RUTE Model

Nature of Dark Energy and Prospect of Vacuum Energy Extraction

Kabir Adinoyi Umar

Department of Physics, Kogi State University Anyigba

kabir_umar@yahoo.com

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 structure 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 and a Gravitational Wave Reheating (GWR) mechanism while ruling out infinite densities such as in black holes. 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, vacuum energy is gravitationally inert and unavailable for useful work in visible 3d space because it is restricted to a Planck size extra dimension. Gravitational waves of a given frequency with strain amplitude above a threshold are predicted to release Standard Model (SM) photons from vacuum energy into visible 3d space. A number of related prospects and verifiable predictions are briefly discussed.

Content

1. **Introduction** **3**

2. **RUTE framework** **5**

3. **Nature of time** **7**
   3.1 Speed constraint
   3.2 Particle-antiparticle transmutation
   3.3 Baryon asymmetry

4. **Second time dimension** **11**
   4.1 Frequency constraint
   4.2 Energy density constraint
   4.3 Gramophone illustration of 2 time dimension

5. **Vacuum state asymmetry** **16**

6. **Cosmological constant dark energy** **18**

7. **Gravitational wave reheating mechanism** **20**

   7.1 Prospect of vacuum energy extraction.

8. **Discussion and Conclusion** **24**

References **26**

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 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 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). 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 projecting vacuum energy from a 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 is the interpretation of time as an irreversible progression of events in a spatial reference frame driven by the motion of that reference frame along either direction of time dimension. It differentiates between time as an entropic effect and time as a space-like dimension. Indeed 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 second time dimension. An 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 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 it is restricted to a Planck size extra dimension. The spacetime metric is only sensitive to component of vacuum energy that spills into the visible 3d space as dark energy. This spill mechanism is discussed in detail in section 6.

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. The gravitational contraction of S_1 by positive pressure and energy drives the expansion of time T_1 dimension as shown in figure 1. The expansion of the 3 visible spatial dimensions 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 surface of time dimension T_1- T_2. Interestingly, the length of time dimension T_1 in Planck Unit is equal to the entropy.

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

.

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 time dimension T_1 by one Planck unit.

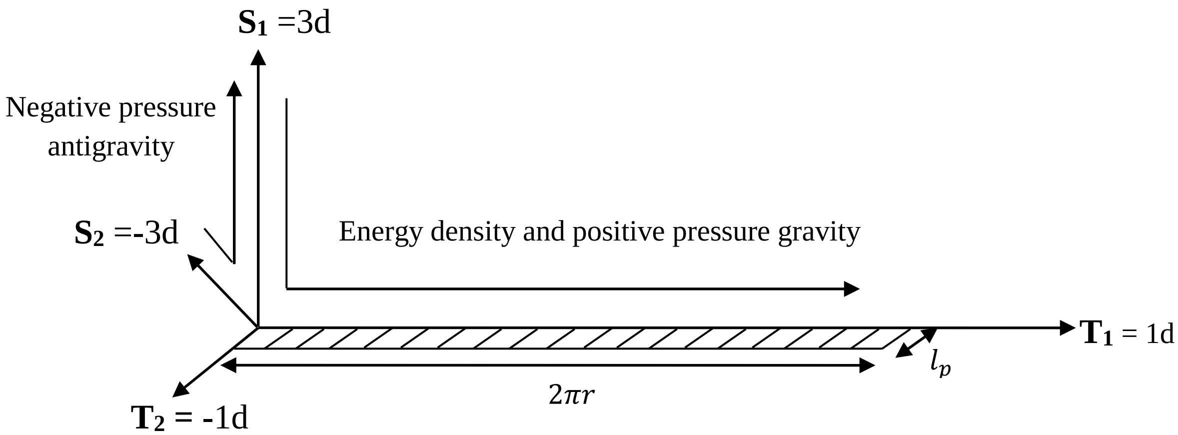


Figure 1: Gravitational traffic across the 7 dimensions of $S_1 = 3d, T_1 = 1d$, and $S_2 = -3d$. T_2 is constant.

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.

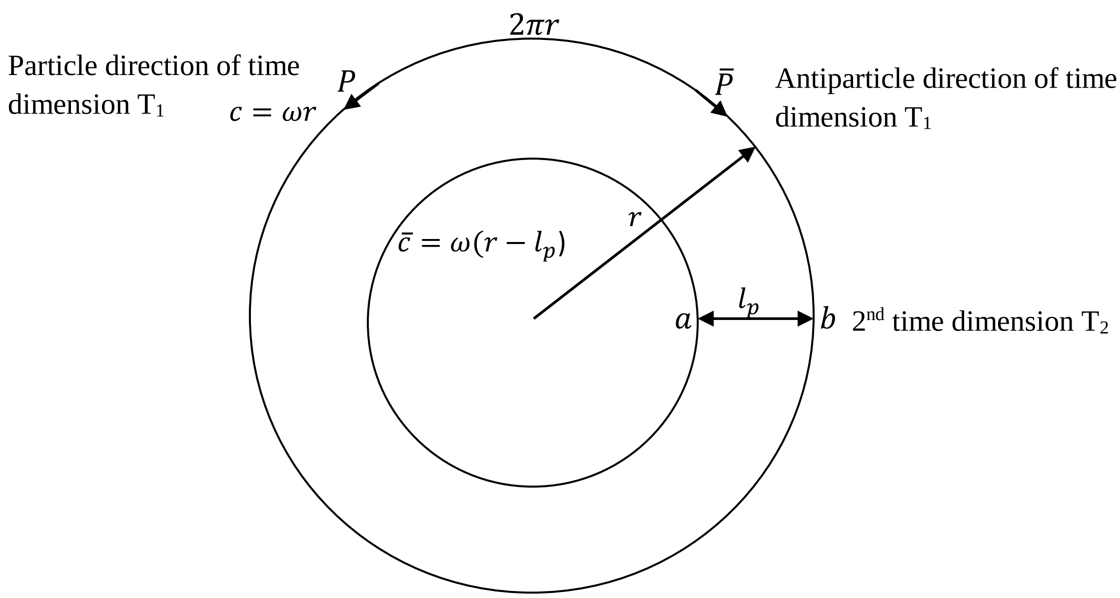


Figure 3: The 2d ring structure of time in RUTE brane universe. The ring thickness (brane thickness) which is Planck length l_P in size represents a space-like second time dimension T_2 which we shall discuss in the next section.

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.

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 time dimension T_1 and velocity **V**, along the spatial dimensions S_1 must always equal **C**.

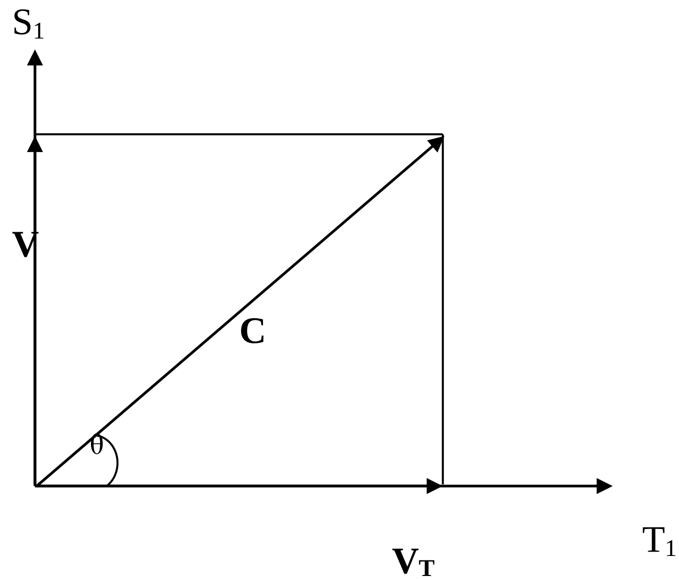


Figure 4: The speed constraint. It is required that the magnitude of the vector sum of the spatial and time dimension components of velocity must always equal c^2.

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

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 can be expressed as

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

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

$$\Gamma = \left(\frac{\mathrm{V_T}}{c}\right)^2 \tag{4}$$

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

Its relative clock rate will be

$$\sqrt{1-\frac{v^2}{c^2}}\ x\ 100 \quad (6)$$

Percent relative to the reference observer who's clock ticks at

$$\sqrt{1-\frac{0^2}{c^2}} \times 100 \quad (7)$$

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

$$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}\,. \quad (8)$$

3.2 Particle-antiparticle Transmutation

As earlier noted, in line with the Feynman-Stueckelberge interpretation, particles and antiparticles travels in opposite directions along the 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. 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

$$P = \left(\frac{v}{c}\right)^2 \quad (9)$$

With $v{\sim}0$, $P = 0$ for non-relativistic massive particles. But for photons, $P = 1$, making a photon 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 in this scenario as a massive particle on approaching c, can simply tunnel 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.

3.3 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

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.

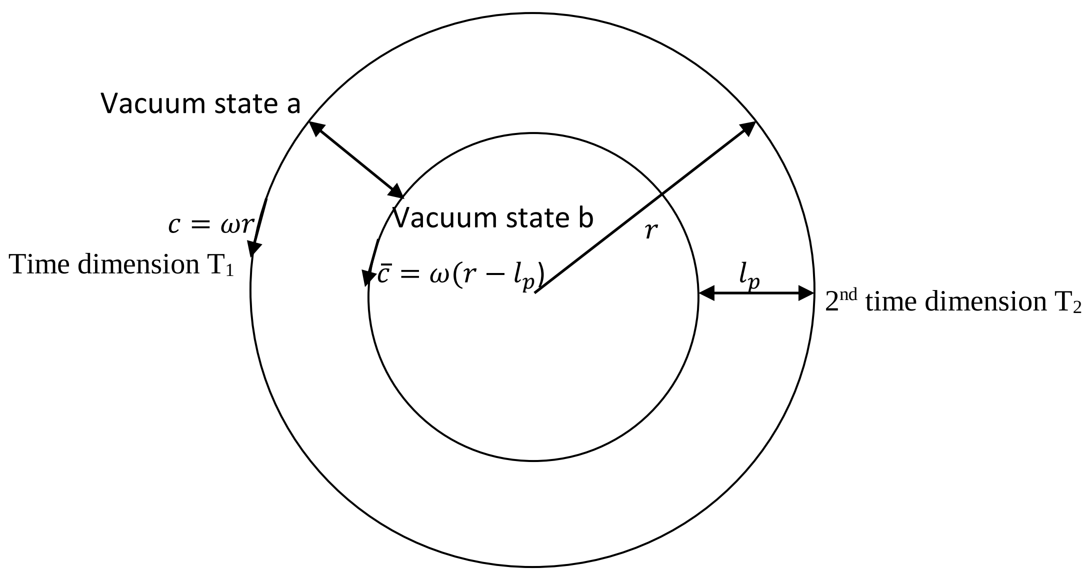


Figure 5: A vacuum reference frame oscillates between the 2 vacuum states a and b along T_2 dimension at the Planck frequency f_{Planck}

4.1 Frequency Constraint

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. (2) results in the frequency constraint.

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

Where f_{vac} is the vacuum oscillation frequency along T_2 dimension and f is the oscillation frequency along the spatial dimensions S_1.

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

$$\sqrt{1-\frac{f^2}{f_{Planck}^2}} \times 100 \tag{11}$$

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

$$\Gamma^2 = 1-\frac{f^2}{f_{Planck}^2} \tag{13}$$

$$\Gamma = \sqrt{1-\frac{f^2}{f_{Planck}^2}} \tag{14}$$

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

$$\gamma = \frac{1}{\sqrt{1-\frac{f^2}{f_{Planck}^2}}} \tag{15}$$

It follows that a vacuum with no spatial oscillation must oscillate along T_2 dimension at the Planck frequency.

$$f_{\text{Planck}} = \sqrt{f_{vac}^2 + 0}\ . \tag{16}$$

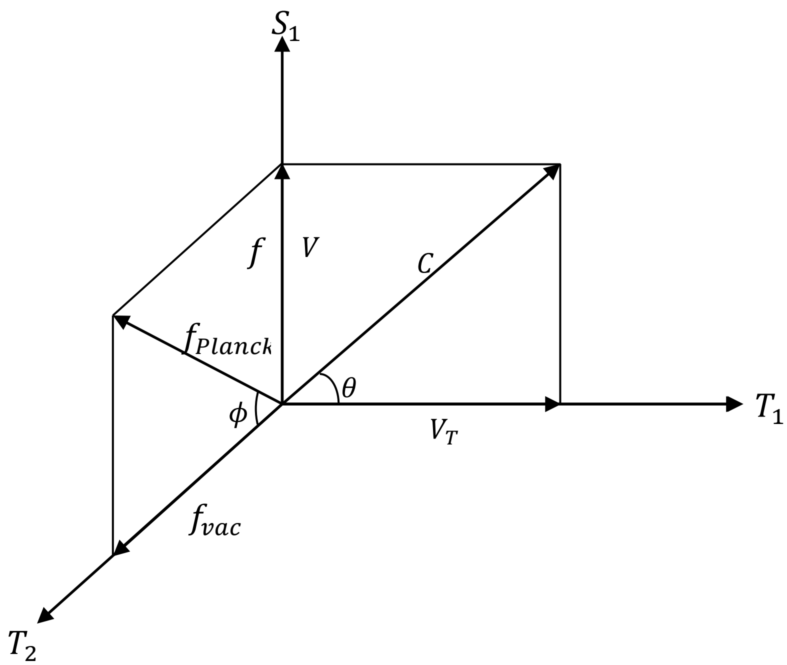


Figure 6: The oscillatory and speed time dimensions T_2 and T_1 in relation to the spatial dimensions S_1.

4.2 Energy density constraint

These oscillations translate to energy as $E = hf$. where h is the Planck constant, leading to the Planck energy and Planck energy density constraints.

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

$$\rho^2_{Planck} = \rho^2 + \rho^2_{vac} \tag{18}$$

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 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}. 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 the next section**.**

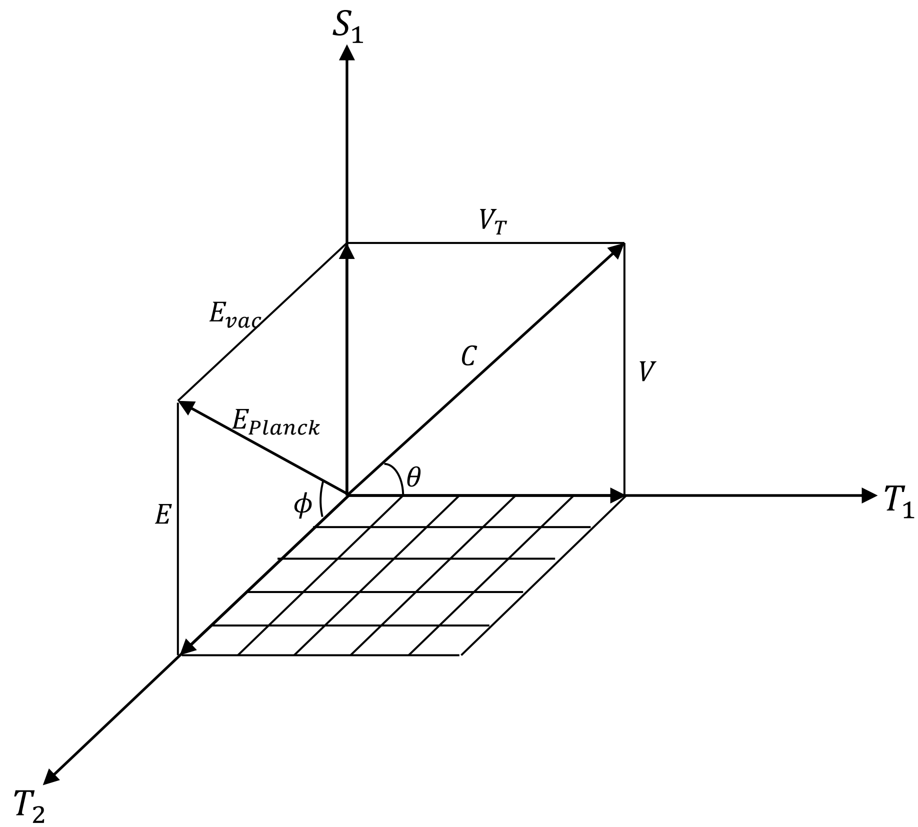


Figure 7: relationship between the spatial dimensions S_1 and the 2 time dimensions in terms of speed and frequency or energy constraints. The length of time dimension T_1 in Planck unit gives the entropy of the universe.

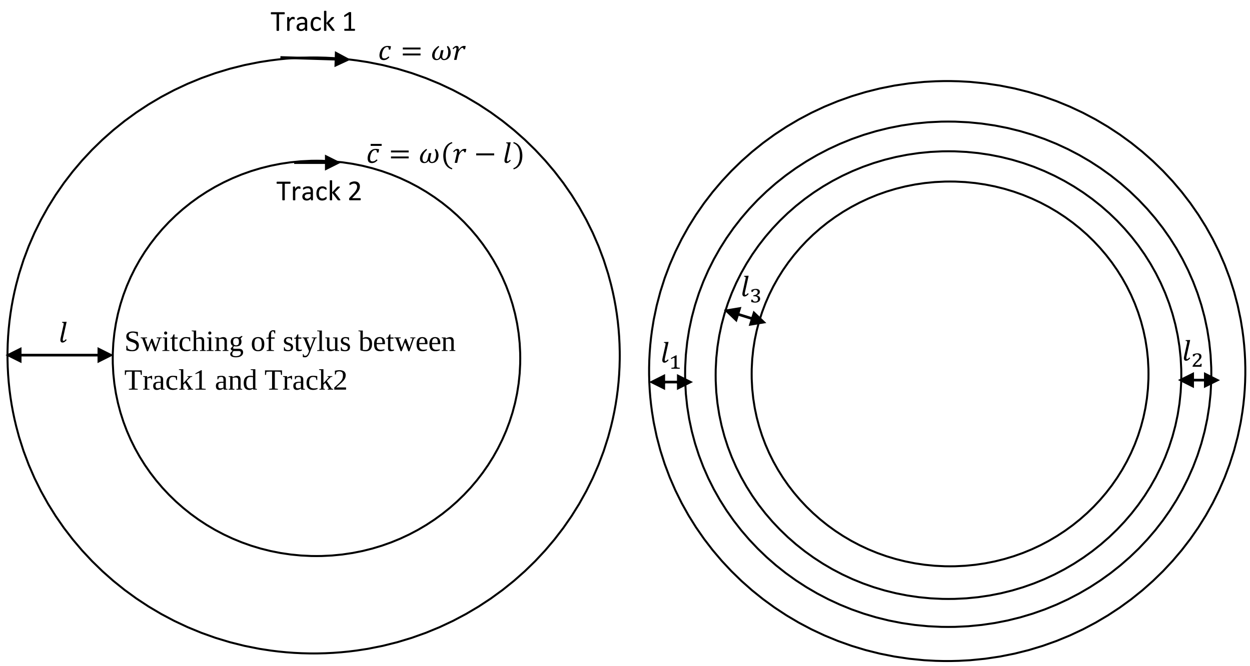
The energy density constraint eliminates infinite energy densities such as black hole singularity and big bang singularity, while predicting the existence of Planck stars also described by [18]. Also,

$$\frac{1}{\gamma} = \sqrt{1 - \frac{\rho^2}{\rho_{Planck}^2}} \tag{19}$$

The inverse Lorentz factor in eq. (19) is also a measure of the relative strength of gravity

4.3 Gramophone illustration of 2 time dimension.

Essentially, the two time dimensions of the RUTE framework can be illustrated using a rotating and oscillating ring structure.



(b) Concentric dual track Gramophone

(a) Concentric Multitrack Gramophone

Figure 8: (a) A dual track gramophone system. While time T_1 dimension for the gramophone system is driven by the rotation of the gramophone record, T_2 is driven by the 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 8, we used a gramophone record with only 2 concentric and identical tracks with a stylus switching between the two, to describe our two dimensional time model. The 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 switching between the 2 identical but different speed tracks is analogous to the 2^{nd} time progression T_2. The surface area $A = 2r\pi l - l$ of the record is proportional to its entropy. As illustrated in Fig. 8b, if our universe is part of a multibrane system like this gramophone analogy, then we can have spatially parallel but time concentric universes.

5. Vacuum State Asymmetry

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

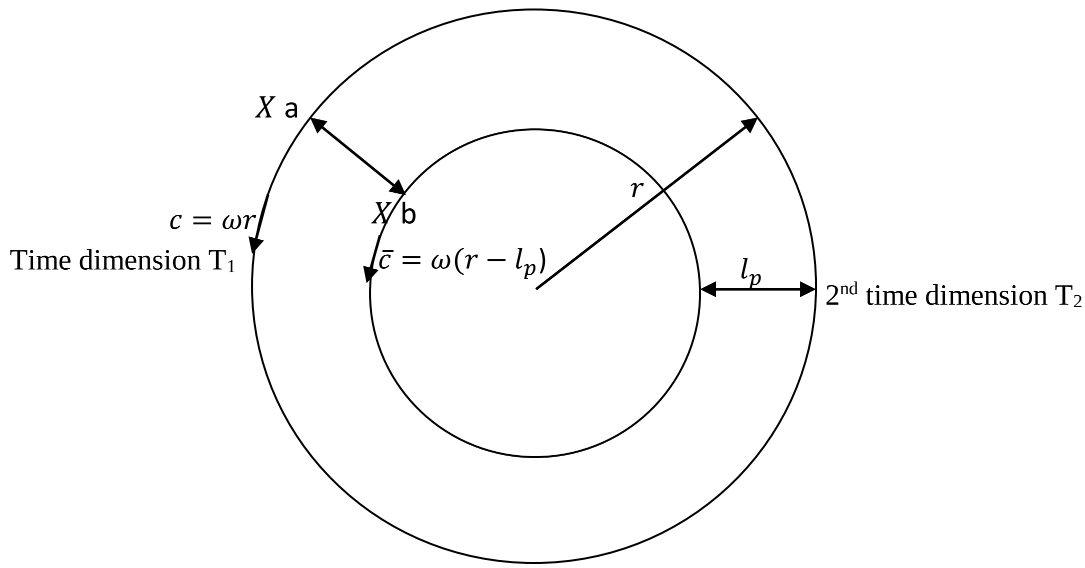


Figure 9: A massless particle x oscillating between two vacuum states a and b along time dimension T_2

As illustrated in figure 9 above, a massless photon x with energy less than the Planck scale, oscillates between the 2 vacuum 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.

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

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

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

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 as $2\pi r$.

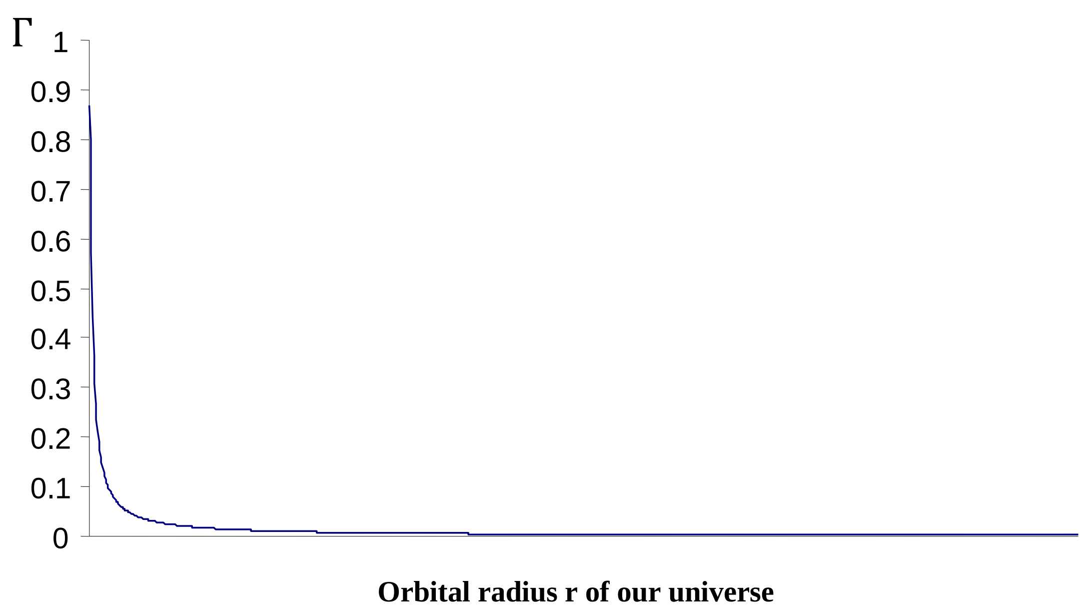


Figure 10: The asymptotic vanishing of Γ with the growth of orbital radius r.

6. Cosmological Constant Dark Energy

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

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

Where ρ_{planck} is the maximum vacuum energy of vacuum state a with a maximum speed limit c as illustrated in figure 11 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.

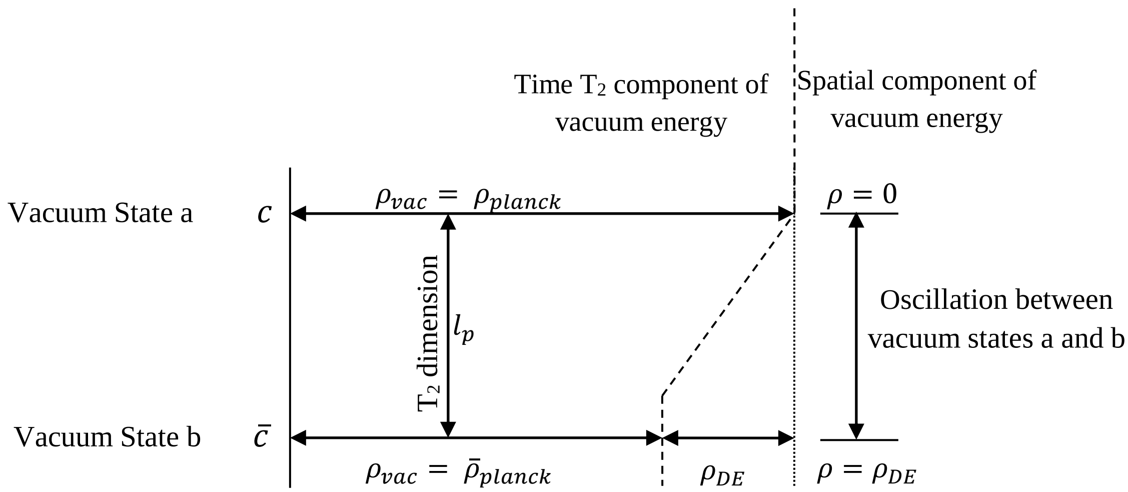


Figure 11: Asymmetry between vacuum states a and b with densities $\rho_{planck} > \bar{\rho}_{planck}$. The vacuum oscillates between states a and b. When at vacuum state a, the time dimension T_2 Component has the maximum value of energy density $\rho_{vac} = \rho_{planck}$ and zero spatial value $\rho = 0$. 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 density constraint $\rho^2_{Planck} = \rho^2 + \rho^2_{vac}$.

Given the energy density 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 figure 11, 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

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

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 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 late time acceleration of our Universe.

7. 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.

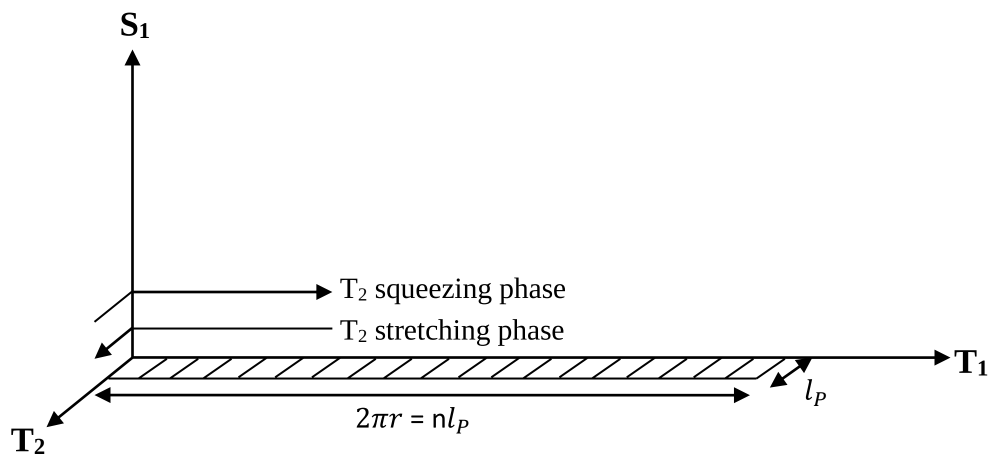


Figure 12: Time T_1-T_2 dimension component of gravitational wave oscillation where one time dimension is stretched at the expense of the other and vice-versa while keeping Area constant.

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 ($f = c/l_p$) drops by a factor h. Where h is the gravitational wave strain amplitude. The vacuum energy of such reference frame drops by the same factor thereby projecting a corresponding amount of energy density

$$E_{Photon} = hE_{Planck} \, , \tag{28}$$

into the visible spatial dimensions due to the energy density constraint in RUTE, manifesting as photons.

During the T_2 squeezing phase of the GW oscillation, the vacuum oscillation frequency of the reference frame is prevented from increasing by the factor h as this would also increase the vacuum energy density ρ_{vac} above the Planck density by the same factor violating the energy density constraint. Instead, vacuum oscillation frequency maintains its value from the expansion phase, while the vacuum oscillation speed V_{T2} drops from c by h $(as\ V_{T2} = hc)$. This conserves the energy earlier spatially released during the expansion phase.

However due to relative stiffness of T_2 compared to the spatial dimension the actual amplitude A of T_1-T_2 oscillation can be expressed as

$$h = Ak \quad (29)$$

Where k is the relative elasticity of the second time dimension compared to the visible spatial dimensions. Eq. (28) becomes

$$E_{Photon} = AkE_{Planck} \quad (30)$$

Where luminosity is proportional to frequency of gravitational waves.

As the GW oscillation continues, it should continuously create standard model photons from the vacuum in its wake until its strain falls below a 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. Dynamic creation and annihilation of other Standard Model particle pairs such as quarks and leptons as well as baryogenesis described in section 3.3 proceeded as the universe rapidly expanded and cooled.

Powerful astrophysical sources of gravitational waves should have Gamma Ray Bursts (GRB) counterparts. Therefore GRBs need to be investigated in the light of RUTE's Gravitational Wave Reheating mechanism.

The detection of Gravitational wave event GW150914 [19] has opened an observational window. The detection of Gamma Ray Burst counterpart GW150914-GBM [20] 0.4 seconds later corresponding to 66% of the peak strain amplitude indicates that there is a threshold strain A_0 for Gravitational Wave Reheating. With threshold strain ~ 10^{-4} in the source frame, the relative elasticity k in eq. (30) ~10^{-20}.

Also there is the possibility of frequency dependence of threshold amplitude where higher frequency results in lower threshold amplitude. More data is however required. Future joint

Gravitational Wave and GRB counterpart observations should provide further observational evidence and constraint for Gravitational Wave Reheating and associated parameters.

7.1 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. Moreover this is worsened by the high threshold strain provided by the GW150914-GBM constraint.

However, there are a number of other physical quantity constraints embedded in the RUTE framework. Apart from the speed constraint and ordinary energy constraint, there is also the force and strain energy constraint as indicated in figure 13. In this scenario the strain energy density in spacetime is constrained to always equal the Planck density. It follows that in the absence of gravitational waves in the visible spatial dimensions, the S_2 dimension must vibrate with maximum strain energy as quantum foam.

As noted in section 2.3, negative pressure contracts the S_2 dimension to expand the visible spatial dimension $S_{1.}$ Whenever this occurs, some component of quantum foam is released into the visible spatial dimensions as high frequency gravitational waves. Photon emission then occurs whenever the threshold amplitude is exceeded with strongly negative pressure. Moreover high frequency should lower the threshold amplitude. More research effort is required in this regard

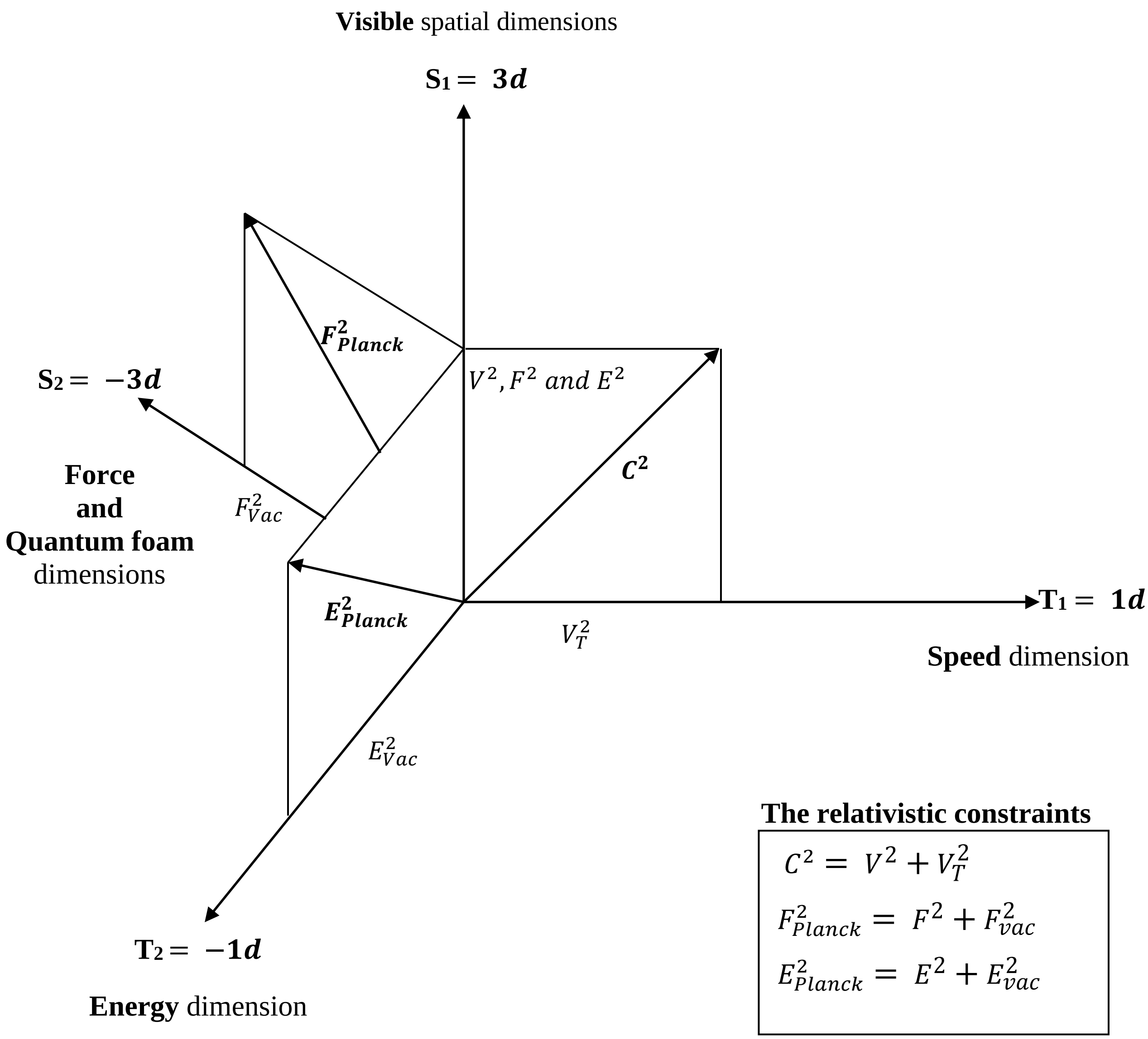


Figure13: The basic structure of 8 dimensional spacetime showing the relative projections of Velocity, Energy and Force into the visible spatial dimensions. There is also quantum foam associated with the S_2 dimension.

8. Discussion and Conclusion

RUTE, with its holistic approach, has provided an elegant solution to dark energy's cosmological constant problem. Specifically, it is a spill model of Λ. It relies on its key dimensional symmetry which doubles every spacetime dimension to 8d, the resulting rotating and oscillating 2d ring model of time dimension and the emergent energy density constraint and vacuum state asymmetry.

The energy density constraint ensures that the total energy density available in the visible spatial dimension and vacuum energy which is only available along T_2, must always equal the Planck density. The deficit vacuum energy density of one of the vacuum states along T_2, ensures a spill of energy into the visible spatial dimensions as dark energy as described by the asymptotically evolving asymmetry parameter – 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.

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 and as such a breakdown of the electromagnetic, the strong and weak nuclear forces should be expected.

Since gravitational waves carry energy and poorly interacts with matter, what happens when a gravitational wave passes through a black hole much bigger than its wavelength? In order not to violate the density constraint, the black hole may either temporarily expand or loss mass with the emission of a corresponding amount of gravitational wave energy. Such Secondary Gravitational Waves (SGW) if they exist would have a unique signature different from the primary gravitation wave.

RUTE's Gravitational Wave Reheating mechanism is an interesting outcome 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 the threshold. Therefore Gamma Ray Bursts needs to be investigated in association with astrophysical sources of gravitational waves.

One 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 entropy. However, with this speed asymmetry more pronounced in the early universe, it is hoped that some relic evidence is imprinted in the CMB photons.

It is also interesting, how the length of the 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 [21]? 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.

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.

If spacetime is quantized according to loop quantum gravity [22], 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.

RUTE as a model of the dimensional structure of spacetime describing the relative projection of physical quantities into the visible spatial dimensions demonstrates a holistic approach to the resolution of the cosmological constant problem among other unsolved problems in Physics. 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 Gravitational Wave Reheating prediction which has far reaching implications on the prospect of vacuum energy extraction. This at least indicates the viability of RUTE. Going forward however, there is still a lot of work to be done.

References

[1] A. G. Riess et al. [Supernova Search Team Collaboration], Astron.J.**116**, 1009 (1998)

[2] S. Perlmutter et al. [Supernova Cosmology Project Collaboration], Astrophys.J.**517**, 565(1999)

[3] P.A.R. Ade et al., [Plank Collaboration], arXiv:1303.5076 [Astro-ph.CO]

[4] R. Brandenberger, arXiv: hep-ph/0101119

[5] R. Bousso and J. Polchinski, JHEP **0006**, 006 (2000)

[6] S. Kachru, R. Kallosh, A Linde and S.P. Triveldi, Phys.Rev.**D68**, 046005 (2003)

[7] T. Banks, M. Dine, L. Motl, JHEP 0101:031(2001) [arXiv:help-th/0007206]

[8] S. Kachru, M. Shulz, and E. Silverstein, Phys.Rev.**D62**, 045021 (2000);

N. Arkani-Hamid, S. Dimopoulos, N. Kaloper, and R. Sundrum, Phys.Lett.B**480**, 193 (2000)

[9] R.J. Sherrer, Phys.Rev.Lett.**93**, 011301(2004) [arXiv:astro-ph/0402316]

[10] H.S. Zhao, B. Li, Astro.Phy.J. **712**, 130 (2010)

[11] E.J. Copeland, M. Sami and S. Tsujikawa, Int.J.Mod.Phys. **D15**, 1753-1936 (2006)

[12] M. Kamionkowski, arXiv: astro-ph /0706.2986

[13] R. Brandenberger, A. Mazumdar, arXiv: hep-th/0402205

[14] I. Bars, Phys.Rev.**D77**:085019 (2006). [arXiv:hep-th/0606045]

[15] E. Verlinde, JHEP04 (2011) 029 [arXiv: 1001.0785]

[16] F.S.N. Lobo, arXiv: 0710.0428[gr-qc]; J. Barbour, arXiv:0903.3489 [gr-qc]

[17] A. Mazumder, arXiv:help–th/1106.5408

[18] I.L. Shapiro, J. Sola, Phys.Lett.B**682**:105-113 (2009) [arXiv: 0910.4925 [hep-th]

[19] B. P. Abbot et al. [LIGO Scientific Collaboration and VIRGO Collaboration], Phys.Rev.Lett.**116**.061102, arXiv :astro-ph/1602.03837 [gr-qc]

[20] V. Connaughton et al. [Fermi-LAT collaboration], arXiv :1602.03920 [astro-ph.HE]

[21] R. Pourhasan, N Afshordi and R.B Mann, arXiv:1309.1487 [hep-th]

[22] L. Smolin, arXiv:hep-th/0408048