AJOU-DM-05/23/2016

X-Particle as a Solution for the Cosmological Constant Problem

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Abstract

The cosmological constant is a fundamental problem in modern physics, and arises at the intersection between general relativity and quantum field theory. In this paper we show how the cosmological constant problem can be solved by X-particles of dark energy with the repulsive force proportional to energy density [8].

Keywords: dark energy, X-particle, X-theory, cosmological constant

1 Introduction

The cosmological constant problem is to understand why the vacuum energy density ρ_V is so small. We can calculate some contributions to ρ_V nearly up to the Planck scale, which is larger than the observationally allowed value by 120 orders of magnitude [1][2][4][5][6][7][13][15]. Another cosmological constant problem is to understand why ρ_V is not only small, but also, as current Type Ia supernova observations seem to indicate, of the same order of magnitude as the present mass density of the universe [3].

In this paper we show how the cosmological constant problem can be solved by X-particles of dark energy with the repulsive force proportional to energy density [8]. We postulate the vacuum as an infinite sea of X-particles of dark energy, called the X-sea. As masses (or energy) in the sea increase at a certain location, nearby X-particle's relativistic masses increase accordingly as gravitational attractive forces and repulsive forces increase [9]. An X-particle's mass may vary from m_Λ at the ΛCDM model to the m_{P} at the Planck scale, but is not limited to this range.

The value of dark energy at each location changes as the vacuum energy density varies. We can regard the observed cosmological constant as the reflection of dark energy throughout the universe, but, locally, there can be a big difference between the dark energy and the observed cosmological constant. As Carroll implied in his paper [1], advances in the understanding of the cosmological constant problem will reveal that a certain theoretical compromise is only superficially distasteful, when in fact it arises as the consequence of a beautiful underlying structure.

The rest of the paper is arranged as follows. In section 2, the previous works on the X-particle are presented. In section 3, we show how the cosmological constant problem can be solved with the X-particle theory of dark energy. Finally, we end with some remarks and future research topics in the last section.

2 Previous Work

2.1 X-particle

The X-particle theory postulates that dark energy exists in the form of X-particle and permeates all of space [8]. 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.

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 " 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 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

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

And 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 ω_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

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

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. (2.15) and vice versa

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

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 $F(l)$). The X-particle variables (m, l, m_o, l_o) can be calculated from w and ρ depending on ΛCDM or quintessence model [8].

It is worth noting that Planck mass

$$m_{\mathrm{P}} = \sqrt{\frac{\hbar c}{G}} \tag{2.13}$$

and Planck length

$$\ell_{\mathrm{P}} = \sqrt{\frac{\hbar G}{c^3}} \tag{2.14}$$

also satisfies the key equation of X-particle of Eq.(2.15) that shows the relation between m and l.

$$m_{\mathrm{P}}\ell_{\mathrm{P}}c = \hbar. \tag{2.15}$$

Therefore a pair of Planck mass and length is one of the possible X-particle solutions.

2.2 ΛCDM

The dark energy has negative pressure which is distributed relatively homogeneously in space [8]

$$P = w\rho c^2, \tag{2.16}$$

where c is the speed of light, ρ 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.(2.16), we define the density ρ from the mass m and the distance l

$$\rho = \frac{m}{l^3}. \tag{2.17}$$

Applying ρ to Eq.(2.15), the distance between X-particles is

$$l = \sqrt[4]{\frac{\hbar}{c\rho}}. \tag{2.18}$$

Using Eq.(2.17), the relativistic mass of the X-particle is

$$m = \rho l^3 = \sqrt[4]{\frac{\hbar^3\rho}{c^3}}. \tag{2.19}$$

For m_o and l_o, we get [8]

$$m_o = G(\frac{c}{\hbar})^2 \frac{m^4 l}{-w\pi c^2} = \frac{G}{-w\pi}\sqrt[4]{\frac{\hbar^5\rho^3}{c^{13}}}, \tag{2.20}$$

and

$$l_o = \frac{\hbar}{cm_o} = \frac{-w\pi}{G}\sqrt[4]{\frac{c^9}{\hbar\rho^3}}. \tag{2.21}$$

Here we have all equations to determine the X-particle variables (m, l, m_o, l_o) from w and ρ. Different theories suggest different values of w. ΛCDM has generally been known as the Standard Model of Cosmology. It is the simplest form in good agreement with a variety of recent observations [18][19]. In this model, $w = -1$ and m_o and l_o can be obtained from Eq.(2.20) and Eq.(2.21) respectively.

2.3 X-Gravitational Field

In a field model of general relativity, rather than two particles attracting each other, the particles distort spacetime via their mass, and this distortion is what is perceived and measured as a "force". In such a model one states that matter moves in certain ways in response to the curvature of spacetime [17].

In X-gravitational field model, a gravitational field can be formed with the X-particle distribution [9], and Newtonian's gravitational equation is postulated to be valid if we add dark energy and Lorentz transformation into the model. In order to simplify the problem, one dimensional array of X-particles is considered as an approximated model.

Suppose X-particles from $X_1..X_\infty$ lined up from left to right with mass M ($M \gg m_i$) at the leftmost. For each X_i there is a gravitational attractive force $F_a[i]$ between M and X_i

$$F_a[i] = G\frac{Mm_i}{{R_i}^2}, \tag{2.22}$$

where m_i is the mass of X_i, and R_i is the distance between M and X_i. As X_i is attracted to M, Newton's third law of "action equals reaction" is applied between X_i and X_{i-1}. Here X_i exerts a force $F_a[i]$ on the X_{i-1}, and the X_{i-1} will push back on X_i with an equal repulsive force $F_r[i-1,i]$ in the opposite direction

$$F_r[i-1,i] = G\frac{m_i m_{i-1}}{{l_{i,i-1}}^2}(\frac{l_o}{l_{i,i-1}} - 1), \tag{2.23}$$

where $l_{i,i-1}$ is the distance between X_i and X_{i-1}. For i from 2 to ∞, if we apply Newton's third law of action equals reaction, we get

$$F_a[i] = F_r[i-1,i]. \tag{2.24}$$

Using Eq.(2.22) and Eq.(2.23), if $l_{i,i-1} \ll l_o$, we get

$$l_{i,i-1} \approx \sqrt[4]{\frac{\hbar l_o R_i^2}{cM}}, \tag{2.25}$$

and

$$l_i \approx \frac{l_{i,i-1} + l_{i+1,i}}{2}, \tag{2.26}$$

where R_i is the sum of X-particle distances

$$R_i = R_1 + \sum_{j=2}^{i} l_{j,j-1}. \tag{2.27}$$

We can get m_i from

$$m_i = \frac{\hbar}{cl_i}. \tag{2.28}$$

Here we have all equations necessary to define the X-particle distribution in one dimension (l_i,m_i,R_i,$F_a[i]$). As an X-particle X_i gets closer to the particle M, Eq.(2.25) and Eq.(2.26) predict l_i to decrease, and Eq.(2.28) shows m_i to increase. Thus, from Eq.(2.22) the gravitational attractive force gets stronger by the increase of m_i as well as the decrease of R_i, and the particle forms very close ties with X-particles in close proximity.

The model can be applied to a three dimensional space with multiple mass objects under the law of superposition. For any X-particle X_i, there are gravitational attractive forces and repulsive forces exerted by neighboring X-particles and other masses. Based on Newton's third law, the attractive forces and repulsive forces of X-particles balance each other by adjusting the distance l with neighboring particles. Therefore it creates quantized distribution of X-particles and spaces between them by forces of gravitational attraction and repulsion.

In that process, each X-particle i has the gravitational force field $g[i]$ information at the current position. From Eq.(2.22) we can get

$$g[i] = \frac{F_a[i]}{m_i} = G\frac{M}{{R_i}^2}. \tag{2.29}$$

We postulate that an X-particle has a mechanism to form the gravitational field and to convert it to a gravitational force. And the X-particle passes the gravity signals to its neighboring X-particles at the speed of light to form the ubiquitous gravitational field throughout the universe. For instance, if we place a mass $\hat{M}$ at the position of X-particle i, the force exerted by the gravitational force field i to the mass $\hat{M}$ is

$$F_{\hat{M}} = F_g[i] = \hat{M}g[i] = G\frac{M\hat{M}}{{R_i}^2}. \tag{2.30}$$

The signal that reflects the change of $\hat{M}$ will reflect the spacetime concept and reach mass M after some time delay

$$t_i = \frac{R_i}{c}. \tag{2.31}$$

Therefore X-gravitational field is formed from the dark energy distribution of X-particles, where the quantized gravitational field can be obtained from Eq.(2.29).

2.4 Vacuum

Vacuum is defined as "space void of matter". However, in quantum mechanics and quantum field theory, the vacuum is defined as the state with the lowest possible energy, which is the ground state of the Hilbert space. QED vacuum contains vacuum fluctuations and a finite vacuum energy, which are an essential and ubiquitous part of quantum field theory [14]. Vacuum energy is an underlying background energy that exists in space throughout the entire universe. Their behavior is codified in Heisenberg's energy-time uncertainty principle. Still, the exact effect of such fleeting bits of energy is difficult to quantify [16].

Einstein's theory of general relativity predicts that this energy will have a gravitational effect. Most theories of particle physics predict vacuum fluctuations that would give the vacuum this sort of energy [12]. In this context, X-theory proposes a model of the vacuum as an infinite sea of X-particles of dark energy, called the X-sea [11]. The X-particle accelerates the expansion of universe [8], sets the maximum speed (c) of any matter, and creates the ubiquitous gravitational field and the hierarchical inertial frames of reference [9]. It is the cause of the uncertainty principle, the wave-particle duality, and paradoxes such as the double-slit experiment and the quantum entanglement [10].

3 A Solution for the Cosmological Constant Problem

The cosmological constant problem is to understand why the vacuum energy density ρ_V is so small. The cosmological observations imply [1]

$$|\rho_\Lambda^{(\mathrm{obs})}| \leq (10^{-12}\ \mathrm{GeV})^4 \sim 2 \times 10^{-10}\ \mathrm{erg/cm}^3\ . \tag{3.1}$$

We can calculate some contributions to ρ_V, nearly up to the Planck scale, which is larger than the observationally allowed value by 120 orders of magnitude [2][3].

The cosmological constant problem can be solved by X-particles of dark energy with the repulsive force proportional to energy density [8]. We postulate the vacuum as an infinite sea of X-particles of dark energy, called the X-sea. As masses (or energy) in the sea increase at a certain location, nearby X-particle's relativistic masses increase accordingly as gravitational attractive forces and repulsive forces increase [9]. This process is described in 2.3 from Eq.(2.22) to Eq.(2.28). It also provides the logic behind another cosmological constant problem of explaining why ρ_V is not only small, but also of the same order of magnitude as the present mass density of the universe [3]. An X-particle's mass may vary from m_Λ at the ΛCDM model to the $m_{\rm P}$ at the Planck scale, but is not limited to this range. Applying the maximum value of $\rho_\Lambda^{\rm (obs)}$ to Eq.(2.18) and Eq.(2.19), the relativistic mass of the X-particle is

$$m_\Lambda = \sqrt[4]{\frac{\hbar^3 \rho_\Lambda^{\rm (obs)}}{c^3}}, \tag{3.2}$$

and the distance between X-particles is

$$l_\Lambda = \sqrt[4]{\frac{\hbar}{c\rho_\Lambda^{\rm (obs)}}}. \tag{3.3}$$

The net cosmological constant is the sum of disparate contributions, including potential energies from scalar fields and zero-point fluctuations of each field theory degree of freedom, as well as a bare cosmological constant Λ_0. In the Weinberg-Salam electroweak model, the phases of broken and unbroken symmetry are distinguished by a potential energy difference of approximately $M_{\rm EW} \sim 200$ GeV. We would expect a contribution to the vacuum energy of order [1]

$$\rho_\Lambda^{\rm EW} \sim (200\ {\rm GeV})^4 \sim 3 \times 10^{47}\ {\rm erg/cm}^3\ . \tag{3.4}$$

Applying $\rho_\Lambda^{\rm EW}$ to Eq.(2.18) and Eq.(2.19), the relativistic mass of the X-particle is

$$m_\Lambda^{\rm EW} = \sqrt[4]{\frac{\hbar^3 \rho_\Lambda^{\rm EW}}{c^3}} \sim 2 \times 10^{14}\ m_\Lambda, \tag{3.5}$$

and the distance between X-particles is

$$l_\Lambda^{\rm EW} = \sqrt[4]{\frac{\hbar}{c\rho_\Lambda^{\rm EW}}} \sim 5 \times 10^{-15}\ l_\Lambda. \tag{3.6}$$

In the strong interactions, the energy difference between the symmetric and broken phases is of order the QCD scale $M_{\rm QCD} \sim 0.3$ GeV, and we would expect a corresponding contribution to the vacuum energy of order [1]

$$\rho_\Lambda^{\rm QCD} \sim (0.3\ {\rm GeV})^4 \sim 1.6 \times 10^{36}\ {\rm erg/cm}^3\ . \tag{3.7}$$

Applying $\rho_\Lambda^{\rm QCD}$ to Eq.(2.18) and Eq.(2.19), the relativistic mass of the X-particle is

$$m_\Lambda^{\rm QCD} = \sqrt[4]{\frac{\hbar^3 \rho_\Lambda^{\rm QCD}}{c^3}} \sim 3 \times 10^{11}\ m_\Lambda, \tag{3.8}$$

and the distance between X-particles is

$$l_\Lambda^{\rm QCD} = \sqrt[4]{\frac{\hbar}{c\rho_\Lambda^{\rm QCD}}} \sim 3.3 \times 10^{-12}\ l_\Lambda. \tag{3.9}$$

These contributions are joined by a possible contribution from grand unification of order $M_{\rm GUT} \sim 10^{16}$ GeV. In the case of vacuum fluctuations, we choose our cutoff at the energy up to the Planck scale $M_{\rm Pl} \sim 10^{18}$ GeV, we expect a contribution of order [1]

$$\rho_\Lambda^{\rm Pl} \sim (10^{18}\ {\rm GeV})^4 \sim 2 \times 10^{110}\ {\rm erg/cm}^3\ . \tag{3.10}$$

Applying $\rho_\Lambda^{\rm Pl}$ to Eq.(2.18) and Eq.(2.19), the relativistic mass of the X-particle is

$$m_\Lambda^{\rm Pl} = \sqrt[4]{\frac{\hbar^3 \rho_\Lambda^{\rm Pl}}{c^3}} \sim 10^{30}\ m_\Lambda, \tag{3.11}$$

and the distance between X-particles is

$$l_\Lambda^{\rm Pl} = \sqrt[4]{\frac{\hbar}{c\rho_\Lambda^{\rm Pl}}} \sim 10^{-30}\ l_\Lambda. \tag{3.12}$$

The value of dark energy at each case changes as the vacuum energy density varies. We can regard the observed cosmological constant as the reflection of dark energy throughout the universe, but, locally, there can be a big difference between the dark energy and the observed cosmological constant. In the above example, an X-particle's mass may take a wide range of values from m_Λ, $m_\Lambda^{\rm EW}$, $m_\Lambda^{\rm QCD}$ to $m_\Lambda^{\rm Pl}$. The X-particle's mass is dynamic, and virtually can take any value as caculated from Eq.(2.19).

As Carroll implied in his paper [1], advances in the understanding of the cosmological constant problem will reveal that a certain theoretical compromise is only superficially distasteful, when in fact it arises as the consequence of a beautiful underlying structure. We argue that the structure is based on the X-particle of dark energy with the repulsive force proportional to energy density.

4 Conclusion

The cosmological constant is a fundamental problem in modern physics, and arises at the intersection between general relativity and quantum field theory. In this paper we described how the cosmological constant problem can be solved by X-particles of dark energy with the repulsive force proportional to energy density [8]. The value of dark energy at each location changes as the vacuum energy density varies. We can regard the observed cosmological constant as the reflection of dark energy throughout the universe, but, locally, there can be a big difference between the dark energy and the observed cosmological constant.

The future research topic is to understand the relationship between X-particles and other quantum gravity theories. X-particles need to be understood in the larger context of X-theory [11]. The theory proposes a model of the vacuum as an infinite sea of X-particles of dark energy, called the X-sea. The X-particle accelerates the expansion of universe [8], sets the maximum speed (c) of any matter, and creates the ubiquitous gravitational field and the hierarchical inertial frames of reference [9]. The X-particle is the cause of the uncertainty principle, the wave-particle duality, and paradoxes such as the double-slit experiment and the quantum entanglement [10]. In X-theory, the predictions of general relativity that have been confirmed in observations and experiments are still valid. However, the repulsive force of dark energy exerted on the moving object creates a fundamental difference with general relativity [11].

The main cause of anomalies in quantum mechanics is postulated to be dark energy. Thus many parts of classical mechanics would be valid in quantum mechanics if we add dark energy, spacetime, and Lorentz transformation into the model.

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