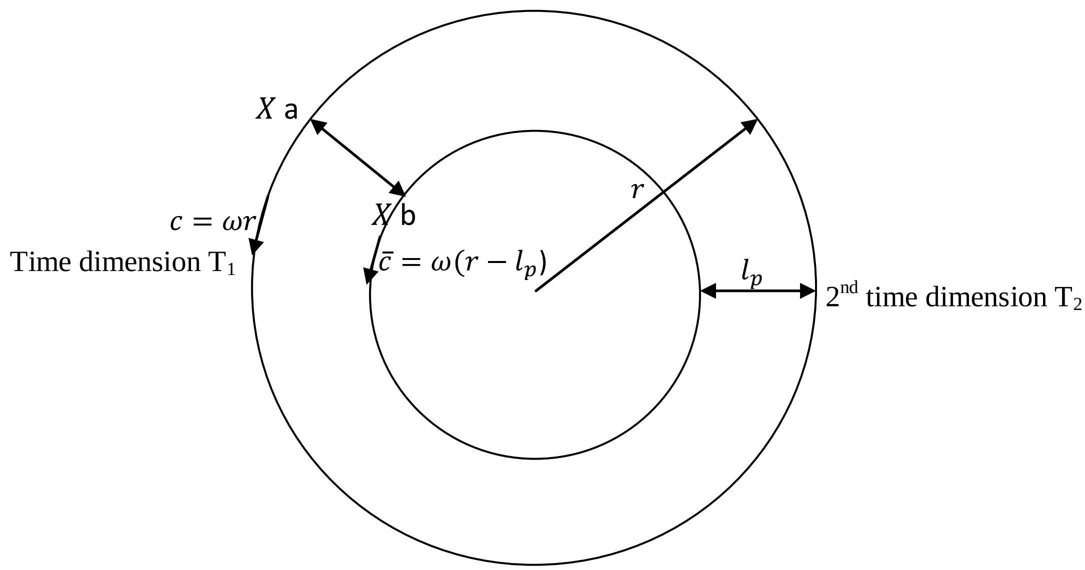

Figure 8: A massless particle x oscillating between two vacuum states a and b along time dimension T_2

As illustrated in figure 8 above, 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 $\bar{c} = \omega(r - l_p)$. 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 $\bar{c} = \omega(r - l_p)$. Where Planck length l_p is the brane thickness or the size of T_2 dimension. The difference in speed ($c - \bar{c}$) between the vacuum states can be described by the cosmological factor Γ.

$$\Gamma = 1 - \frac{\bar{c}}{c} \tag{24}$$

$$\Gamma = 1 - \frac{\omega(r - l_p)}{\omega r} \tag{25}$$

$$\Gamma = \frac{l_p}{r} \tag{26}$$

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

$$\gamma = \frac{1}{1-\Gamma} \tag{27}$$

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

$$\gamma = \frac{r}{r-l_p} \tag{28}$$

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. (26) 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 ($2\pi r$).

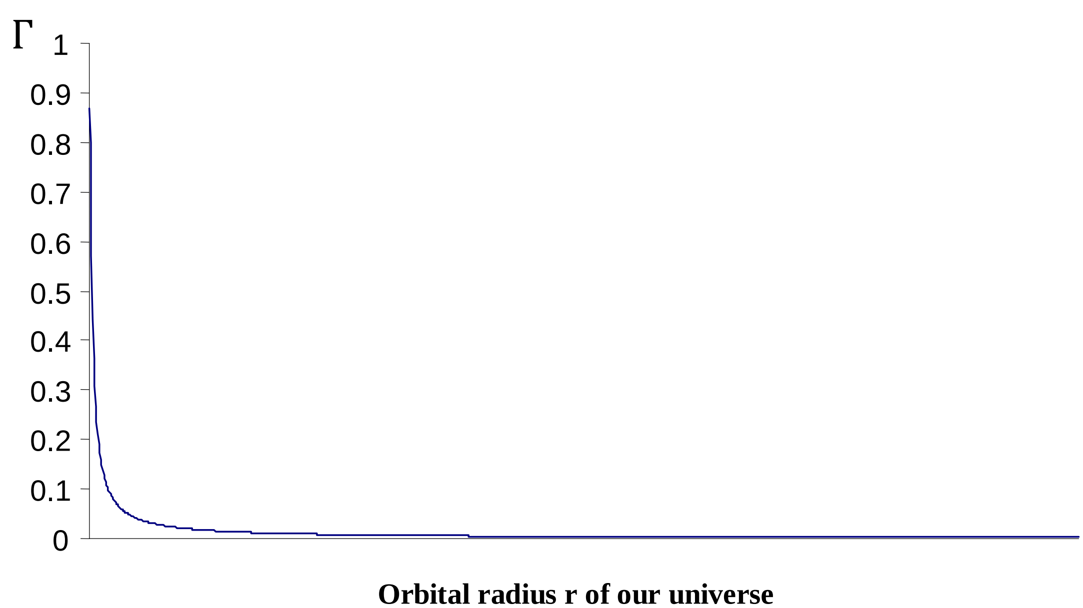

Figure 9: The asymptotic vanishing of Γ with the growth of orbital radius r.

6. 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.

$$\rho_{planck} - \bar{\rho}_{planck} = \Gamma^2\, \rho_{planck} \qquad (29)$$

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

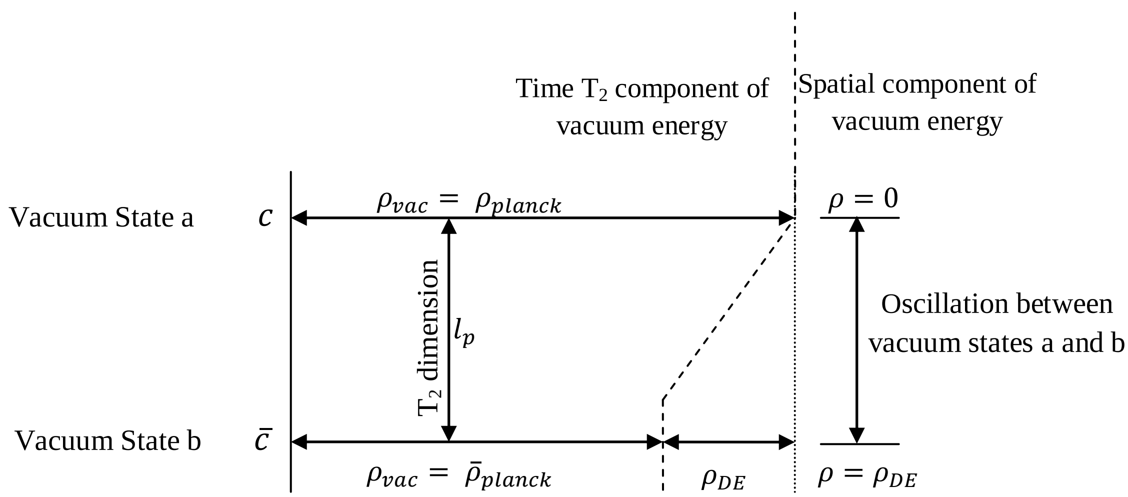

Figure 10: Asymmetry between vacuum states a and b with densities $\rho_{planck} > \bar{\rho}_{planck}$. The vacuum oscillates between states a and b. When at vacuum state a, the time dimension T_2 Component has the maximum value of energy density $\rho_{vac} = \rho_{planck}$ and zero spatial value $\rho = 0$. When at vacuum state b, the T_2 dimension component has a deficit value of energy density $\rho_{vac} = \bar{\rho}_{planck}$ and therefore the spatial component of vacuum energy $\rho = \rho_{DE} \neq 0$ 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 4, 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_1. Therefore, as the vacuum oscillates at f_{planck}, moving from state a to state b as shown in figure10, the resulting deficit along T_2 as the energy density changes from ρ_{planck} to $\bar{\rho}_{planck}$ has to be compensated for with the emergence of dark energy ρ_{DE} along the spatial dimensions where

$$\rho_{DE} = \Gamma^2 \rho_{planck} \quad (30)$$

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

$$\Lambda = \frac{8\pi G}{c^4}\rho_{DE} \quad (31)$$

With Γ evolving asymptotically 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 $r \gg l_p$, $\Gamma \to 0$ and with reheating effectively ending inflation and leaving a residual asymptotically vanishing cosmological constant now driving the late time acceleration of our Universe.

6.1 Gravitational Wave Reheating Mechanism

In RUTE with two time dimensions, where gravity drives the expansion of the time dimension T_1, a Gravitational Wave (GW) oscillation along the spatial dimensions S_1 has to be mirrored by a corresponding GW oscillation along the T_1-T_2 time dimensions. In what follows, we examine how the T_1-T_2 component of the GW oscillation gives rise to reheating. GW oscillation as seen at the fundamental Planck scale, is essentially an oscillation of the Planck length l_p, while the Planck area A_p is non reducing.

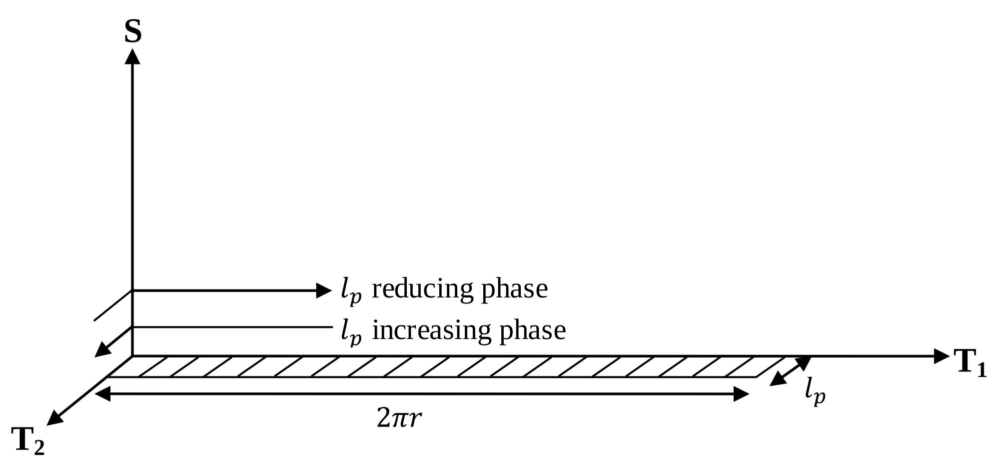

Figure 11: Time T_1-T_2 dimension component of gravitational wave oscillation where one time dimension expands at the expense of the other and vice-versa while keeping Area constant (entropy constraint).

At this Planck scale, GWs simply increase Planck length in one dimension while decreasing it in another, keeping the Planck area and volume constant. During GW oscillation of l_p of T_2 dimension, an expansion or contraction in l_p of T_2 must be balanced by a corresponding contraction or expansion of T_1 respectively, to keep area and entropy from reducing.

During the l_p (size of T_2) increasing phase of GW oscillation, vacuum oscillation frequency $f = c/l_p$ drops by a factor h_g which is the gravitational wave amplitude. Given that $E = hf$ and with h being constant, the energy and hence energy density ρ_{vac} of such reference frame drops by the same factor h_g, thereby projecting a corresponding amount of energy density $\rho = h_g \rho_{planck}$ into the spatial dimensions due to the energy conservation constraint in RUTE, manifesting as photons or other Standard Model particles depending on the energy scale.

During the l_p reducing phase of the GW oscillation, the vacuum oscillation frequency of the reference frame is prevented from increasing by the factor h_g as this would also increase the vacuum energy density ρ_{vac} above the Planck density by the same factor h_g violating the energy conservation constraint. Instead, vacuum oscillation frequency is pegged at the last deficit value during l_p increasing phase, while the oscillation speed V_{T2} drops from c by h_g ($V_{T2} = h_g c$). That is, $f_{vac} = V_{T2}/l_p$. This preserves the energy earlier spatially released during l_p increasing phase. As the GW oscillation continues propagating, it should progressively get attenuated as Standard Model particles are being created from the vacuum in its wake.

Thus RUTE provides an ideal reheating mechanism whereby Inflationary Gravitational Waves (IGWs) imprints its unique signature in the primordial density distribution of the created particles.

7. Discussion

Using a rotating and oscillating 2 dimensional ring model of time which we have developed, we have provided an elegant resolution of the cosmological constant problem in this paper. In achieving this, we defined the nature of time as an irreversible progression driven by motion of a spatial reference frame along either direction of 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 as illustrated in subsection 4.1 using the DIGIT analogy (DIgital Gramophone Interpretation of Time) within this RUTE framework.

Another important milestone within this framework, is the interpretation of energy as a vector quantity in space-timeT_2 (i.e. Spatial + T_2 time dimension) and only appear locally as a scalar quantity in spatial dimensions S. 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 spacetime 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 also results in the spatial availability of energy or momentum respectively. 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_1 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's effect along T_2. Despite the asymmetry, vacuum contributions from vacuum states a and b gives:

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

i.e.

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

Where G and $\bar{G}$ are the gravitational constants for vacuum states a and b respectively.

Since

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

and

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

The asymptotically evolving nature of the deficit vacuum energy which emerges as dark energy is described by the cosmological factor Γ. Γ~1 in the early Universe provided a Planck scale Λ that can automatically power 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 a Planck energy scale particle. Such particle creation mechanism can reheat the Universe during and after inflation. However as discussed in subsection 6.1 IGWs can reheat the universe during and after inflation obviating the need for scalar field driven inflation. Detailed analysis of this reheat mechanism is expected in future work.

The energy density constraint 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 $S = 2\pi r - 1$) in an analogous way the surface area A of the event horizon of a black hole describes its entropy S (with $s = \frac{1}{4}A$). 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 3.1 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 $\bar{c}$ (Where $\bar{c}$ is the deficit speed of vacuum state b) at a frequency $f_{vac} = \sqrt{f_{Planck}^2 - f^2}$. Again the size of 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.

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

$r = \frac{l_p}{\Gamma} \sim 10^{25} m$ and $\Gamma \sim 10^{-60}$, we should have a present cycle period $t_{p \leftrightarrow \bar{p}} = \frac{2\pi r}{c} \sim 10^{17} s$ though progressively more frequent in the earlier Universe with smaller r. The effect of this on the spin reversal of spiral galaxies should provide some observational constraints regarding previous reversals.

In all of this, the DIMSY requirement which doubled the spacetime dimensions here is key and the very idea of using the equation of state of radiation and Λ to constrain the number of functional spacetime dimensions is interesting. If spacetime is quantized according to loop quantum gravity [21], then as the contracting extra spatial dimension S_2 reach the minimum Planck scale, the expansion of the 3 macroscopic spatial dimensions S_1 stops, leading to the contraction of our Universe as gravity reigns. 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. What happens from this point depends precisely on the nature of quantum gravity. Nevertheless, if contraction is to proceed, the spatial energy content of the Universe has to be emptied into the T_2 dimension until the Hubble length reaches the Planck scale.

Although RUTE is still in its infancy, as a fundamental model of spacetime structure and its energy content, it demonstrates a holistic approach to the resolution of the cosmological constant problem among other unsolved problems in Physics. Going forward however, there is still a lot of work to be done such as clearly relating the required expansion of T_2 dimension during Λ driven inflation to produce the observed scalar spectral index, clearly connecting general relativity and quantum mechanics, and accounting for the Standard model of particles and forces among others. But most importantly, RUTE is a testable and viable model.

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