RUTE Model

Nature of Dark Energy and Prospect of Vacuum Energy Extraction

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Abstract

A cosmological constant (Λ) dark energy capable of early universe inflation is described within the frame work of the Rotating Universe interpretation of Time and Energy (RUTE). RUTE is a model of spacetime consistent with entropic gravity and has a key dimensional symmetry that doubles the number of spacetime dimensions with microscopic dimensional partners. Its energy density constraint provides a spill model of dark energy sensitive to matter and radiation presence and a Gravitational Wave Reheating (GWR) mechanism. Recent observational constraints for gravitational wave and gamma ray counterpart are consistent with RUTE's GWR – a shake-spill mechanism of vacuum energy extraction. In this scenario, gravitational waves of a given frequency with strain above a threshold are predicted to release Standard Model (SM) photons from vacuum energy. Verifiable predictions are briefly discussed.

1. Introduction

Dark energy have so far constituted an enigma since 1998 after Riess et al.[1] followed by Perlmutter et al.[2] published their supernova observations of the accelerated expansion of our Universe. 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 the 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 new Physics. Such a solution should also provide some clues to other problems like the Physics of inflation, baryogenesis, and the nature of time among others.

In this paper, we approach the Λ problem using the RUTE model we have developed. RUTE is not a cancellation model since vacuum energy is gravitationally insensitive (See the next section). In this scenario, vacuum energy is gravitationally inert and unavailable for useful work in visible 3d space because zero point oscillations are restricted to a Planck size extra dimension. Here dark energy is modeled as a spill component of vacuum energy that had inflationary energy scale in the early universe before it asymptotically fell to its present energy scale. It is well known however, that a Λ driven inflation usually suffer from the graceful exit and reheating problems as attempted in [13]. This can be resolved with an asymptotically falling Λ and the Gravitational Wave Reheating (GWR) mechanism provided by this framework for releasing some component of vacuum energy from the microscopic extra dimension into the visible spatial dimensions first as Standard Model (SM) photons before pair creation and annihilation of other SM particles, obviating the need for a scalar field driven inflation.

Another key element of RUTE is the interpretation of time as an irreversible progression of events in a spatial reference frame driven by the relative motion of that reference frame along either direction of a spacelike time dimension. It differentiates between time as an entropic effect and time as a space-like dimension. Indeed such separate interpretations of time as a progressive effect and time as a space like dimension provides an extra degree of freedom in tackling the dark energy problem. A problem that still requires a Planck size spacelike partner of the known entropic time dimension. The idea of two time dimension had been suggested in [14] although in a different context of SM particles and forces.

2. The RUTE Framework.

RUTE is an 8 dimensional model of spacetime structure. Its dimensional symmetry requires that for every macroscopic spacetime dimension, there is a microscopic dimensional partner with a negative dimension number D_N. This is such that the total dimension number of the universe adds up to zero. In this case, the dimensional partner of macroscopic time dimension T_1 is a Planck size T_2 dimension ($T_2 = -1d$) where as for the macroscopic set of visible spatial dimensions S_1, the microscopic counterpart is S_2 dimensions ($S_2 = -3d$).

2.1 Entropic Gravity

While RUTE is in agreement with general relativity, it is also in agreement with recent developments in entropic gravity [15]. Here, attractive gravity is caused by any change in information encoded in visible 3d space due to presence of mass/energy or changes in particle position or even changes in the curvature of spacetime (gravitational waves). Presence of negative pressure on the other hand does not constitute entropy change in 3d space and therefore can't be gravitationally attractive. It follows that it has to be repulsive according to general relativity.

2.2 Insensitive Vacuum Energy

Vacuum energy in this framework is gravitationally insensitive because it does not encodes any information changes in visible 3d space and its oscillations are restricted to a Planck size extra dimension. The spacetime metric is only sensitive to component of vacuum energy oscillation that gets directed (spills) into the visible 3d space as dark energy. This spill mechanism is discussed in section 5.

2.3 Volume constraint and entropic gravity

The volume constraint simply infers that the 8d volume of the universe is constant. That is, the contraction or expansion of any dimension must be balanced by a corresponding expansion or contraction of another dimension. While the gravitational contraction of S_1 by positive pressure and energy drives the expansion of spacelike time dimension T_1 as shown in figure 1, the expansion of S_1 driven by negative pressure is required to be fed by the contraction of its microscopic dimensional partner S_2.

In this scenario, any entropy change (change in encoded information) in the visible spatial dimension is required to be encoded on the ring like surface of spacelike time dimension T_1- T_2. Interestingly, the length of time dimension T_1 in Planck Unit is equal to the entropy of the universe.

$$S = 2\pi r \tag{1}$$

.

Where r is the radius of the space-like time dimension due to its ring like structure.

It follows that any change in entropy (or change in information in Planck unit) encoded in visible 3d space, reduces its volume to increase the length of the spacelike time dimension T_1 by one Planck unit.

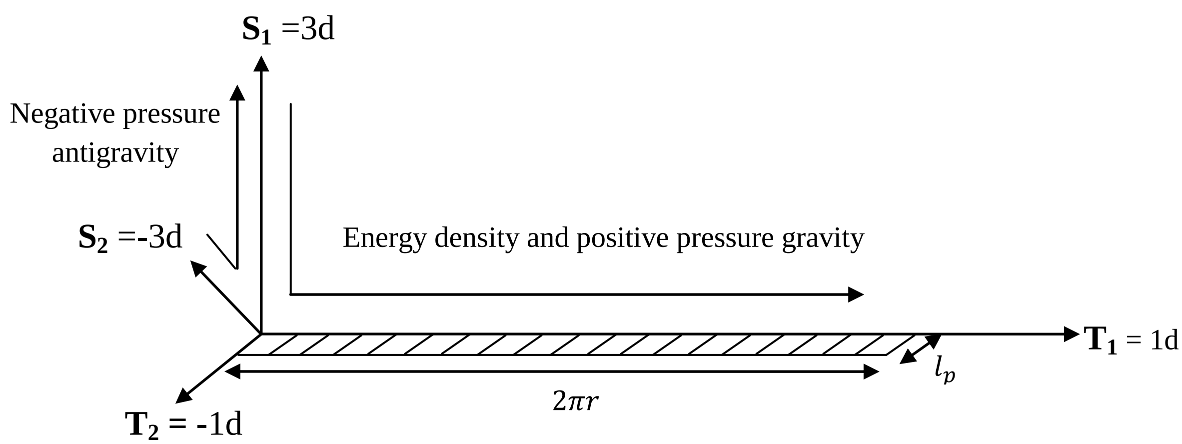

Figure 1: Gravitational flow across the 7 dimensions of $S_1 = 3d$, $T_1 = 1d$, and $S_2 = -3d$. T_2 is constant.

3. Nature of Time

The actual nature of time has been one of the unsolved problems in Physics [16]. RUTE essentially interpret time as an irreversible progressive effect of motion of a spatial reference frame along either direction of a time dimension. There is difference between time as an effect and time as a dimension. In essence while a time dimension is space-like, it is the motion of a reference frame along either direction of such dimension that drives time as an irreversible entropic progression. In this scenario, it is the rotation of the brane universe along its macroscopic time dimension that drive time as we know it and relativistic effects such as time dilation results from speed deficit along such dimension.

In line with the Feynman-Stueckelberge interpretation, particles and antiparticles travels in opposite directions along the spacelike time dimension T_1, as illustrated in figure 2. 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

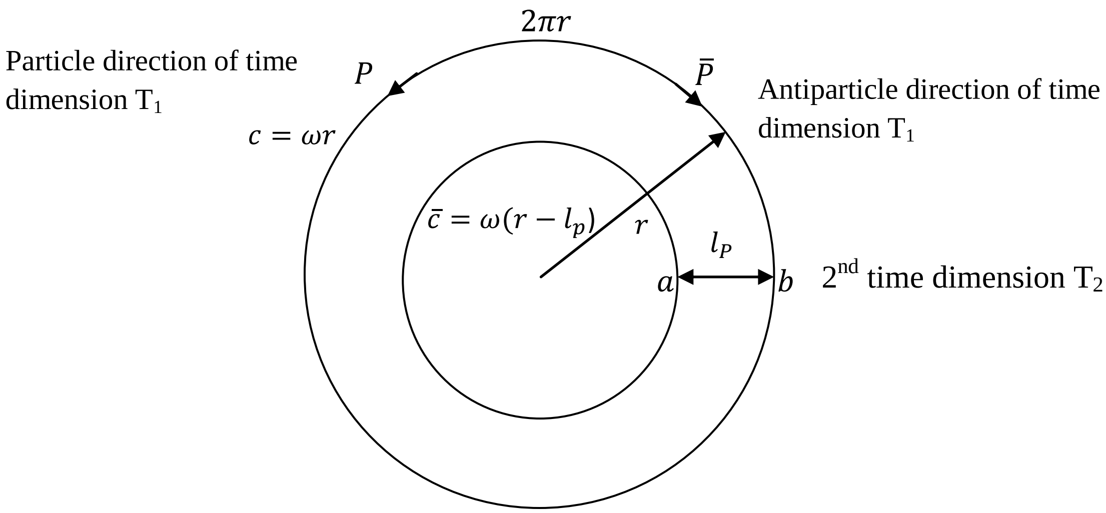

Figure 2: The 2d ring structure of time in RUTE brane universe. The ring thickness (brane thickness) which is Planck length l_P in size represents a space-like second time dimension T_2.

3.1 Speed Constraint

Given the speed of light constraint from special relativity and associated relativistic effects, the interpretation within the RUTE framework requires that all reference frames must always travel at speed of light c through combined spacetime dimensions. That is the vector sum of its velocity $\mathbf{V_T}$ along spacelike time dimension T_1 and velocity **V**, along the spatial dimensions S_1 must always equal **C**.

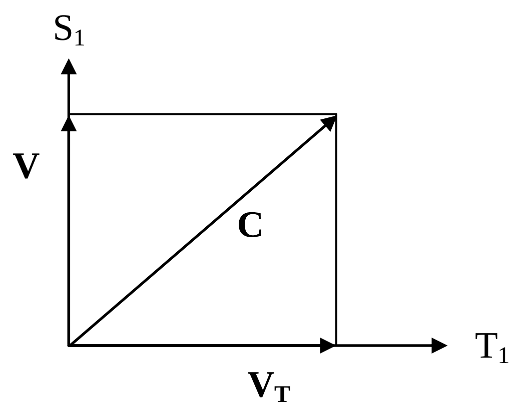

Figure 3: The speed constraint. It is required that the magnitude of the vector sum of the spatial and time dimension components of velocity of must always equal c.

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

For a spatial reference frame or massive particle with spatial velocity v (relative to an observer), its velocity v_T component along the spacelike time dimension T_1 can be expressed as

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

Its clock rate factor Γ can be expressed as the ratio of its speed along the spacelike time dimension to the speed of light

$$\Gamma = \frac{\mathrm{v_T}}{c} \tag{4}$$

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

The inverse of the clock rate factor gives the Lorentz factor

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \tag{6}$$

4. Second Time Dimension

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 is the Planck size brane thickness with which the speed constraint equally applies. Its Planck size and reflective boundary condition makes it an oscillatory time dimension.

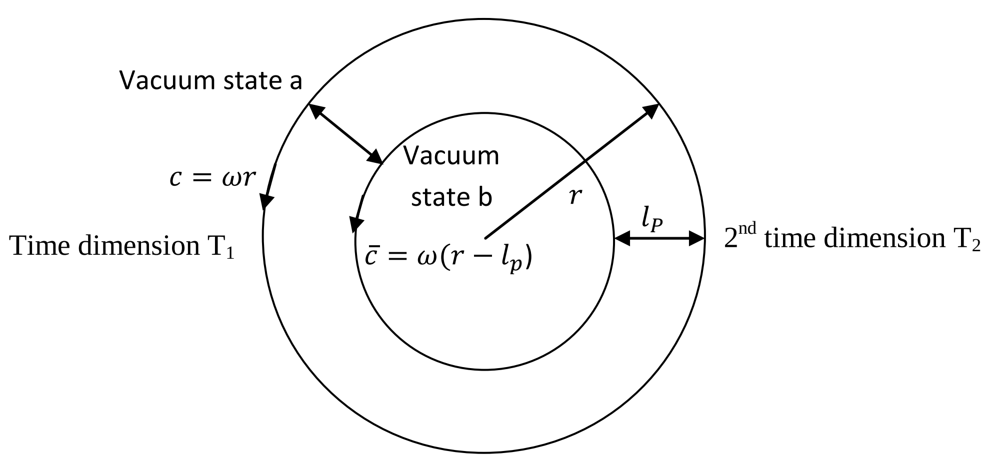

Figure 4: A vacuum reference frame oscillates between the 2 vacuum states a and b with different speed limits c and $\bar{c}$ along T_2 dimension at the Planck frequency f_{Planck}

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 and there is a difference in speed limit c and $\bar{c}$ between the 2 states. This difference in speed ($c - \bar{c}$) between the vacuum states can be described by the cosmological factor Γ.

$$\Gamma = \frac{(c-\bar{c}\ )}{c} \tag{7}$$

$$\Gamma = \frac{l_p}{r} \tag{8}$$

And $0 < \Gamma < 1$, asymptotically approaching zero with growth of entropy $2\pi r$
The factor $\frac{\Gamma}{2\pi}$ gives the relative size of the two time dimensions T_1 and T_2.

4.1 Energy Density Constraint

If we apply the speed constraint to time dimension T_2, then 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. (2) results in the frequency constraint.

$$f^2_{\text{Planck}} = f^2 + f^2_{vac}. \tag{9}$$

Where f_{vac} is the vacuum oscillation frequency along T_2 dimension and f is the oscillation frequency along the spatial dimensions S_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.

$$E^2_{\text{Planck}} = E^2 + E^2_{vac} \tag{10}$$

$$\rho^2_{Planck} = \rho^2 + \rho^2_{vac} \tag{11}$$

Where E and E_{vac} are the energy of a particle and its associated zero point 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 frame and its component vacuum energy density ρ_{vac} along time dimension T_2 must always equal the upper limit of the Planck density ρ_{Planck}. The reference to upper limit here is due to an intrinsic asymmetry between the 2 vacuum states along T_2 dimension. 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 in [17].

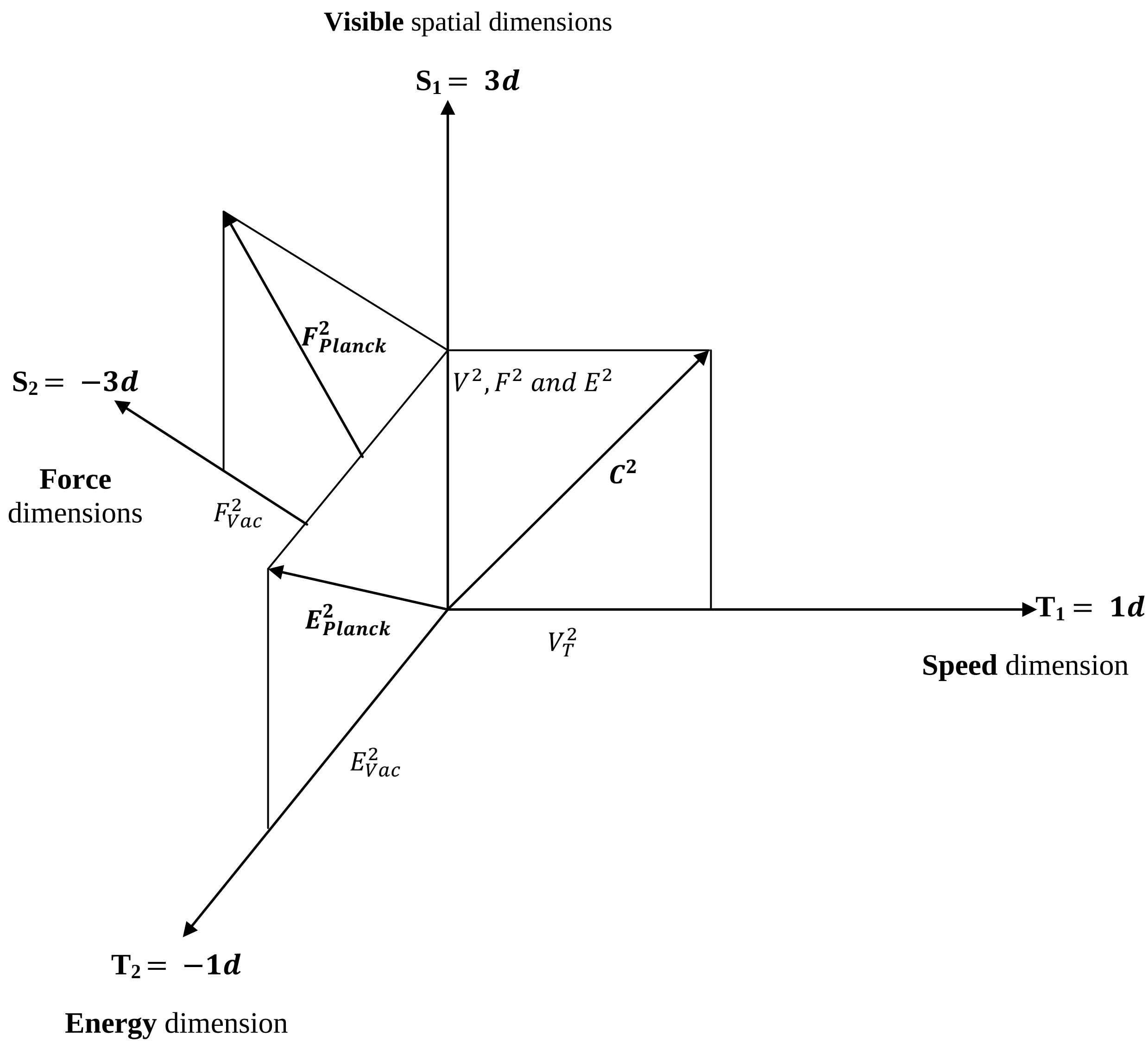

Figure 5: The basic structure of 8 dimensional spacetime showing the relative projections of Velocity, Energy and Force into the visible spatial dimensions S_1.

5. Cosmological Constant Dark Energy

The speed limit asymmetry discussed in section 4 results in the following relationship between the 2 vacuum states.

$$\rho_{Planck} - \bar{\rho}_{Planck} = \Gamma^2 \rho_{Planck} \tag{12}$$

Where ρ_{Planck} is the maximum vacuum energy of vacuum state a with a maximum speed limit c as illustrated in figure 5 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 radius r .

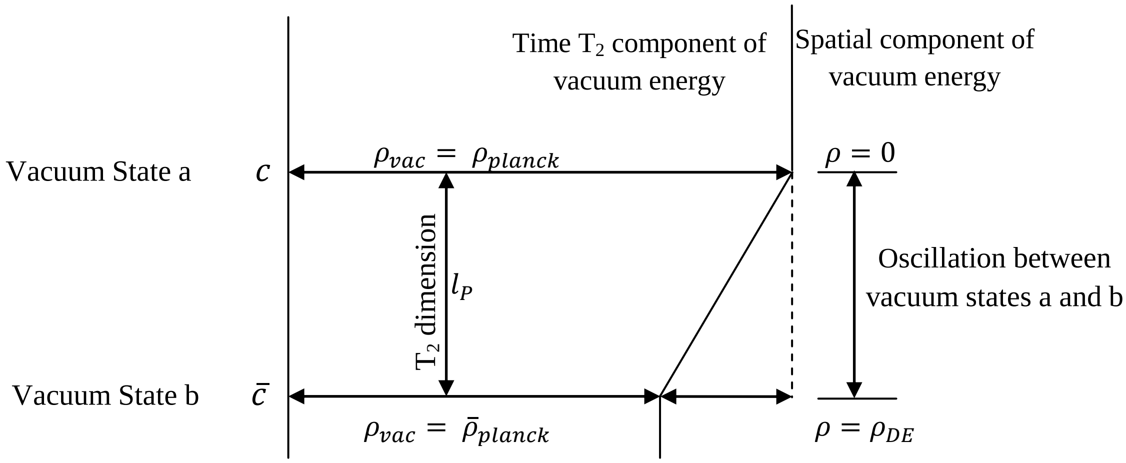

Figure 6: Asymmetry between vacuum states a and b with densities $\rho_{planck} > \bar{\rho}_{planck}$. The vacuum oscillates between states a and b. At vacuum state a, the time dimension T_2 Component has the maximum value of energy density $\rho_{vac} = \rho_{planck}$ and zero spatial value $\rho = 0$. 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 density constraint $\rho_{Planck}^2 = \rho^2 + \rho_{vac}^2$.

Given the energy density constraint where 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 zero point oscillation 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 figure 6, 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

$$\rho_{DE} = \Gamma^2 \rho_{planck} \tag{13}$$

With equation of state $\omega = -1$, it results as a negative pressure cosmological constant

$$\Lambda = \frac{8\pi G}{c^4}(\rho_{DE} + 3P) \tag{14}$$

With Γ evolving asymptotically with the growth of entropy, Λ runs in a step wise manner. In the early universe with $r \sim l_P$ and $\Gamma \sim 1, \Lambda \sim \mathrm{M}_{\mathrm{Planck}}^4$ enough to power the inflation of the early Universe. However the energy scale here asymptotically falls from the Planck scale with increasing entropy of the universe and with reheating effectively ending inflation and leaving a residual asymptotically vanishing cosmological constant now driving the observed late time acceleration.

Due to the energy density constraint, the presence of an energy scale (such as matter and radiation presence) above ρ_{DE} at any given moment prevents a spill making the density of dark energy zero at that point in space. In this case eq. (13) becomes

$$\rho_{DE} = \Gamma^2 \rho_{Planck} - \rho_T \tag{15}$$

Where ρ_T is the local matter and radiation density and $\rho_{DE} = 0$ when $\rho_T \geq \Gamma^2 \rho_{Planck}$.

Given a volume of space, the average density of dark energy ρ_{DE} can then be expressed as

$$\rho_{DE} = \int (\Gamma^2 \rho_{Planck} - \rho_T)\, dv \tag{16}$$

6. Gravitational Wave Reheating (GWR) 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 can be mirrored by a corresponding GW oscillation along the T_1-T_2 time dimensions. In what follows, we examine how a T_1-T_2 component of the GW oscillation produces heating effect on empty space releasing some vacuum energy as standard model photons. GW oscillation as seen at the fundamental Planck scale in this frame work is essentially an oscillation of the Planck length l_P, while the Planck area A_P remains constant.

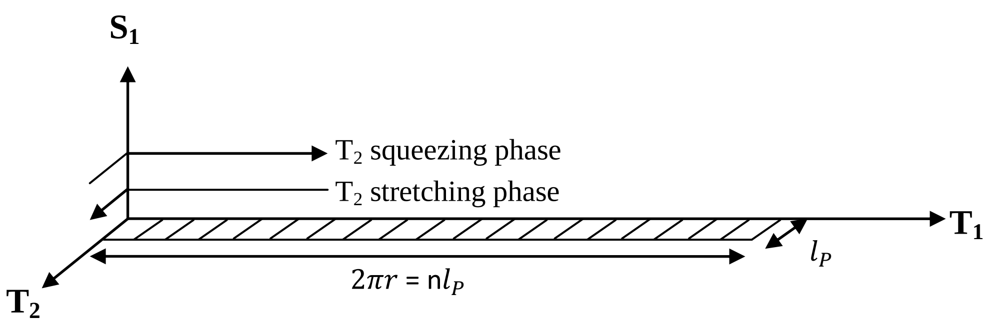

Figure 6: Spacelike time dimension T_1-T_2 component of gravitational wave oscillation where one time dimension is stretched at the expense of the other and vice-versa while keeping area constant.

At the 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 T_1-T_2 dimension, an expansion or contraction of T_2 is balanced by a corresponding contraction or expansion of T_1 respectively.

During T_2 stretching phase of GW oscillation, vacuum oscillation frequency and hence vacuum energy density reduces by the same factor as the gravitational wave strain h. Due to the energy density constraint, this results in the release of a corresponding amount of energy E into the visible spatial dimensions as photons with energy E. It is not reversed during the contraction phase.

$$E = hE_P \tag{17}$$

However due an Active Vibration Isolation mechanism involving destructive interference, the actual strain A of T_1-T_2 oscillation can be expressed as

$$A = h - k \quad (18)$$

Where k is the strain of an interfering gravitational wave causing destructive interference, making A essentially zero, hence no photon emission occurs. But k has a maximum value k_{max}. This leads to a threshold amplitude h_0 above which T_2 can undergo gravitational oscillation such that reheating occurs. Eq. (17) becomes

$$E = (h - k)E_P \quad (19)$$

Or simply

$$E = AE_P \quad (20)$$

As the GW oscillation continues, it should continuously create standard model photons from the vacuum in its wake until its strain falls below the threshold. Thus RUTE provides an ideal reheating mechanism for a Λ driven inflation. In this case, inflationary gravitational waves readily reheated the universe with high energy gamma radiation during and immediately after inflation until the amplitude fell below the threshold. This implies that powerful astrophysical sources of gravitational waves should have Gamma Ray Bursts (GRB) secondary. Therefore GRBs need to be investigated in the light of RUTE's Gravitational Wave Reheating mechanism.

The detection of Gravitational wave event GW150914 [18] has opened an observational window. The detection of Gamma Ray Burst counterpart GW150914-GBM [19] 0.4 seconds later corresponding to 66% of the strain amplitude indicates that there is a threshold strain h_0 for Gravitational Wave Reheating. Future joint Gravitational Wave and GRB counterpart observations should provide further observational evidence and constraint for Gravitational Wave Reheating and associated parameters.

6.1 Prospect of vacuum energy extraction.

In RUTE, gravitational waves are required for the extraction of vacuum energy but the conventional way of generating them requires astronomical amount of mass-energy. This is worsened by the high threshold strain required before reheating can occur. Therefore any effort to extract vacuum energy for energy generation purpose will have to rely on the astrophysical gravitational wave background and a way to lower the threshold amplitude by possible disruption of the Active Vibration Isolation mechanism (AVI) that tends to prevent the T_2 dimension from gravitationally oscillating. More research effort is required in this regard as this not only potentially provides a means to generate energy but also a potentially effective window for detecting gravitational waves.

7. Discussion

RUTE with its key dimensional symmetry and interpretation of time, has provided an elegant solution to dark energy's cosmological constant problem. Specifically, it is a spill model of Λ. It relies on the nonentropic and therefore gravitationally inert nature of vacuum energy oscillations directed along a Planck size extra dimension, and an energy density constraint. The energy density constraint ensures that the total energy density available in the visible spatial dimension and vacuum energy must always equal the Planck density. Vacuum energy oscillation between two unequal vacuum energy states ensures a spill of vacuum energy into the visible spatial dimensions as dark energy as described by the asymptotically evolving 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. Moreover spatial variation of such dark energy is predicted as it is sensitive to presence of matter and radiation. As a direct consequence of energy constraint, any energy scale higher than that of dark energy tends to suppress it by preventing a spill. Such spatial variation should be measurable with precision measurement.

The energy density constraint also forbids all forms of infinite energy densities like black hole and big bang singularities. Just like the speed constraint it was derived from, exceeding the Planck density is equivalent to exceeding the speed limit c. Instead, black holes are replaced with Planck stars like in [18]. Moreover, the vacuum energy density in such a Planck star must be zero, since the spatial component is already at the maximum Planck value which may lead to the breakdown of quantum mechanics.

RUTE's Gravitational Wave Reheating mechanism is also an interesting outcome of the energy constraint where gravitational waves release vacuum energy as electromagnetic counterpart. This conveniently provides a reheating mechanism for Λ driven inflation obviating the need for scalar field inflation. Powerful astrophysical gravitational waves should always have gamma ray counterpart once their strain exceeds a threshold. Therefore Gamma Ray Bursts needs to be investigated in association with astrophysical sources of gravitational waves.

It is also interesting, how the length of the spacelike time dimensions T_1 describes 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. This agreement with entropic gravity, raises the question: Is our Universe a holographic one in a much bigger and older Universe as also suggested in [20]?

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.

Beyond its testability, RUTE tends to provide solution to other unsolved problems in Physics like the nature of time and Physics of inflation. The commencement of gravitational wave astronomy provides an observational tool to test some of its predictions. Interestingly the first signal detected was accompanied by a gamma ray burst which is consistent with the reheating prediction and can have far reaching implications on gravitational wave detection and even the prospect of vacuum energy extraction if confirmed with more data.

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