Cosmological Constant from Asymptotically Vanishing Particle-Antiparticle Asymmetry in a Rotating Brane Universe

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Abstract

Using an interpretation of special relativity in the context of a rotating brane universe, it is shown that an asymptotically vanishing particle antiparticle asymmetry described by a cosmological factor Γ can result such that $0 < \Gamma < 1$. We discus a cancellation scenario in which an asymptotically vanishing effective cosmological constant Λ arise from this asymmetry where virtual particles and antiparticles contribute attractive and repulsive terms respectively to the quantum vacuum. The asymmetry is fundamentally in the form of difference in speed limit c and $c_{\bar{p}}$ for particles and antiparticles which in this scenario, exists as excitations of the opposite surfaces of a brane universe rotating along its time dimension. Using estimates from quantum field theory and the observed value of dark energy density, the cosmological factor is constrained to be $\approx 10^{-120}$ in the present universe. Observational constraint may also come from precision measurement of spatial curvature. $\Gamma \approx 1$ obtainable in the early universe would produce large effective cosmological constant ($\Lambda \sim 10^{68}$ m^{-2}) capable of driving inflation and possibly the baryon asymmetry of our universe.

1. Introduction

A number of unsolved problems in physics seems to suggest an asymmetric universe. One of such problems is the observed excess of matter over antimatter. In the standard model of particle physics, particles and antiparticles are always created equally to conserve the baryon and lepton numbers of our universe except in the violation of CP symmetry in the decays of neutral Kaons and B mesons. For a review see Ref. [1]. Yet this effect has been determined far too inadequate to account for the baryon asymmetry of our universe. One possibility however is that there is an intrinsic particle-antiparticle asymmetry evolving asymptotically with the growth of our universe. In this paper we provide a viable framework that advances this possibility though in the context of resolving the cosmological constant problem.

In 1998, redshift studies of light from type 1A supernova led to the conclusion that the expansion of our universe is accelerating. Since this discovery first published in Refs.[2,3], several independent lines of evidence have confirmed the existence of a mysterious dark energy component driving the expansion. Recent results from the WMAP (Wilkinson Microwave Anisotropy Probe) collaboration indicates that dark energy now constitutes about 73% of the total energy density of our universe while ordinary baryonic matter constitutes about 4.6%[4,5]. The remaining 22% is made of dark matter, an invisible and collisionless (weakly interacting) form of matter that is gravitationally attractive influencing the motion of galaxies and the growth of Large Scale Structures. In the standard model of cosmology known as the ΛCDM (Lambda Cold Dark Matter) model, dark energy is in the form of a cosmological constant term which was introduced by Einstein in his field equations but which he later abandoned. The cosmological constant has since been determined to arise from vacuum energy, an intrinsic energy embedded in empty space. But estimate from quantum field theory gives a vacuum energy density 10^{120} times greater than the observed density of dark energy (10^{-47} GeV^4). This is the cosmological constant problem. Also, there was no known connection with inflation (a brief period of exponential growth of the early universe).

There are cancellation models such as that in string theory in the form of a four-form guage flux which cancels the bare Λ down to a small effective value, originally realized in [6] which led to the KKLT scenario [7] and the string landscape with 10^{100} vacuum [8]. Though viable, it still suffers the fine tuning problem. There are also relaxation models where the value of the vacuum energy density is relaxed such as in [9] and even an approach that makes the spacetime metric insensitive to the cosmological constant [10]. Anthropic considerations have also been advanced as possible explanation [11]. There are several other alternative routes which avoid the thorny problem of the cosmological constant such as quintessence, unification of dark energy and dark matter [12] and modification of gravity [13]. For a detailed review see Ref. [14].

In this paper, we shall attack the dark energy mystery via the Λ route by providing a cancellation mechanism from a vanishing particle antiparticle asymmetry assuming antiparticles are gravitationally repulsive. This provides a large value of Λ (though rapidly fell initially) comparable to the Planck scale in the early universe capable of driving inflation and vanishingly approach a constant value now 10^{-52} m^{-2} driving the accelerated expansion of our universe.

The model relies on brane cosmology which involves a 3+1 dimensional spacetime seen as a 4 dimensional membrane in a higher dimensional spacetime known as Bulk (See Ref. [15] for a review). In this context however, it involves a rotating universe (In the direction of its time dimension) where standard model particles are modeled as excitation of spacetime (elevation of the opposite surfaces of the brane). The basic idea of standard model particles existing as excitations of spacetime already exists within the framework of loop quantum gravity [16]. In the next section, we discuss the rotating universe interpretation of special relativity. We discuss in section 3, the particle antiparticle asymmetry arising from difference in speed limit arising from such scenario which we use to resolve the cosmological constant problem in section 4.

2. Rotating Universe Interpretation

Despite the current status of brane cosmology with several variants opening up new horizons, existing models are quite difficult to test. We discuss a rotating brane scenario where standard model particles exists as excitations of its opposite surfaces as an interpretation of special relativistic effects. In this context, the 3+1 dimensional brane rotates along its time component with an average orbital speed c relative to the bulk. The clock rate of any inertial frame is proportional to its orbital speed relative to the bulk. Special relativistic effects arises for instance when a particle moves through space with a velocity v. This is such that for any velocity v through the spatial dimensions, there is always an imaginary component of that velocity in time but in the opposite direction to the orbital speed c of the brane as illustrated in figure 1.

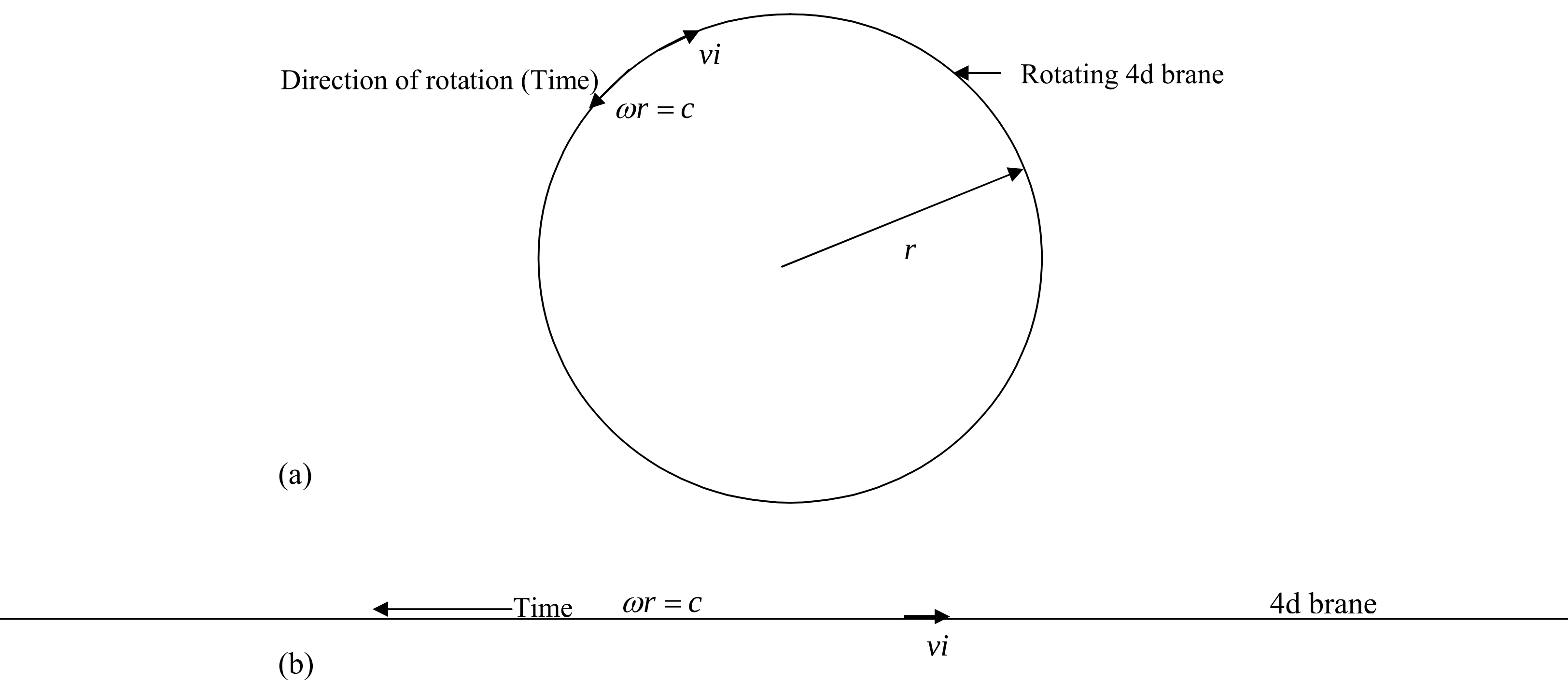

Figure 1: A 4d brane with a thickness α rotating in the direction of its time component relative to the bulk with orbital speed c and orbital radius r. In (a), $r \gg \alpha$ and in (b), $r \ll \alpha$.

As a result, for any inertial reference frame with a speed v through space, its orbital speed relative to the bulk will be c-v, hence a reduction in clock rate that is proportional to the factor $\chi = 1 - \frac{vi}{c}$.

$$|\chi|^2 = \sqrt{1 - \frac{v^2}{c^2}}, \tag{1}$$

Where $\frac{1}{|\chi|^2}$ equals the Lorentz factor

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

In this Interpretation, traveling at the speed of light means zero orbital speed, while tachyonic speed through space means retrograde orbital speed as illustrated in figure 2. Also any prograde particle with orbital speed greater than c should have negative spatial velocity and kinetic energy.

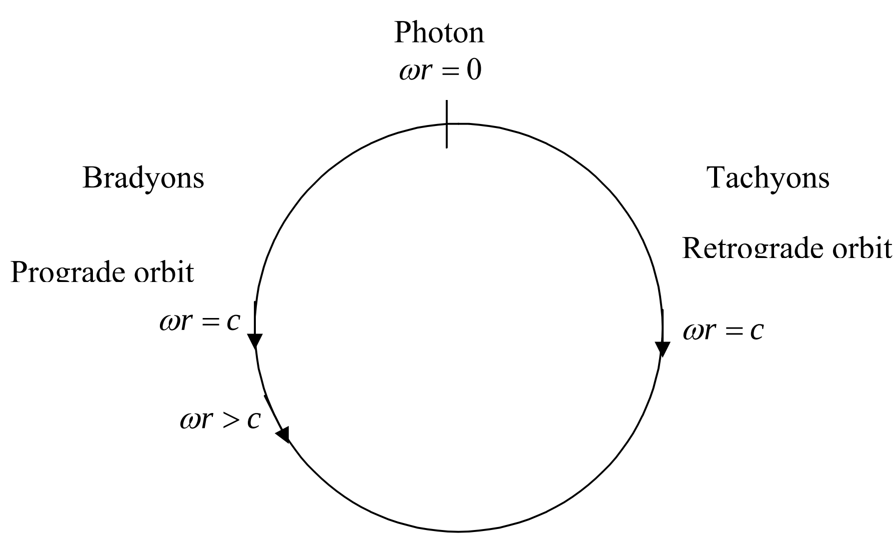

Figure 2: An illustration depicting tachyons as particles with retrograde orbital speed while slower than light particles (Bradyons) have prograde orbit. Photons (Luxons generally) have zero orbital speed.

As seen from the perspective of the bulk, a tachyon is just like any other particle but with retrograde orbit. The Lorentz factor for such particles becomes.

$$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \tag{3}$$

Comparing eq. (2) and (3), the clock rate for a tachyon traveling at 2c, would be equivalent to that of a bradyon at rest.

From quantum mechanical perspective, for an ultra relativistic particle with a small mass, there should be a non zero probability of it tunnelling into the tachyonic phase. This tunnelling can be seen as tunnelling in time with the speed of light as the barrier. The probability of tunnelling into the tachyonic phase can be described by

$$p = \frac{a^2}{A^2}, \tag{4}$$

Where a is the leaked amplitude of the particle wave function and A is the incident amplitude. As a particle approaches the speed of light, the probability of tunnelling into the tachyonic phase becomes higher. Hence the energy dependence of this hypothetical tachyonic transition. If neutrinos have mass as required by neutrino flavor oscillation, then they may undergo such tachyonic transitions which may account for the result of the OPERA collaboration [17].

3. Particle-Antiparticle Asymmetry.

One of the requirements in this model is that particles and antiparticles are excitations of the opposite surfaces of a rotating brane and that antiparticles are gravitationally repulsive. The gravitational interactions of antimatter is still one of the open questions in physics. It is yet to be determined observationally or experimentally, though some experiments are ongoing [18] while some are still underway. In what follows, we shall examine the implications of these assumptions within this framework.

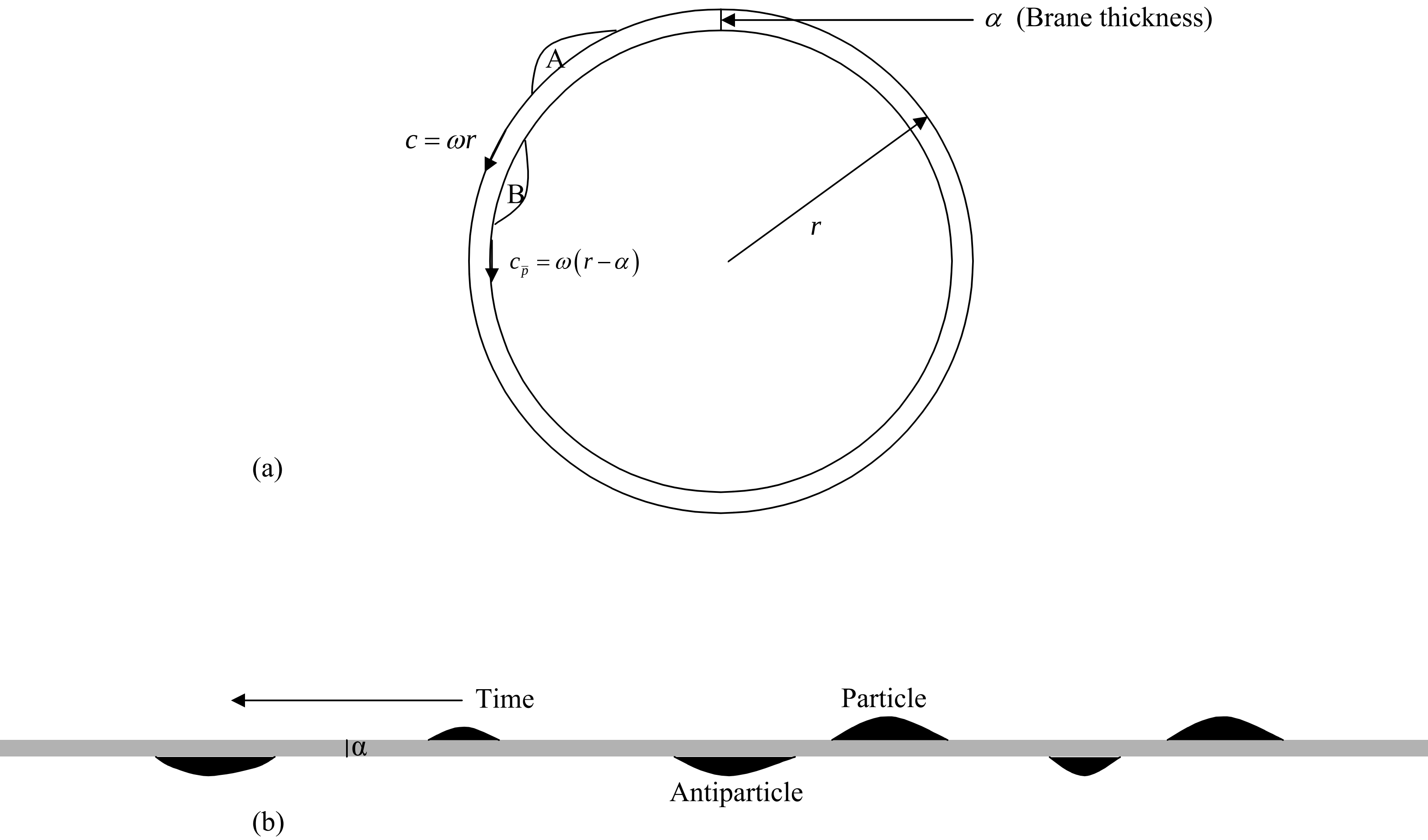

Figure 3: An illustration of fundamental particles (A) and antiparticles (B) as excitations of the opposite surfaces of the brane (spacetime). In (a), r [illegible] α while in (b), r [illegible] α .

In figure 3a, we assume particle A and antiparticle B are massless and as such will always travel through space at the speed limit which implies zero orbital speed in this framework. Particle A would have to travel through space at $c = \omega r$ in order to have zero orbital speed, while antiparticle B would have to travel through space at $c_{\bar{p}} = \omega(r-\alpha)$. As such $c > c_{\bar{p}}$. The difference $c - c_{\bar{p}}$ between these speed limits can be described by

$$c - c_{\bar{p}} = \Gamma c, \tag{6}$$

where Γ is the cosmological factor which evolves asymptotically with the relative size r/α of our universe as shown in figure 4.

$$\Gamma = 1 - \frac{r-\alpha}{r}, \tag{7}$$

and $0 < \Gamma < 1$ where r is the orbital radius and α is the brane thickness.

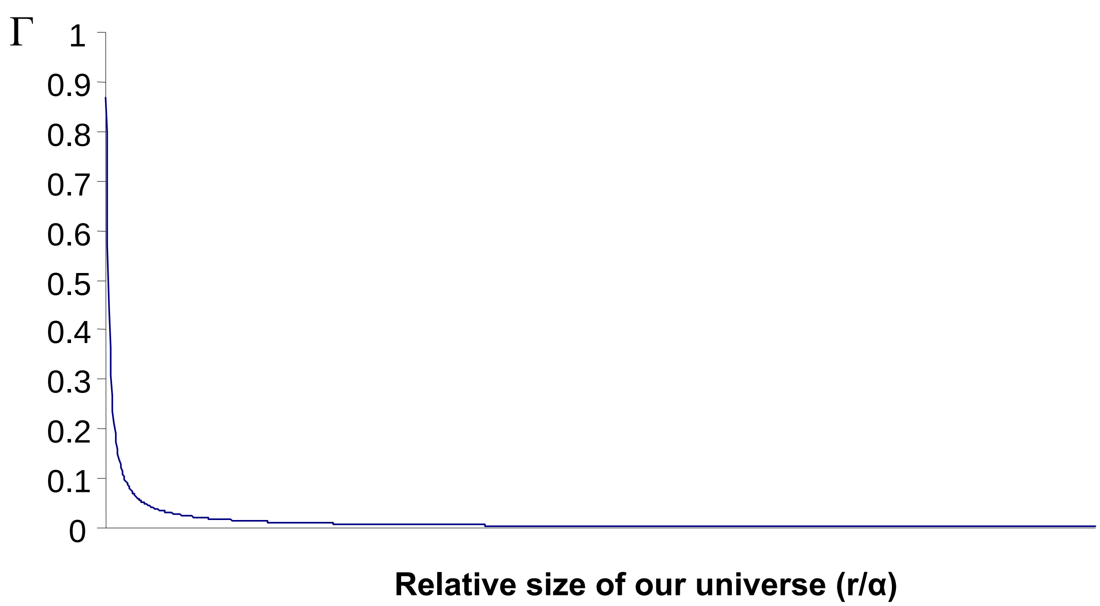

Figure 4: The asymptotic vanishing of Γ with the growth of our universe.

This dual speed limit implies that for conservation of momentum for any particle antiparticle pair of mass m_p and $m_{\bar{p}}$,

$$m_p c = m_{\bar{p}} c_{\bar{p}}. \tag{8}$$

Here the mass m_p of the particle is less than the mass $m_{\bar{p}}$ of the corresponding antiparticle ($m_p < m_{\bar{p}}$) by the same factor Γ as given by

$$m_{\bar{p}} - m_p = \Gamma m_{\bar{p}}. \quad (9)$$

From $E^2 = (mc^2)^2 + (pc)^2$,

$$E_p^2 = (m_p c^2)^2 + (pc)^2, \quad (10)$$

and

$$E_{\bar{p}}^2 = (m_{\bar{p}} c_{\bar{p}}^2)^2 + (pc_{\bar{p}})^2, \quad (11)$$

Where E_p and $E_{\bar{p}}$ are the total energy of the antiparticle and antiparticle respectively. Here $E_p > E_{\bar{p}}$ by Γ as given by

$$E_p - E_{\bar{p}} = \Gamma E_p \quad (12)$$

Thus while the mass $m_{\bar{p}}$ of an antiparticle here is greater than the corresponding particles by Γ, the total energy E_p of the particle is greater than that of the antiparticle by the same cosmological factor Γ. i.e

$$E_p m_p = E_{\bar{p}} m_{\bar{p}}. \quad (13)$$

Since the total energy of a particle can be greater than that of the antiparticle, for $\Gamma \sim 1$ (i.e significant difference $E_p - E_{\bar{p}}$ in the early universe and asymptotically vanishing), the resulting inexact annihilations can result in a universe baryonically dominated by matter.

4. The Cosmological Constant.

From Einstein's Field Equation,

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}, \quad (14)$$

We have the cosmological constant

$$\Lambda = \frac{8\pi G}{c^4} \rho_{vac}, \quad (15)$$

$$\rho_{vac} = \rho_p + \rho_{\bar{p}}, \tag{16}$$

Where ρ_{vac} is the total vacuum energy density, ρ_p is the energy density due to virtual particles and $\rho_{\bar{p}}$ is the energy density due to virtual antiparticles. In a scenario where virtual particles contributes attractively, while virtual antiparticles contributes repulsively, in a perfectly symmetric vacuum,

$$\Lambda = \frac{8\pi G}{c^4}\left(\rho_{\bar{p}} - \rho_p\right), \tag{17}$$

and Λ is effectively zero.
Using $c > c_{\bar{p}}$ discussed in the previous section so that we have an asymmetric vacuum,

$$\Lambda = \frac{8\pi G_{\bar{p}}}{c_{\bar{p}}^4}\rho_{\bar{p}} - \frac{8\pi G}{c^4}\rho_p, \tag{18}$$

Where $c_{\bar{p}}$ and $G_{\bar{p}}$ are the speed limit and gravitational constant for antiparticles respectively.

Since G/c^2 is an absolute constant,

$$\frac{G}{c^2} = \frac{G_{\bar{p}}}{c_{\bar{p}}^2}. \tag{19}$$

For conservation of momentum,

$$\frac{\rho_p}{c} = \frac{\rho_{\bar{p}}}{c_{\bar{p}}}, \tag{20}$$

$$\frac{\rho_{\bar{p}}}{c_{\bar{p}}^2} > \frac{\rho_p}{c^2} \quad (m_{\bar{p}} > m \text{ by } \Gamma). \tag{21}$$

This gives,

$$\Lambda = \frac{8\pi G_{\bar{p}}}{c_{\bar{p}}^4}\Gamma\rho_{\bar{p}}. \tag{22}$$

With $\rho_{\bar{p}}$ in the form of mass density,

$$\Lambda = \frac{8\pi G}{c^2}\Gamma\rho_{\bar{p}}. \tag{23}$$

For $\rho_p \approx \rho_{\bar{p}}$, $\rho_{\bar{p}} \approx \frac{1}{2}\rho_{vac}$ and

$$\Lambda \approx \frac{4\pi G}{c^2}\Gamma\rho_{vac}, \tag{24}$$

where $\rho_{vac} \approx m_{Planck}^4$.

An observed Λ value of 10^{-52} m^{-2} implies $\Gamma \approx 10^{-120}$ in the present universe. This shows that we can achieve the very small value of the cosmological constant provided that the vacuum repulsion of virtual antiparticles is nearly cancelled by the vacuum attraction of virtual particles in the asymmetric vacuum described in this model.

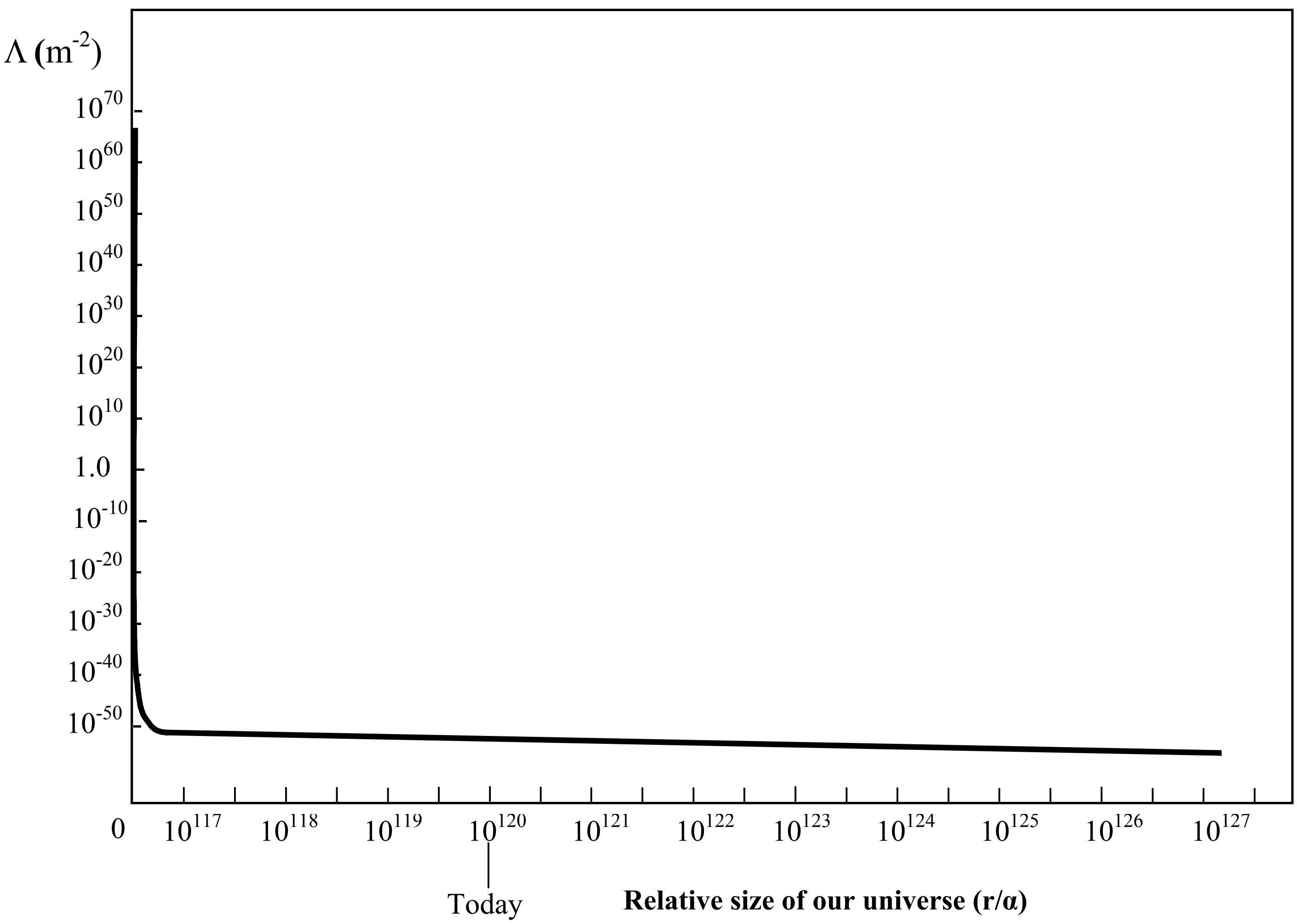

Figure 5: The asymptotic vanishing of the effective cosmological constant with the growth of our universe.

When $\Gamma \sim 1$ as obtainable in the early universe, $\Lambda \approx 10^{68} m^{-2}$. Such a large effective cosmological constant likely drove inflation though with energy scale asymptotically dropping from the Planck scale so that by the time effective inflation ended, its energy scale is already well below the eV scale vanishingly approaching its current value.

5. Discussion

We have discussed the rotating universe interpretation of special relativity which we have used to show that there is an asymptotically vanishing asymmetry in speed limit c and $c_{\bar{p}}$ for particles and antiparticles. This asymmetry coupled with the required repulsive nature of antimatter serves as a cancellation mechanism which provide viable resolution of the cosmological constant problem. Thus while the universe is baryonically dominated by matter, it is gravitationally dominated by antimatter (virtual antiparticles). This is unique as it is natural compared to other approaches to the cosmological constant problem and it is also a possible mechanism for baryon asymmetry and inflation. Besides since Γ which is the cancellation factor here, is a measure of curvature of the time dimension, its value can possibly be constrained observationally (depending on the shape of our universe) from precision measurement of the spatial curvature of our universe. The consequence of non-zero spatial curvature in this model, for one dimensional time, is spatial variation in the speed of light and other associated constants like the fine structure constant. Although spatial variation in the fine structure constant has been reported in [19], it remains to be seen how far it can be proven beyond reasonable doubt.

There is the possibility that the rotating brane interpretation as discussed in section 2, can account for the OPERA result [17] and we hope to advance this possibility as well as the case for baryon asymmetry in future work. The ALPHA experiment at CERN [18] in which antihydrogen atoms are being confined and subsequent work provides a way to test the gravitational interactions of antimatter as well as other asymmetries between matter and antimatter. The key prediction of asymmetry in the speed limits for particles and antiparticles can be verified by observing possible differences in the arrival time of particles and antiparticles from distant cosmic sources. If indeed the large effective Λ described by this model drove inflation, then such inflation with energy scale that asymptotically fell, should produce unique signature of gravitational wave spectrum and amplitude of primordial inhomogeneities since they are directly tied to the energy scale of inflation.

Like every other model, it remains to be seen how far it can go with stringent observational and experimental tests. But it's quite a viable model potentially resolving multiple unsolved problems in physics and we hope to examine various aspects of it in detail in subsequent papers.

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