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Article

Dark Energy and Dark Matter from Extra Dimensional Symmetry as Different Manifestations of Vacuum Energy

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Abstract: Dark energy and dark matter are described as different manifestations of vacuum energy using a newly developed framework of Extra Dimensional Symmetry (EDS) that doubles large spatial dimensions with microscopic partners. In this framework, the bare vacuum energy component exists in a gravitationally dark state where actual gravitational constant $G_0 = 0G$, while real particles oscillate between this inert state and an active state where $G_0 = 2G$. A small component of vacuum energy is constrained to exist in the gravitationally active state as dark energy due to energy density constraint and speed limit asymmetry determined by an asymmetry parameter Γ . Furthermore, neutrinos induce small component of the gravitational constant G_ν in the dark state within a volume of space described by the wavelength, enabling the gravitation of virtual particles which manifests as dark matter. The resulting G_ν has oscillating light and heavy terms. The heavy term is usually inactive due to its suppression by negative pressure and becomes active for a lifetime t_ϕ once shear stress exceeds negative pressure threshold. This results in a light form of dark matter and a heavy form of dark matter that is detectable through its increased gravitational interaction and resulting acceleration.

Keywords: dark energy; dark matter; extra dimension; gravity; neutrino; vacuum energy

1. Introduction

Dark energy is a mysterious energy component that has been observed to be driving the accelerated expansion of the universe, and have defied several explanations since its discovery in supernova observations [1]. Its existence has since been confirmed by several independent observations like the Planck measurements of the Cosmic Microwave Background (CMB), indicating that it accounts for about 68.3% of the gravitating energy content of the universe [2]. This is in addition to the older dark matter mystery [3] of a gravitationally attractive but invisible matter component constituting about 26.8% of the gravitating energy content of the universe. Only about 4.6% is in the form of visible baryonic matter.

The cosmological constant (Λ) earlier introduced into Einstein's Field Equations, while being the simplest solution, results in a serious conflict between measured density of dark energy and the 120 orders of magnitude larger value predicted from quantum field theory [4]. The Λ problem has defied logical solution from supersymmetric cancellation approaches, relaxation of vacuum energy [5] and anthropic approach [6]. It also defies an approach that simply makes the spacetime metric insensitive to Λ [7].

Slowly evolving scalar field models like quintessence [8,9] is one of the many alternative approaches to solve the dark energy mystery without the Λ route. We also have modified gravity models [10] and unification of dark energy and dark matter [11]. See Ref. [12] for detailed review and Refs.[13, 14] for recent review.

The amount of theoretical and observational efforts that has been applied to understand dark energy and dark matter indicates that they require new physics beyond the existing standard model of cosmology and particle physics. Attempts to resolve the dark matter mystery can be mainly classified as either a modification of gravity or introduction of new particles beyond the standard model of particle physics. However, both approaches of modified gravity and particle dark matter

tends to fail in providing consistent explanations to the dark matter mystery as each approach tends to succeed in explaining some observations and fail at some others.

There is an approach that explains dark matter as gravitational polarization of vacuum energy by baryonic matter without invoking new particle or modifying gravity in the traditional sense [15]. It is based on the idea that matter and antimatter have opposite gravitational charges which requires a violation of the Weak Equivalence Principle. Preliminary findings from measurements of antiproton to proton charge to mass ratio imply that matter and antimatter gravitate the same way [16]. Furthermore, the recent result from the ALPHA collaboration has ruled out the possibility of gravitationally repulsive antimatter [17].

In this paper, the dark energy and dark matter puzzle are approached using the new framework of Extra Dimension Symmetry (EDS) that doubles the number of large extra dimensions with microscopic partners. EDS provides a solution to the dark energy puzzle by placing the bare vacuum energy component in a gravitationally inert state where the actual gravitational constant $G_0 = 0G$. Due to a speed limit asymmetry and energy density constraint, a nonzero component of vacuum energy is constrained to the gravitationally active state where $G_0 = 2G$, manifesting as dark energy. For dark matter, it relies on the background effect of neutrinos which induces a nonzero gravitational constant in the inert state, enabling the gravitation of virtual particles which appears as dark matter. This neutrino substrate approach for dark matter doesn't require the polarization of the quantum vacuum or opposite gravitational charges for particles and antiparticles like in [15].

This paper is organized as follows. Section 2 discusses the key dimensional symmetry in which spatial dimensions are grouped as a set of dimension(s) with dimensional partners having opposite dimension numbers that determines either a positive or negative response to the stress energy tensor. It also discusses the selective response of some other sets of dimension(s) to the components of the stress energy tensor. It further discusses the speed constraint, the two gravitationally inert and active states, their speed limit asymmetry and density constraint, which is then applied in section 3 to provide a possible solution to the Λ problem of dark energy. Section 3 discusses the emergence of dark energy due to the speed limit asymmetry and energy density constraint discussed in section 2. Section 4 discusses General Relativity in two set of these extra dimensions which has impact on the heavy term of neutrino induced gravitational constant. Section 5 discusses the neutrino induced gravitation of virtual particles which appears as dark matter. Discussion and conclusion follows in Section 6.

2. Extra Dimensional Symmetry Framework

In this framework, the number of spatial dimensions is described by the dimension number S_n with dimensionality d that can either be +1 or -1, such that,

$$S_n = (4n - 1)d. \quad (1)$$

where $n = 0, 1, 2, 3, \dots$ $n = 0$, corresponds to $S_n = -1d$ which is a time like spatial dimension that is invisible due to speed constraint discussed in Section 2.2. $n = 1$, corresponds to $S_1 = 3d$ which is the visible set of spatial dimensions. $n = 2$, corresponds to $S_2 = 7d$. It is assumed that $d = +1$ in the present universe.

The EDS framework further doubles these set of spatial dimensions (-1, 3 and 7) with dimensional partners with opposite dimension numbers (anti-spatial dimensions) such that the total dimension number of the universe is zero as illustrated in Table 1. While the dimensional partner of S_0 , is a Planck size S_p dimension, the dimensional partner of S_1 is denoted S_α and that of S_2 is denoted S_β .

The negative dimension numbers implies the inversion of the sign of the stress energy tensor in which expansion becomes contraction while contraction becomes expansion. As a result of this, the expansion of the large spatial dimensions S_1 and S_0 in the early universe is equivalent to the gravitational collapse of their dimensional partners. This is partly enabled by the selective response to the stress energy tensor discussed in section 2.1. Any set of dimensions with $n > 1$, such as S_2 remain static neither able to expand, nor contract if they exist.

Table 1. Periodic table of spatial dimensions indicating dimension number symmetry between the sets of spatial and anti-spatial dimensions within the EDS framework. The direction of the arrow from left to right indicates a positive dimensionality d in which the large spatial dimensions expands while their microscopic dimensional partners collapse. S_2 and beyond are static neither able to expand, nor contract if they exist.

	Anti-spatial dimensions		Spatial dimensions
n	$-(S_n)$		$S_n = (4n - 1)d$
2	$S_\beta = -7d$		$S_2 = 7d$
	Microscopic	Large	
1	$S_\alpha = -3d$	$S_1 = 3d$	
0	$S_P = 1d$	$S_0 = -1d$	

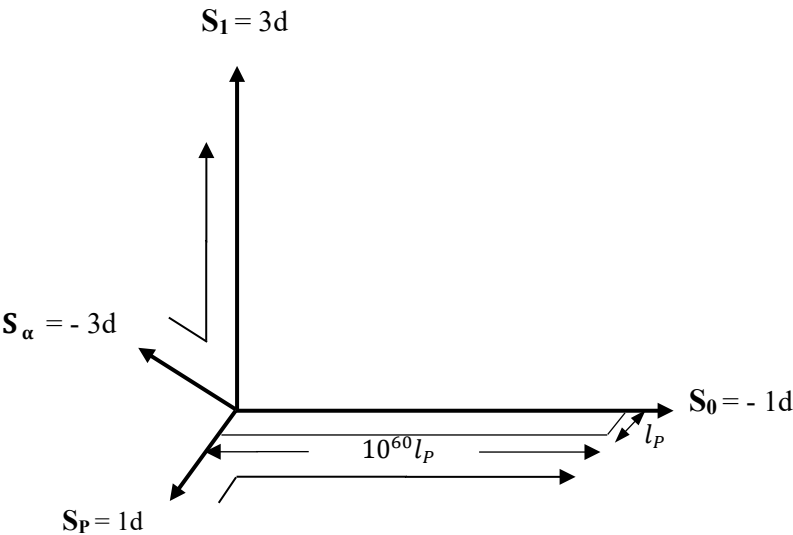


Figure 1. Large spatial dimensions S_1 and S_0 and their microscopic dimensional partners S_α and S_P . The opposite dimension numbers which inverts the sign of the stress energy tensor implies that S_P and S_α collapsed to their minimum microscopic sizes during the inflation of S_0 and S_1 in the early universe.

In resolving the mysteries of dark energy and dark matter, this paper focuses on the large spatial dimensions S_1 and S_0 , their microscopic dimensional partners S_α and S_P as well as some of their interactions with one another.

2.1. Selective Response to Components of the Stress Energy Tensor

In the EDS framework, while the S_0 dimension is unable to respond to shear stress due to its one spatial dimensionality, (shear stress requires at least two spatial dimensions), S_P doesn't respond to negative pressure. Also, the S_α dimension is unable to respond to energy density, momentum flux and positive pressure. It only responds to shear stress and negative pressure.

2.2. Speed Constraint and Invisibility of S_0 Dimension

Despite its cosmic size, the S_0 dimension is invisible due to its time like behavior from the speed constraint illustrated in Equation (2). Consistent with Special Relativity, the speed constraint requires that a particle's velocity must always equal the maximum speed limit c in the $S_1 - S_0$ dimensions.

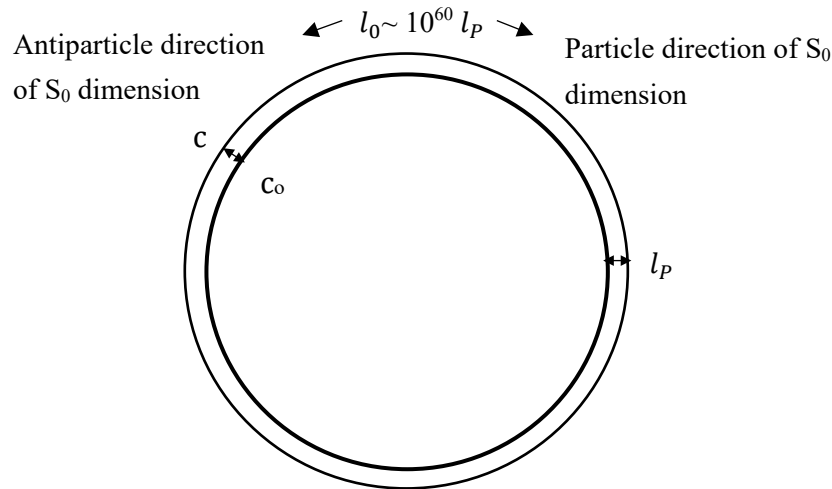


Figure 2. Ring structure of $S_0 - S_P$ dimensions with two slightly unequal speed limit states C and C_0 , at the two ends of S_P dimension that can be seen as two brane surfaces. Traveling in opposite directions of S_0 represents particle and antiparticle states.

Massless particles like photons have zero velocity component along S_0 , while massive particles and antiparticles travel in opposite directions along S_0 . This motion along S_0 is quantitatively equivalent to the passage of time such that,

$$c^2 = \mu^2 + v^2. \quad (2)$$

where μ is particle velocity along S_0 , and v is particle velocity along visible spatial dimension S_1 .

When $v \rightarrow 0$, for massive particles, $\mu \rightarrow c$ and conversely, when $v = c$, for massless particles, $\mu = 0$, to satisfy the speed constraint. This suggests that time can be an emergent temporal dimension driven by the velocity of a particle along S_0 dimension. How fast time appears to pass for a massive particle can be equivalent to the ratio of its S_0 component of velocity μ to the speed limit c as,

$$\frac{1}{\gamma^*} = \frac{\mu}{c}. \quad (3)$$

where γ^* is the equivalent Lorentz factor for the S_0 dimension. Since $\mu^2 = c^2 - v^2$,

$$\gamma^* = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}. \quad (4)$$

2.3. Speed Limit Asymmetry

The asymmetry in speed limits c and c_0 is described by the asymmetry parameter Γ which is the ratio of the Planck size of S_P to the size of S_0 dimension, illustrated in Figure 2. $0 < \Gamma < 1$ such that,

$$\Gamma = \frac{2\pi}{l_0}. \quad (5)$$

where l_0 is the size of S_0 in Planck unit. And

$$l_0 = \Delta l_0 + l_f. \quad (6)$$

where $l_f \sim 10^{60}$ in Planck unit, is the value of l_0 in flat spacetime. The increase in size Δl_0 is proportional to the gravitational potential Φ .

The asymmetry relationship between the two speed limits c and c_0 , as shown in Figure 2 can be expressed as,

$$C_o = C[1 - \Gamma]. \quad (7)$$

2.4. Gravitational State Oscillation

In EDS, Standard Model particles oscillates between the two speed states which are also opposite gravitational on and off states. This is such that for a particle of energy E , the state life time t_s for such particle is,

$$t_s = \frac{4\pi\hbar}{\sqrt{E_p^2 - E^2}}. \quad (8)$$

where $\hbar$ is the reduced Planck constant and E_p is the Planck energy.

The oscillation of Standard Model particles between the two gravitational states $G_0 = 0G$ and $G_0 = 2G$, makes gravity discrete on microscopic spacetime scale. It however appears smooth on macroscopic spacetime scale with an average gravitational constant G . Furthermore, the value of the gravitational constant in both gravitationally active and inert state, is constrained such that,

$$G^2 = \frac{G_1^2 + G_2^2}{4}. \quad (9)$$

where G_1 and G_2 are the gravitational constants in the active and the inert states respectively.

2.5. Energy Density Constraint

The energy density constraint essentially constrains the total energy density in a given volume of spacetime to always equal the upper limit of the Planck density ρ_p . This is only obtainable in the gravitational active state where the speed limit is c while the bare vacuum energy component exists in the inert state with lower speed limit and hence lower Planck density ρ_{p0} .

$$\rho_p^2 = \rho_m^2 + \rho_{vac}^2. \quad (10)$$

where ρ_{vac} is the vacuum energy density, and ρ_m is the total baryonic matter density. The key significance of this, is in the emergence of non zero Λ dark energy in section 4. However, such energy density constraint implies a Planck density limit to the density of black holes like that suggested in [18], where Planck stars replace black hole singularities.

3. General Relativity in S_0 and S_α Dimensions

3.1. General Relativity in S_0 Dimension

In -1+1 dimensionality, just as in 1+1 where the curvature term is zero [19], Einstein Field Equations can be expressed as,

$$\Lambda^* g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}. \quad (11)$$

Where Λ^* is the equivalent cosmological constant in S_0 dimension, $g_{\mu\nu}$ is the metric tensor and $T_{\mu\nu}$ is the stress energy tensor. The negative one dimensionality of the S_0 dimension which inverts the sign of the stress energy tensor, confers on it some unique features such as:

- i. Positive energy density in S_1 is equivalent to negative energy density everywhere in S_0 .
An energy density associated with a given Planck volume of 3d space S_1 appears as an equivalent negative energy density everywhere along S_0 dimension associated with it as a positive cosmological constant as illustrated in Figure 3.
- ii. Positive pressure in S_1 is equivalent to negative pressure in S_0 .
Any form of positive pressure in S_1 appears as negative pressure in S_0 for the same reason of negative dimensionality. The result is a positive cosmological constant expansion of S_0 .

- iii. Negative pressure in S_1 is equivalent to a positive pressure in S_0

The same negative dimensionality causes the inversion of negative pressure in S_1 appearing as positive pressure in S_0 driving its negative cosmological constant contraction. The result is that in the absence of shear stress component to which S_0 is insensitive to, as mentioned in section 2.1, the curvature of S_1 ($G_{\mu\nu}$) is equivalent to the cosmological constant expansion of S_0 as illustrated in Figure 4, such that,

$$G_{\mu\nu} + \Lambda^* g_{\mu\nu} = 0, \quad (12)$$

and a positive cosmological constant term ($\Lambda g_{\mu\nu}$) in S_1 is equivalent to a negative cosmological constant term ($-\Lambda^* g_{\mu\nu}$) in S_0 such that,

$$\Lambda g_{\mu\nu} - \Lambda^* g_{\mu\nu} = 0. \quad (13)$$

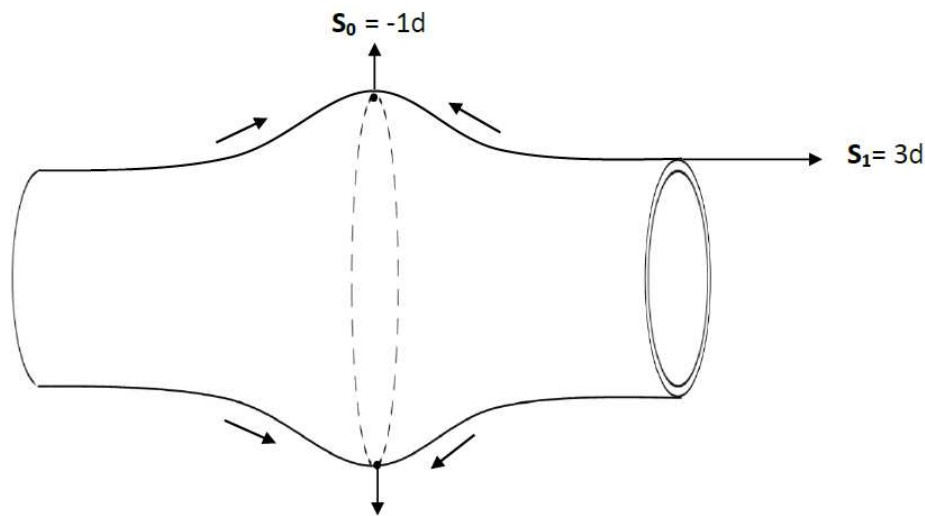


Figure 3. A gravitational well in S_1 is inverted into a gravitational hill with the expansion of S_0 by a test particle. The test particle is replicated over 10^{60} times everywhere along S_0 dimension.

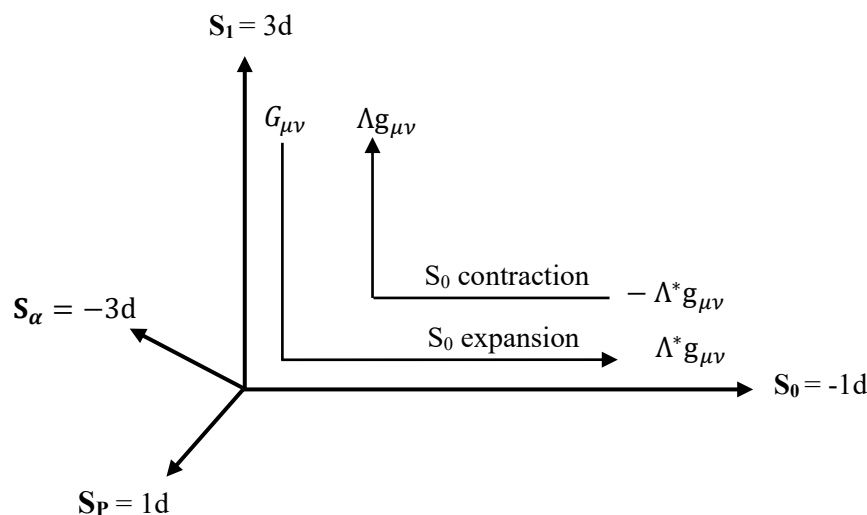


Figure 4. Gravitational inversion S_1 - S_p dimensions. A positive cosmological constant expansion of S_0 is equivalent to curvature of S_1 . Also, a negative cosmological constant contraction of S_0 is equivalent to a positive cosmological constant expansion of S_1 .

3.2. General Relativity in S_α Dimensions

Unlike the one dimensionality of S_0 dimension where the Einstein tensor is zero, the three dimensionality of S_α dimensions ensures that the Einstein tensor is not zero. Furthermore, it only responds to shear stress and negative pressure due to selective response to the stress energy tensor as discussed in section 2.1. The result is that the positive curvature effect ($G_{\mu\nu}$) of shear stress on S_1 dimensions is equivalent to the negative curvature effect ($-G_{\mu\nu}^{**}$) of shear stress on the S_α dimensions. Therefore,

$$G_{\mu\nu} - G_{\mu\nu}^{**} = 0. \quad (14)$$

Furthermore, the positive cosmological constant (Λ) expansion of S_1 due to negative pressure, can be equivalent to the negative cosmological constant ($-\Lambda^{**}$) contraction of S_α .

$$\Lambda g_{\mu\nu} - \Lambda^{**} g_{\mu\nu} = 0. \quad (15)$$

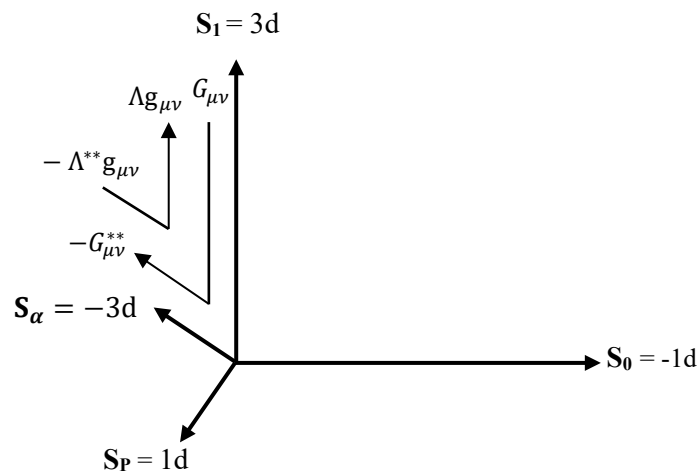


Figure 5. Gravitational inversion in S_1 - S_α dimensions. Positive curvature of S_1 resulting from shear stress, is equivalent to the negative curvature of S_α due to the same shear stress component. Also, a positive cosmological constant expansion of S_1 is equivalent to a negative cosmological constant contraction of S_α provided it has not reached its minimum length scale.

The gravitational inversion of S_1 - S_α dimensions as illustrated in Figure 5 should be true until the size of the S_α dimension l_α falls to its characteristic minimum length scale of not less than 2π in Planck unit, and it can be as much as 137 Planck units depending on limits from geometrical considerations and other possible interactions that might be associated with it. Beyond this minimum length scale, the S_α dimension appears irresponsive to negative pressure as it becomes pinned down, unable to contract further or vibrate in response to weak gravitational wave oscillations. At this point it is only the cosmological constant contraction of S_0 that balances the cosmological constant expansion of S_1 as expressed in Eq. (13).

4. Emergence of Nonzero Cosmological Constant

The asymmetry in speed limit described in Equation (7) between the two gravitational states also reflects in the values of their Planck densities such that

$$\rho_{P0}^2 = \rho_P^2 [1 - \Gamma^4]. \quad (16)$$

where ρ_{P0} is the lower Planck density in C_0 state and ρ_P is the Planck density in the C state.

The existence of the bare vacuum energy component ρ_{vac} in the lower C_0 state implies that

$$\rho_{vac} = \rho_{P0}, \quad (17)$$

which is less than the Planck density and the energy density constraint in section 2.5 requires that the total vacuum energy density should be equal to the Planck density in the absence of matter.

Since the gravitationally inert lower speed state lacks the capacity to contain all the vacuum energy components, a small component is therefore constrained to the gravitationally active state as dark energy ρ_{DE} as illustrated in Figure 6, such that,

$$\rho_{DE} = \rho_P \Gamma^2. \quad (18)$$

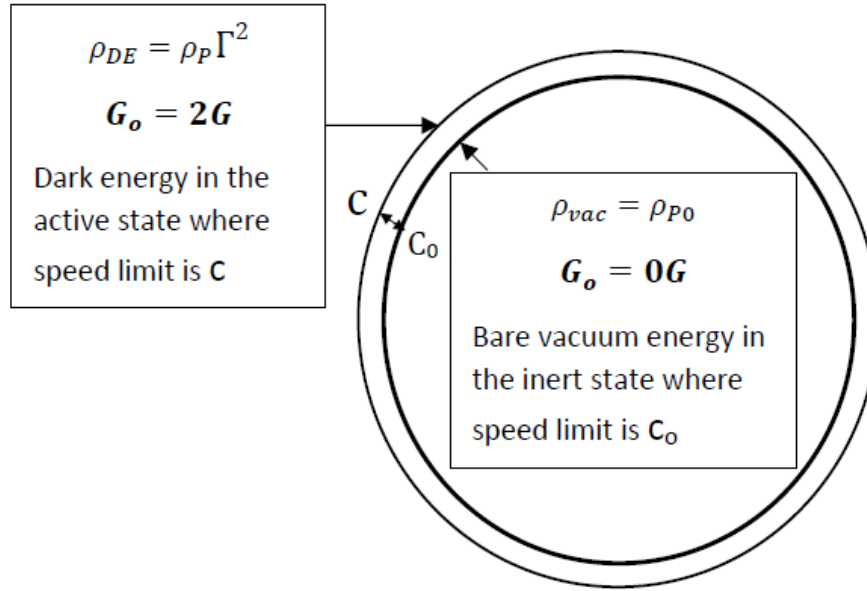


Figure 6. While the bare vacuum energy component occupy the gravitationally inert state C_o to its limit, there has to be a component ρ_{DE} in the gravitationally active state C to satisfy the energy density constraint. The lower Planck density ρ_{P0} is associated with speed state C_o .

Since Γ is suppressed with the expansion of S_0 in the gravitational well of massive objects (Equation (5) and Figure 3), the density of this form of dark energy varies spatially according to this suppression by gravitational potential wells. The deeper the gravitational well the more the suppression. And substituting Γ from Equation (5),

$$\rho_{DE} = \frac{4\pi^2 \rho_P}{l_0^2}. \quad (19)$$

where l_0 is the size of S_0 dimension in Planck unit, which increases with the gravitational potential.

5. Dark Matter from Neutrino Enabled Gravitation of Virtual Particles

In the EDS framework, the existence of the bare vacuum energy component in the gravitationally dark state with actual gravitational constant $G_o = 0G$ ensures that virtual particles in such state are gravitationally inert. However, neutrinos can induce small component of the gravitational constant in this inert state as described by Eq. (20). It enables virtual particles within a spatial volume determined by the neutrino wave length to gravitate with positive pressure and appear as dark matter.

$$G_v^2 = (2\Gamma^2 \beta \phi_f G)^2 + (2\beta \phi G)^2. \quad (20)$$

where G_v is the neutrino induced gravitational constant in the inert state. Γ is the asymmetry parameter involved in the emergence of dark energy. ϕ_f is the dimensionless flavour parameter. It oscillates with neutrino flavour such that $0 < \phi_f \leq 1$. ϕ is a dimensionless phase parameter that also oscillates between zero and one ($0 \leq \phi \leq 1$), but gets dampened and constrained to zero by negative pressure. Once shear pressure exceeds negative pressure, ϕ oscillation resumes and

remains in this active phase for a life time t_ϕ . β is a dimensionless energy scale parameter. $0 < \beta < 1$ and it is described by,

$$\beta = \frac{E_\nu}{E_P}. \quad (21)$$

where E_ν is neutrino energy and E_P is Planck energy.

Eq. (20) consists of a usually inactive heavy term ($2\beta\phi G$) with ϕ constrained to its zero phase by negative pressure and an oscillating light term ($2\Gamma^2\beta\phi_f G$), lightened to the scale of dark energy by Γ . While the light term tends to produce the effect of light and hot dark matter, the heavy term produces the effect of heavy dark matter. Furthermore, such neutrinos can be significantly slowed down from the gravitational drag of the gravitationally enabled virtual particles appearing as cold dark matter.

5.1. Detectability

In terms of detectability, light dark matter can be quite thin and can only be detected through the CMB, gravitational lensing and dynamics of large stellar binaries, galactic and extra galactic structures. Heavy dark matter on the other hand, should in addition, be detectable through small scale mass and particle accelerations due to the strong gravitational interactions which also tends to increase neutrino interaction cross-section. From Eq. 20, an ultra high energy neutrino with 10^{-16} eV energy and with $\phi \sim 1$, should induce a gravitational constant $G_\nu \sim 10^{-12}G$ for virtual particles to gravitate within the volume of space described by the neutrino wavelength. Such heavy term enabled gravitation of virtual particles produces the effect of heavy dark matter while active.

The key role of shear stress in activating the heavy term in Eq. (20) by neutralizing the suppressive effect of negative pressure as indicated in section (3.2), provides a means of activation and subsequent detection of heavy dark matter from relatively intense neutrino flux such as solar neutrino and even geoneutrinos. The life time t_ϕ can provide a way to determine the effective interaction distance l_e (from the point of shear activation), where $\phi = 1$ and the heavy term is at its heaviest. While the detailed dynamics of t_ϕ is yet to be fully worked out, it is expected to be inversely proportional to neutrino energy and negative pressure after shear activation of the heavy term. This can be worked out from future theoretical and experimental works.

6. Discussion and Conclusions

EDS provides a framework for the possible resolution of the mysteries of dark energy and dark matter. In doing so it provides potential insights into the dimensional structure of spacetime and gravity. Specifically, it places the bare vacuum energy component in a state where the gravitational field is switched off with actual gravitational constant $G_0 = 0G$, while real standard model particles, oscillate between this gravitationally inert state and the active state.

Due to an energy density constraint and a speed limit asymmetry described by an asymmetry parameter, a small component of vacuum energy is constrained to exist in the gravitationally active state and appear as dark energy. The asymmetry parameter is the ratio of the size of a large extra spatial dimension S_0 and its microscopic partner S_P . Furthermore, EDS describes dark matter as resulting from neutrino enabled gravitation of virtual particles, in which neutrinos induce non zero component of the gravitational constant in the gravitational dark state. The induced gravitational constant has an oscillating light term and a similarly oscillating heavy term that is suppressed by negative pressure but can be activated by shear stress. The result is a barely detectable light form of dark matter and a detectable heavy form dark matter. This neutrino substrate dependent form of dark matter should exhibit hybrid behaviour of particle dark matter and modified gravity form of dark matter like the gravitational polarization of vacuum energy approach [10] and superfluid dark matter [20]. The detailed dynamics of this form of dark matter shall be discussed in future papers.

Expected results from the trio of the JWST, Euclid and upcoming Nancy Grace Roman Telescope and Vera Rubin Observatory, are expected to provide precision measurements of dark energy density as well as the dynamics of dark matter. Such precision measurements should glean out the predicted

suppression of dark energy density in the deep gravitational potential wells of baryonic matter like it apparently does to dark matter.

There are number of potential insights that can have interesting outcome but are beyond the scope of this article. For instance, a possible oscillation of dimensionality d in Eq. (1) which can determine either a positive or negative response to the stress energy tensor might give rise to a cyclic universe scenario. This possibility and more, shall be explored in future works.

In conclusion, the EDS framework offers new physics explanations for dark energy and dark matter as different manifestations of vacuum energy that can be tested and provides potential insights into the dimensional structure of spacetime and gravity.

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