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A Different Point of View of Vacuum Problem

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Abstract

The cosmological constant problem is localizated in the convergence between general relativity and quantum field theory, it is considered as a fundamental problem in modern physics. In this paper we describe a different point of view of this problem. We discuss how the problem could depend to different definition of the vacuum energy density.

Keywords: Vacuum energy density • Cosmological constant problem • Physics • Energy

Introduction

Quantum Field Theory (QFT) which is fundamental in modern physics show zero-point energy in space, including in areas which are in another way 'void' (i.e. without radiation and matter). Maybe we could think these zero-point energy give a vast vacuum energy density ρ_{vac}. On the other hand it is expected to cause an increase of cosmological constant Λ appearing in Einstein's field equations [1].

Vacuum Energy Density

The constant $\kappa = 8\pi G/c^4$ is regulated by the principle that equations should be agree with Newtonian theory in the limit for medium and small gravitational fields and small velocities, and this should be consonant also with the value of Λ1. In fact, compare eq.(1) with observations show that Λ is minuscule.

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

Where $R_{\mu\nu}$ and R allude the curvature of space-time, $g_{\mu\nu}$ is the metric, G is the gravitational constant, $T_{\mu\nu}$ is the energy-momentum tensor, and c is the speed of light.

$$|\Lambda| < 10^{-56} cm^2 \qquad (2)$$

This equation usually has been understood as the vacuum energy density in gravitational theory.

$$|\rho_{vac}| = \frac{3H_0{}^2 c^2}{8\pi G} < 10^{-56} cm^2 \sim 10^{-47}\ GeV \sim 10^{-9} \frac{erg}{cm^3}$$

Nevertheless, theoretical estimates the vacuum energy density in QFT exceed the observational measurement by at least 40 orders of magnitude. This contrast constitutes the cosmological constant problem [2]. Quantum electrodynamics is one of the principal components in the standard model, first, and most productive case of a working quantum field theory. We first remembrance that systems studied in non-relativistic quantum mechanics, spatial-temporal coordinates, energy and others are represented by operators in Quantum electrodynamics. One of the most simple quantum system is the quantum harmonic oscillator. The ground state of the quantum harmonic oscillator has a non-null zero-point energy [3].

Free electromagnetic field in a classical theory

In classical electromagnetism, electromagnetic fields have values E(x, t), and B(x, t) in all space-time. The energy density in the classical electromagnetism theory is:

$$H = 1/2\,(E^{-2} + B^{-2})$$

When electromagnetic field is quantized. In the quantization, quantum operators take the place of classical fields. The ground state |0> is the vacuum state of QED. Whole zero-point energy of the quantum electrodynamic theory can be expressed by

$$E = \langle 0 |\, \hat{H}_i \,| 0 \rangle \qquad (3)$$

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$$E = \frac{1}{2} < 0| \left(\hat{\mathbf{E}}_i^{-2} + \hat{\mathbf{B}}_i^{-2} \right) |0 >= \delta(0)^3 \int d^3k \frac{1}{2}\hbar\omega_k \quad (4)$$

Where ω_k are wave-numbers and k are frequencies of a continuum of (plane wave) modes. The infinite delta-function $\delta^3(0)$ can be regularized introducing a cube of volume V. This volumes (in the limit $V \rightarrow \infty$) represent the standard box-quantization process for the electromagnetic field in which an artificial quantization volume V is used to create an equivalence with a harmonic quantum oscillator field mode. Energy density can be extract from the zero-point energy of harmonic quantum oscillator mode.

$$\rho_{vac} = \frac{E}{V_i} = \frac{1}{V}\sum_k \frac{1}{2}\hbar\omega_k = \frac{\hbar}{2\pi^2c^3}\int_0^{\omega_{max}} \omega^3\, d\omega$$

$$\rho_{vac} = \frac{\hbar}{8\pi^2c^3}\omega_{max}{}^4 \quad (5)$$

If we imagine that the QFT framework is valid to the Planck energy.

$$E_p = \left(\frac{\hbar c^5}{G}\right)^{\frac{1}{2}} = 10^{19}\,\text{GeV} \quad (6)$$

It is easy to see, modern physics could enter between electroweak scales and Planck scales but if the alternations are still out of the framework of quantum field theory, we could admit vacuum energy can be expressed using Planck energy in equation 6.

$$E_p = \left(\frac{\hbar c^5}{G}\right)^{\frac{1}{2}} = \hbar\omega_{max})^2$$

$$\rho_{vac} = 10^{114}\,\frac{\text{erg}}{\text{cm}^3} \quad (7)$$

There are a difference between QED and observational result by more than ~120 orders of magnitude.

Proposition

On the one hand, we introduce these concepts. The Hubble velocity of an object is given by Hubble's law.

$$v = H_0 x \quad (8)$$

Replacing v with speed of light c and solving for proper distance x we obtain the radius of Hubble.

$$r = \frac{c}{H_0} \quad (9)$$

Hubble´s radius is a theoretical horizon defining the limit between particles that are moving slower and faster than the speed of light. In the current expansion model FWR light emitted from the Hubble´s radius will reach us in a finite amount of time. From another point of view, in an accelerating universe, if two particles are separated by a distance greater than the Hubble´s radius, they not be able to interchange information in the future [4-6]. In this proposition we think that Friedman's equations and Einstein's field equation using to calculate age of the universe, length and other parameter are directly relate with Hubble´s radius. Friedman's model have a scale around Hubble´s radius and we use this scale to calculate space with similar dimensions that Friedman's model [7]. We use a new definition, Hubble surface is a two dimensional region can be applied to any region of space with a surface of order and represent the scale of the Friedmann model. Energy of the quantum electro-dynamic theory can be expressed by:

$$E = \frac{1}{2} < 0| \left(\hat{\mathbf{E}}_i^{-2} + \hat{\mathbf{B}}_i^{-2} \right) |0 >= \delta(0) \int dk \frac{1}{2}\hbar\omega_k \quad (10)$$

Where ω_k are wave-numbers and k are frequencies of a continuum of (plane wave) modes. The infinite delta-function $\delta(0)$ can be regularized in a line of length L. "Line regularization" (enclosing energy in a line of length L) implies the following substitution.

$$\delta(0) = \frac{1}{2\pi}\int e^{ikx} dx \rightarrow \frac{L}{2\pi} \quad \text{if} \quad k \rightarrow 0 \quad (11)$$

This L length represent the standard 'L-quantization' process for the energy' First we will calculate the linear vacuum energy density ρ_L due to the intrinsic properties of the wave.

$$\rho_L = \frac{E}{l_i} = \frac{1}{L}\sum_k \frac{1}{2}\hbar\omega_k \sim \frac{1}{2}\frac{\hbar}{\pi c}\int_0^{\omega_{max}} \omega\, d\omega \quad (12)$$

In our model Hubble surface will be the surface we use to calculate vacuum energy density.

$$\rho_{vac} \sim \left(\frac{H_0}{c}\right)^2 \rho_L = \left(\frac{H_0}{c}\right)^2 \frac{1}{2}\frac{\hbar}{\pi c}\int_0^{\omega_{max}} \omega\, d\omega$$

$$\rho_{vac} \sim \frac{\hbar H_0{}^2 \omega_{max}{}^2}{4\pi c^3} \quad (13)$$

Assuming this energy to be of the QED zero-point energy type, (by inserting the Planck energy in equation 13.

$$E_p = \left(\frac{\hbar c^5}{G}\right) = \hbar\omega_{max})$$

$$|\rho_{vac}| \sim \frac{H_0^2c^2}{4\pi G} \sim \frac{3H_0^2c^2}{8\pi G} \quad (14)$$

Conclusion

Conclusions obtained are following, a simple model has been exposed, most basic model possible, it is not intended to deepen in details, it is not intended to give it a large complexity mathematical theory, it is intended to visualize the following point, if we the choose Hubble distance (which is large used in Friedman's model and defines breadth of dimensions in it) as dimension of space to calculate vacuum energy density we will obtain interesting results.

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