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Original Research Article

TIME VARYING COSMOLOGICAL CONSTANT 'Λ' AS DARK ENERGY CANDIDATE

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Abstract The best candidate source for dark energy is the energy contained in vacuum fluctuations (otherwise known as zero point energy). As mentioned in this paper cosmologists trying hard to know the amount of energy in the vacuum, and they came to a result that is $\mathbf{10^{120}}$ times larger than amount of **dark energy** required for accelerating the expansion of our universe. Through the recent studies, it is firmly established that the hypothetical fluid (dark energy) is tied to the Einstein's cosmological constant Λ. It is also much speculated that the most interesting candidate of **dark energy** is the Vacuum Energy and the cosmological model in which Λ is assumed to be the source of dark energy, is called **ΛCDM** model.

Introduction: The cosmological constant Λ was introduced by Einstein in 1917, as the universal repulsion to allow static homogeneous solutions to Einstein's equations [1,2]. The introduction of this force is in the presence of matter and was subsequently withdrawn several times before the discovery of expansion of the universe. In the mean time, Scientists have realized that the cosmological constant can be measured as the energy density of the vacuum which is the state of lowest energy and in principle, there is no reason yet for this vacuum energy to be zero the vacuum energy-momentum tensor can be written as

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$$T_{ij}^{vac} = -\rho_{vac}\ g_{ij} \tag{1}$$

and vacuum can also be treated as a perfect fluid with Equation of State

$$P_{vac} = -\rho_{vac}$$

We use to take $\rho_{vac} = \rho_\Lambda = \frac{\Lambda}{8\pi G}$ (2)

and moving the Λg_{ij} term into the Einstein Field equation we may write :

$$G_{ij} + \Lambda g_{ij} = \frac{8\pi G}{c^4} T_{ij} \tag{3}$$

It is easy to observe that the effect of energy-momentum tensor for vacuum is equivalent to that of Λ which is the actual origin of Λ with the energy density of the vacuum. In GTR, any kind of energy affects the gravitational field, which makes the cosmological constant in the form of vacuum energy as the potentially crucial ingredient of the universe

Recent Evidences for "Λ" as "DE"

When we search the literature then observe that the powerful evidences of nonzero, small but positive Λ is from the various sources as from studies of :

- supernovae,
- clusters of galaxies,
- large scale structure,
- and the CMB,

the inclusion of such remarkable parameter Λ was confirmed and firmly established. Here It is essential to formulate a theory which sets a very small nonzero value to the vacuum energy. So that one can differentiate between a “true” vacuum and a “false” vacuum ***True vacuum*** would be the state of lowest possible energy with nonzero value and a metastable state in which Λ might be zero corresponds to the ***false vacuum***. Such a metastable state could decay into the state of lowest energy, although its life span could be much larger than the current age of the universe. Such a scenario point towards the time varying vacuum energy or the dynamical cosmological constant Λ. Through the recent studies, it is firmly established that the hypothetical fluid (dark energy) is tied to the Einstein’s cosmological constant Λ. It is also much speculated that the most interesting candidate of ***dark energy*** is the *Vacuum Energy* and the cosmological model in which Λ is assumed to be the source of dark energy, is called ***ΛCDM*** model. The remarkable feature of these models is that the density of dark energy evolves with the expansion of universe and commonly described by the Equation of state parameter ω relating pressure and density as

$$p=\omega\rho, \qquad (4)$$

provides a useful phenomenological description [3] of the dark energy. Here it is worthwhile to mention that the value of EoS parameter for a fluid like cosmological constant, is −1.

The Accelerated Expansion of The Universe

The idea of accelerated expansion itself in a matter dominated universe was quiet surprising but a cosmological model composed with a mixture of matter and cosmological constant could describe these observations very well [4,5]. In such a universe with both matter and cosmological constant or vacuum energy, there is always a competition between the tendency of matter to cause deceleration, the tendency of Λ to cause acceleration and the ultimate fate of the universe depends upon the precise amounts of these components. Various probes of cosmic acceleration such as SNeIa, CMB and many other have constrained density parameters (Ω_M & Ω_Λ) but the analysis of temperature anisotropies in the CMB is the best method for constraining these density parameters while the most direct way to measure the cosmological constant is the Hubble diagram i.e., by determining the relationship between red shifts and distances of far away galaxies. The supernovae results, observations from the CMB, and dynamical measurements of the matter density are impressively consistent and constrained as:

- Ω_M close to 0:3 and Ω_Λ close to 0:7.
- Spergel *et al.* [6] have constrained Ω_Λ = 0:74 and Ω_M = 0:26 as favored by the three years WMAP collaboration.
- Recently, with the assumption that our universe is spatially flat and cosmological constant is the candidate of dark energy, Komatsu *et al.* [7] constrained Ω_Λ = 0:727±0:030.

In modern cosmology, one of the most recent problem is *Cosmological Constant Problem*. The problem may be referred to as the large discrepancy between the observed value of energy density of vacuum which is very small and the value which is derived by the particle physicists. Moreover, the difference is of the order of 10^{120}. Therefore, to understand the smallness of cosmological constant is one of the fundamental goal in Cosmology and other approaches of quantum gravity. So, much attention is required by researchers in this area.

Bose-Einstein Condesation (BEC) Phase & DE

A group of physicists pointed out that the physics of sound waves in an expanding BEC appear to be analogous to the physics of the accelerating expansion of the Universe. So in such situation, we may be able to know the microscopic source of the energy, driving the BEC expansion. So, the waves can act as a pretend cosmological constant (As presented above we may say that the cosmological constant is the simplest description of dark energy) and possibly tell us something about the amount of energy in the real one.

There are some interesting hints published in our papers [8-10]. We may say that the cosmological constant is independent of most of the zero point energy fluctuations. But in the BEC, this is a direct result of an energy gap that arises from the presence of a phase transition between a normal gas and a BEC. .

Concluding Remarks

The Nobel prize in physics for 2011 was awarded to three astronomers/cosmologists, who discovered that the rate of our Universe's expansion was increasing. The author of the paper along with the research fellows have already published few research papers on this topic [11-12] After the above stated discovery we have strong believe that there was some sort of previously unknown, long-range repulsive force permeating the Universe. As we also know that force, however, requires energy, which earned as dark energy. Using the data obtained from observations, cosmologists calculated the amount of energy required to produce the Universe which we observe. The best candidate source for dark energy is the energy contained in vacuum fluctuations (otherwise known as zero point energy). As mentioned in the above section cosmologists trying hard to know the amount of energy in the vacuum, and they came to a result that is $\boldsymbol{10^{120}}$ times larger than amount of ***dark energy*** required for accelerating the expansion of our universe. The author of this paper want attention of young researchers on this part of research where some attempts to combine quantum mechanics and gravity may be done. As this may have a phase transition, which may provide a similar decoupling between zero point energy modes.

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