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# Repulsive Force Proportional to Energy Density as an Origin of Dark Energy

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**Abstract**

An X-particle with repulsive force proportional to energy density is postulated as an origin of dark energy. Like photon, the particle has only relativistic mass (zero rest mass), and acts like a particle that has a definite position and momentum. It creates spaces between them by forces of gravitational attraction and repulsion, where the repulsive force is postulated to be proportional to energy density. The model could be applied to explain the ΛCDM model of dark energy which is filling space homogeneously or to scalar fields such as quintessence whose energy density can vary in time and space.

**Keywords:** X-particle, repulsive force, origin, dark energy

# 1 Introduction

Dark energy is an unknown form of energy that is hypothesized to permeate all of space, tending to accelerate the expansion of universe [1][2][3][4]. As Steven Weinberg puts it, the problem of dark energy is central to todays physics. For decades the problem was to find a symmetry or cancellation mechanism that would make the cosmological constant zero. Now that a dark energy is found, the problem has become even harder. It is difficult to attack this problem without knowing "what it is" that needs to be explained. Until it is solved, the problem of the dark energy will be a roadblock on our path to a comprehensive fundamental physical theory [5][6][7].

This paper is on "what it is". We postulated the X-particle with repulsive force proportional to energy density that provides fundamentally new perspective for an origin of dark energy. X-particles interact only to gravitational attractive force $F_a$ and repulsive force $F_r$. Each X-particle creates space between them where net repulsive force ($F = F_r - F_a$)

matches with its neighboring particles' net repulsive forces. When $F$ is larger than zero, the X-particle exerts pressure to expand.

The paper is arranged as follows. In section 2, our postulated model of the X-particle is presented. In section 3, we describe how model could be applied to cosmological constant form of dark energy or to scalar fields such as quintessence. Finally, we end with some remarks and future research topics in the last section.

# 2 X-Particle

We postulate that dark energy exists in the form of X-particle and permeates all of space. Like photon, the particle is a boson that has only relativistic mass (zero rest mass) and acts like a particle with a definite position and momentum. Quantum mechanics is essential to understanding the behavior of systems at atomic length scales and smaller. However, we postulate that classical mechanics can also be applied for dark energy, since it is believed to be the cause of anomalies in quantum mechanics.

Suppose there are X-particles $i, j$ with distance $l_{ij}$. If we squash them, there is a large repulsive force that pushes them apart. On the other hand, if we pull them apart, there is an attractive force field. When the attractive force is equal to the repulsive force ($F_a = F_r$), we define $l_{ijo}$ as the "stable distance". At the same time, $m_{io}$ and $m_{jo}$ are defined as the "stable mass" for X-particle $i, j$. Throughout the universe, each X-particle exerts force to one another (negative pressure) to reach its stable distance $l_{ijo}$. We postulate the repulsive force to be proportional to energy density

$$F_r = G_r \frac{m_i + m_j}{{l_{ij}}^3}, \tag{2.1}$$

where $G_r$ is a repulsive variable, and $l_{ij}$ is the distance between particle $i, j$. The gravitational attractive force between particles $i, j$ with $G$ as the gravitational constant is

$$F_a = G \frac{m_i m_j}{{l_{ij}}^2}. \tag{2.2}$$

The relation between the the repulsive variable $G_r$ and the gravitational constant $G$ is

$$G_r = G \frac{m_i m_j}{m_i + m_j} l_{ijo}. \tag{2.3}$$

Therefore the "net" repulsive force $F$ exerted on the particle can be defined as

$$F = F_r - F_a = G \frac{m_i m_j}{{l_{ij}}^2} (\frac{l_{ijo}}{l_{ij}} - 1). \tag{2.4}$$

As $l_{ij}$ decreases (less than $l_{ijo}$), there is a large repulsive force $F$ that pushes particles apart. On the other hand, as $l_{ij}$ increases (larger than $l_{ijo}$), an attractive force $F$ dominates. As $l_{ij}$ increases to infinity, $F$ approaches to zero. When $l$ is equal to the stable distance $l_{ijo}$, particles $i, j$ will experience zero force. We can observe an analogical example in electromagnetic forces between atoms, where at the radius of an atom, two atoms may experience nearly zero force.

When particles have a same mass, we can simplify variables as

$$m = m_i = m_j, \qquad l = l_{ij}, \qquad m_o = m_{io} = m_{jo}, \qquad l_o = l_{ijo}. \tag{2.5}$$

Then the net repulsive force equation becomes

$$F = G(\frac{m}{l})^2(\frac{l_o}{l} - 1). \tag{2.6}$$

We postulate that the angular frequency of X-particle as $\omega_x$ that satisfies

$$E = mc^2 = \hbar\omega_x, \tag{2.7}$$

and

$$c = l\omega_x. \tag{2.8}$$

From Eq.(2.7) and Eq.(2.8), we can obtain the key equation of X-particle that shows the relation between $m$ and $l$

$$mlc = \hbar. \tag{2.9}$$

It is important to note that, assuming $\hbar$ and $c$ are constants, the product of $m$ and $l$ ($ml$) is constant. We can get $l$ as a function of $m$ from Eq. (2.9) and vice versa

$$l = \frac{\hbar}{mc}. \tag{2.10}$$

Here the net repulsive force equation can be described as a function of $m$

$$F(m) = G(\frac{c}{\hbar})^2(\frac{m}{m_o} - 1)m^4, \tag{2.11}$$

or as a function of $l$

$$F(l) = G(\frac{\hbar}{c})^2(\frac{l_o}{l} - 1)l^{-4}. \tag{2.12}$$

Here $F(m)$ and $F(l)$ are basically the same force equations with different representations. When $m$ and $m_o$ (or $l$ and $l_o$) are obtained, we can calculate the net repulsive force $F(m)$ (or $F(l)$). In the following section, we will describe how the X-particle variables $(m, l, m_o, l_o)$ can be calculated from $w$ and $\rho$ depending on ΛCDM or quintessence model.

# 3 ΛCDM and Quintessence

In formal terms, "accelerating expansion of the universe" means that the cosmic scale factor $a(t)$ has a positive second derivative ($\ddot{a} > 0$). The velocity at which a distant galaxy is receding from the observer is continuously increasing with time [8]. The Friedmann equation defines how the energy in the universe drives its expansion [9]

$$H^2 \equiv \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho - \frac{kc^2}{a^2} + \frac{\Lambda c^2}{3}, \tag{3.1}$$

where $H$ is the Hubble parameter, $a(t)$ is the scale factor, $\rho$ is the total energy density, $K$ is the curvature of the universe, and $\Lambda$ is the cosmological constant [10]. The hypothesized contributors to the energy density of the universe are curvature, matter, radiation and dark energy [11]. Except the dark energy term, each of the components decreases with the expansion of the universe. The acceleration equation describes the evolution of the scale factor with time [9]

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}\left(\rho + \frac{3P}{c^2}\right) + \frac{\Lambda c^2}{3}, \tag{3.2}$$

where the pressure P is defined by which the cosmological model is chosen. The dark energy has negative pressure which is distributed relatively homogeneously in space

$$P = w\rho c^2, \tag{3.3}$$

where c is the speed of light, $\rho$ is the energy density, and $w$ is a value that depends on a dark energy model. To apply our model of X-particle to Eq.(3.3), we define the density $\rho$ from the mass $m$ and the distance $l$

$$\rho = \frac{m}{l^3}. \tag{3.4}$$

Applying $\rho$ to Eq.(2.9), the distance between X-particles is

$$l = \sqrt[4]{\frac{\hbar}{c\rho}}. \tag{3.5}$$

Using Eq.(3.4), the relativistic mass of the X-particle is

$$m = \rho l^3 = \sqrt[4]{\frac{\hbar^3 \rho}{c^3}}. \tag{3.6}$$

In the accelerated expansion of universe, since repulsive force is much larger than attractive force, the net repulsive force Eq.(2.11) and Eq.(2.12) can be simplified as

$$F(m) \approx G(\frac{c}{\hbar})^2(\frac{m}{m_o})m^4, \qquad F(l) \approx G(\frac{\hbar}{c})^2(\frac{l_o}{l})l^{-4}, \tag{3.7}$$

where $m/m_o \gg 1$ and $l_o/l \gg 1$. The negative pressure $P$ multiplied by the surface area $\pi l^2$ is equal to the net repulsive force $F(m)$ and $F(l)$

$$F(m) = -w\rho c^2(\pi l^2) = G(\frac{c}{\hbar})^2(\frac{m^5}{m_o}), \tag{3.8}$$

and

$$F(l) = -w\rho c^2(\pi l^2) = G(\frac{\hbar}{c})^2(\frac{l_o}{l^5}). \tag{3.9}$$

By rearranging each equation for $m_o$ and $l_o$, we get

$$m_o = G(\frac{c}{\hbar})^2 \frac{m^4 l}{-w\pi c^2} = \frac{G}{-w\pi}\sqrt[4]{\frac{\hbar^5\rho^3}{c^{13}}}, \tag{3.10}$$

and

$$l_o = \frac{\hbar}{cm_o} = \frac{-w\pi}{G}\sqrt[4]{\frac{c^9}{\hbar\rho^3}}. \tag{3.11}$$

Here we have derived all equations to determine the X-particle variables $(m, l, m_o, l_o)$ from $w$ and $\rho$. Different theories suggest different values of $w$. $\Lambda$CDM has generally been known as the Standard Model of Cosmology. It is the simplest form in good agreement with a variety of recent observations [12][13]. In this model, $w = -1$ and $m_o$ and $l_o$ can be obtained from Eq.(3.10) and Eq.(3.11) respectively

$$m_o = \frac{G}{\pi}\sqrt[4]{\frac{\hbar^5\rho^3}{c^{13}}}, \qquad l_o = \frac{\pi}{G}\sqrt[4]{\frac{c^9}{\hbar\rho^3}}. \tag{3.12}$$

The distance between particle $l$ and relativistic mass $m$ is a function of $\rho$ only, and can be directly obtained from Eq.(3.5) and Eq.(3.6)

$$m = \sqrt[4]{\frac{\hbar^3\rho}{c^3}}, \qquad l = \sqrt[4]{\frac{\hbar}{c\rho}}. \tag{3.13}$$

In $\Lambda$CDM, we postulate that the universe is filled with a sea of X-particles with distance $l$ and mass $m$ as obtained above.

Our model of X-particles can be applied to other form of dark energy such as quintessence. It differs from the static explanation of dark energy with cosmological constant in that it is dynamic. It is suggested that quintessence can be either attractive or repulsive depending on the ratio of its kinetic and potential energy. Quintessence is a scalar field with an equation of state where $w$ is given by the potential energy $V(Q)$ and a kinetic term [12][13].

$$w = \frac{P}{\rho c^2} = \frac{\dot{Q}^2 - 2V(Q)}{\dot{Q}^2 + 2V(Q)} \tag{3.14}$$

If $w$ and $\rho$ are given, using Eq.(3.5), Eq.(3.6), Eq.(3.10), and Eq.(3.11), the X-particle variables $(m, l, m_o, l_o)$ can be obtained for quintessence model. However, since no real evidence of quintessence is yet available, more research is needed to understand the meaning of X-particles in the quintessence model.

# 4 Conclusion

An X–particle with repulsive force proportional to energy density is postulated as an origin of dark energy. The particle can be defined by Eq.(2.6) with distance $l$ and mass $m$ as varibles. We showed how the X-particle variables $(m, l, m_o, l_o)$ can be obtained from $w$ and $\rho$. For $\Lambda$CDM form, cosmological data is in good agreement with a variety of recent observations, and a model of X-particles with $l$ and $m$ is expected to work well. However, for quintessence form, since no real evidence of quintessence is yet available, more research is needed to understand the meaning of X-particles in the quintessence model.

We postulate that the universe is filled with a sea of X-particles which creates negative pressure to accelerate the expansion of universe. The future research topic will be a computational modeling and simulation showing whether X-particles could be introduced from outside of the universe or be created from baryonic or dark matter to predict the future of the universe.

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