Polarized vacuum field interaction interpretation for varying dark energy model and its implications

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**Abstract**

In this paper, we attribute the dark energy phenomena to a specific type of interaction of the vacuum field with charged particles, resulting in a varying field model. We test our theory by quantifying this interaction and deriving the dark energy density while staying within the classical domain. Up to a redshift of z = 1 for Type Ia supernovae, we obtain a value of 5.33x10-10 J/m3, agreeing with observation. We illustrate the evolution of our model by deriving the equation of state while comparing it to other varying models. We then briefly discuss the implications concerning Hubble tension and the possible support of a proposed dark matter candidate due to the nature of this effect.

*Keywords:* dark energy, Hubble tension, dark matter

**1. Introduction**

The expansion of the universe has been a topic of discussion ever since the recording and analysis of the Hubble data. The measurements of the redshifts of Type Ia supernovae, amongst other observations, have revealed that the universe's expansion is accelerating (Riess et al., 1998). This led to the inference of what is called dark energy. A prediction from quantum field theory suggests a value of the dark energy density of about 10120 larger than what we observe (Adler et al., 1995), the observed value being only (Ade et al., 2016).

Candidates for the nature of dark energy involve varying and non-varying models. The cosmological constant, or ΛCDM model suggests a constant energy density throughout space (Carroll, 2001). Another non-varying model considers the vacuum as a zero-point harmonic oscillator (Dikshit, 2019). On the other hand, varying models proposed by Wetterich (1998) and others (Ratra & Peebles, 1988; Barboza & Alcaniz, 2008; Jassal & Bagla, 2010), suggest a hypothetical form of energy that is repulsive, represented by scalar fields that vary with time and space. Recently, observations from the Dark Energy Spectroscopic Instrument, or DESI, may indicate that dark energy evolves over time (Biron, 2024). Our approach also suggests a varying model that involves a hypothetical type of interaction involving the vacuum field. We test our theory by quantifying this interaction and deriving the dark energy density and the equation of state.

In our method, we attribute dark energy to an interaction involving the polarized vacuum field, in which virtual particle-antiparticle pairs from the vacuum undergo polarization due to the presence of a charge. A moving charge would then have a small non-zero net force applied to it due to the difference of the changing proximity between the forward and rearward sides of the surrounding virtual particles, and has the form

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| --- | --- |
|  | (1) |

for a particle traversing in the z-axis, where is the z-component of the total electric field from the polarized virtual particles, and the overall net force applied on the charge is determined by the dimensionless factor . In Section 2, we derive using delta potentials and derive the dark energy density. In Section 3 we derive the equation of state. And in Section 4 we discuss the significance of this interaction concerning Hubble tension and possible support for an already proposed dark matter candidate.

**2 Dark Energy Density Calculation**

*2.1 Derivation of*

Consider a one-dimensional problem, where the production of two virtual particle-antiparticle pairs from the vacuum is represented by two delta potentials with an infinitesimal distance of apart, where and are the distances between a charged particle starting at the origin ( and the potentials. We must use the difference of these potentials: and differentiate to find the net force

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| --- | --- |
|  | (2) |

Where is a coupling constant and we’ve used the property on the first term. Using a smooth function for the derivative of a distribution: , we choose a trial function . Using which works as long as is small in order to apply the same limits throughout to avoid the divergence on the LHS, while having , defined as the average force over a small lifetime of the virtual particle pairs, we have

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| --- | --- |
|  | (3) |

Where has only a very small variance, so that: . Integrating, we have

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| --- | --- |
|  | (4) |

Where we define and as the particle’s momentum at and , respectively. To obtain the correct units, we use: , where is the particle's mass, is the lifetime of the particle-antiparticle pairs, and has units of velocity and is defined as the velocity of the propagating field, which is the speed of light . We then approximate the lifetime to the time after a small displacement of the charge, or . Having , and for low speeds, we have

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| --- | --- |
|  | (5) |

Since the force is a constant, for any , and having for an interaction near the origin, we have

|  |  |
| --- | --- |
|  | (6) |

Where we’ve derived the dimensionless factor: , where is the initial velocity. In the trivial case: , as required. Over time, we consider this effect to be a continuous process.

At high speeds, we must incorporate the relativistic properties of the particle in the next subsection. Expanding our problem to three dimensions by including the contributions due to a spherical field, we will use for a particle traversing along the z-axis. In the next subsection, we will assume that the electric field from the polarized particle-antiparticle pairs is equivalent to the electric field's strength of the charge near its classical limit: . This allows us to remain within the classical domain.

*2.2 Relativistic Implementation of the Vacuum Field Interaction*

For high-speed particles, one must consider relativistic effects. We accomplish this through the contraction of the electric field. For a particle traversing along the z-axis, the electric potential energy from an electric field undergoing a Lorentz transformation is

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| --- | --- |
|  | (7) |

Where . Using , , and being the limit of the interaction while inputting the value of , we obtain the energy attributed to the acceleration of a particle from the vacuum field interactions as

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| --- | --- |
|  | (8) |

Where we’ve used the classical radius .

*2.2.1 The Classical Limit*

There needs to be some clarification on the meaning of the classical radius concerning this type of interaction. In the case of the proton, the classical radius is meters. In comparison, the effective quark radius is smaller than this, which limits the quark size to be less than meters (Abramowicz et al., 2016). The classical limit is interpreted here as the limit of the interaction between the proton, treated in this case as a single particle, and the vacuum field, before quantum effects must be considered. The charge of this particle is then the sum of the absolute value of the quark charges, , since each quark contributes positively to this interaction regardless of the sign of the charge. A quick check shows that if we were to instead apply the effective quark radius as the limit on each quark with their respective charges, the result would be quantitatively similar and on the same order of magnitude as our approach. We will find that using the classical limit and the sum of the absolute value of the quark charges gives us an accurate solution without including adjustments to fit the data and allows us to differentiate between protons and neutrons.

*2.3 The Dark Energy Density*

To find the energy density is straight forward: we first take the sum of all the particle energies from (8) within a given volume. For this we require the density of the total mass of a specific type of particle within the volume of the observable universe with radius (Vopson, 2021). According to Vopson (2021), the number of total protons and neutrons in the observable universe is approximately and respectively. This gives a total mass of for protons and for neutrons, which gives us the proton and neutron densities: and , respectively. We can then find the number of charged particles of mass within a specified spherical volume for a universe of uniform density

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| --- | --- |
|  | (9) |

Using (8) and (9) together to take the sum of all particle energies, where and using Hubble’s law , we integrate from our stationary frame of reference to a specified distance

|  |  |
| --- | --- |
|  | (10) |

Integrating and dividing by the spherical volume , the energy density of dark energy for a specific type of particle is

|  |  |
| --- | --- |
|  | (11) |

Since each charge contributes positively to this interaction regardless of the sign, we take the sum of the absolute value of the quark charges for baryons: since we are treating them as singular particles due to our use of the classical limit, as we’ve discussed in section 3.1. For protons and neutrons, we have the charges and respectively, where coulombs. Due to the classical radius of the electron, its contribution is negligible compared to the baryons and will be ignored.

Using the proton and neutron densities , along with we have

|  |  |
| --- | --- |
|  | (12) |

For Type Ia supernovae, we choose a volume up to a redshift of , or , and , where the value for the dark energy density contribution due to light matter is . This accounts for close to 15% of the dark energy contribution, which is approximately the same percentage of matter in the universe that is composed of light matter as expected, giving certainty to our method.

In the case of dark matter, which is theorized to be composed of particles that weakly interact with light matter, its structure is yet to be determined. However, we can use variations of equation (12) to approximate and compare its contribution to the dark energy density assuming that dark matter is self-interacting (Spergel & Steinhardt, 2000) including with its corresponding vacuum field. Using the composition for dark matter identical to that of equation (12), or 87% proton-like and 13% neutron-like particles, and the fact that dark matter makes up 85% of all matter, the total dark energy density becomes , while using the composition of only neutron-like particles gives us . But for dark matter that is comprised of only proton-like particles, the total dark energy density becomes , which is very close to the observed value of . We will see in our analysis how this last result can give credence to a proposed dark matter particle candidate.

**3 Equation of State and the Quintessence Region**

In Figure 1 we show the equation of state of multiple models varied by the redshift , including our proposed model as the solid blue curve, where

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| --- | --- |
|  | (13) |

When varied by redshift, as shown in Figure 2, equation (12) converges at , which means as , so that . Our model is mostly within the range of the quintessence region between and (Avsajanishvili, 2019). What’s unique in our model is the convergence at , approaching a constant energy density further into the expansion.

A graph of a model

Description automatically generated with medium confidence

**Figure 1.** The equation of state for dark energy varied by redshift. Our proposed model in blue compared to other varying models (Wetterich, 1988; Barboza & Alcaniz, 2008; Jassal & Bagla, 2010; Avsajanishvili, 2019) and the cosmological constant or ΛCDM model.

A graph of a model

Description automatically generated

**Figure 2.** Measurement of the dark energy density (J/m3) at varying redshift z. Our proposed model is in blue compared to the cosmological constant or ΛCDM model, .

**4 Conclusion and analysis**

The interaction due to the polarized vacuum field suggests a varying model akin to the models by Wetterich (1988) and others (Ratra & Peebles, 1988; Barboza & Alcaniz, 2008; Jassal & Bagla, 2010; Avsajanishvili, 2019). Our model also hints at a decreasing acceleration at farther distances. Andrei and others suggest a varying scalar field that leads to decreasing dark energy over time (Andrei et al., 2022). Recent observations from the Dark Energy Spectroscopic Instrument or DESI may indicate that the accelerated expansion of the universe is not only evolving but may also be slowing down (Biron, 2024).

It is also suggested that a varying field, and more specifically, a possibly higher amount of dark energy in the early universe (Poulin et al., 2018) may resolve the discrepancy of the Hubble constant, known as Hubble tension (Rameez & Sarkar, 2021; Hu & Wang, 2023), where the measurement of from CMB observations is compared to for Type Ia supernovae (Rameez & Sarkar, 2021). However, since the acceleration due to the interaction proposed here pertains to charged particles and not photons, it may have a significant impact on the resolving of this discrepancy, as Goldstein and others have stated that it would take substantially more than early dark energy to resolve Hubble tension due to the considerable mismatch between the predictions and observations of a series of quasar-spectra absorption lines (Goldstein et al., 2023).

In the realm of what constitutes dark matter, much research has been done on the possible candidate being of the form of atomic hydrogen which agrees with our result when using the quark makeup of protons to describe dark matter, assuming it can interact exclusively with other dark matter and its corresponding vacuum field. Oks and Tatum speak of a ‘second flavor’ of hydrogen atoms or SFHA, having only ‘S-states’ that do not interact with electromagnetic radiation other than the hydrogen 21-cm absorption line (Oks, 2022; Tatum, 2020). McGaugh’s analysis of the strength of the signal from the detection of redshifted 21 cm absorption at (Bowman et al., 2018) also suggests dark matter as baryonic (McGaugh, 2018). Analysis from atomic experiments concerning the high-energy tail of the linear momentum distribution in the ground state of hydrogen atoms (Oks, 2001) may also provide possible experimental evidence for SFHA (Oks, 2022). Another example from experimental analysis is that, due to the absence of the Stark effect in SFHA, the inclusion of their theoretical cross-sections in the experimental results of resonant charge exchanges between hydrogen atoms and low-energy protons (Fite et al., 1962) better agrees with the data as opposed to their absence as demonstrated by Oks (2022). Lastly, studies on ultra-dense hydrogen, or H(0), such as the measurement of the rotational spectra that agree well with observations of the extended red emission (ERE) suggest that H(0) is a major part of dark matter in the universe (Holmlid, 2019).

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