The Cosmological Constant problem is not a problem: It is a misconception

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Abstract

The persistent discrepancy between quantum field theoretical predictions of vacuum energy density and the observed value of the cosmological constant suggests a fundamental issue in our understanding of their gravitational effects. We argue that General Relativity developed without quantum mechanical input, is not suited to accommodate zero-point energy as a source term in the Einstein field equations. Instead, we propose that the cosmological constant arises from large-scale curvature effects rather than an intrinsic vacuum energy density. This approach naturally resolves the cosmological constant problem without requiring fine-tuning or exotic physics. Furthermore, we outline how this perspective aligns with the idea that only energy contributions with physical boundaries (e.g., mass-affected zero-point fluctuations) gravitate, while uniform vacuum fluctuations do not.

Keywords: cosmological constant problem, dark energy, expansion

1. Introduction

The cosmological constant (Λ) problem arises from the vast discrepancy between quantum field theory (QFT) predictions of vacuum energy density, somewhere between 10^{60} and 10^{122} [1- 4], larger than observed) and the small measured value of *Λ*. Attempts to resolve this discrepancy often invoke fine-tuning, modified gravity, anthropic reasoning, or several other exotic explanations [4], such as extra dimensions and the landscape approach in string theory.

However, let us take a step back here. General Relativity (GR) was formulated in a classical setting, where only physically measurable mass-energy sources enter the stress-energy tensor. Quantum Field theory was developed at least 10-30 years after Albert Einstein developed his General Relativity theory in 1915. There is absolutely no reason to assume that the Einstein Field Equations should already contain a kind of "placeholder" to take into account quantum effects, such as the Zero Point Energies (ZPE). It has always been taken for granted that the stress-energy tensor $T_{\mu\nu}$ in the Einstein Field Equations (EFE) has to include all types of energy and thus also ZPE. However, there are no scientific or mathematical reasons to make this assumption.

On the other hand, it is clear that quantum interactions within matter are a significant contribution to the masses. For instance, most of the proton's mass does not come from quark rest mass but from quantum interactions (gluon energy represents 40 % of the proton's mass), as confirmed by

Lattice QCD simulations. This might be a possible reason for the often-used assumption that vacuum energy always contributes to the stress-energy tensor in the EFE.

Using the concept of Feynman diagrams, one should however make the distinction between diagrams with external legs (representing the interaction by virtual particles between real particles) and diagrams without external legs (contributing to the ZPE of the vacuum). In what follows, we will argue that that the energy associated with the diagrams without external legs does not contribute to the stress energy tensor (in the EFE). Previously, the author presented a framework for a quantum theory of gravity [5] in which a uniform vacuum energy density, however large, does not contribute to a gravitational force. This will be described in the next paragraph. Finally, the consequences for the cosmological constant problem will be discussed.

2. A view on Quantum Gravity

The Einstein Field Equations describe how matter curves spacetime. Although GR is highly successful, it does not describe how matter curves spacetime. This is an often-overlooked question. Many physicists believe that the "how" will emerge once we develop a complete quantum gravity theory. However, the "how" is essential when we decide on the role of ZPE in the stress-energy tensor. In 1992, the author presented a new approach [5] on Quantum Gravity. Let us recapitulate the basic elements of this theory:

1) Matter itself is a self-sustained dynamical structure of the quantum vacuum. It consists of virtual particles which are perpetually regenerated. From the outside, it looks stationary just like a water fountain keeps it outer stable appearance.

2) Matter is always in interaction with the surrounding vacuum, a fact which is in agreement with QFT.

3) Matter imposes boundary conditions on the vacuum fluctuations (QVF) in the space surrounding the particles. Because of this, the surrounding vacuum is modified. This is analogues to the boundary conditions imposed by the conducting plates in the Casimir set-up [6].

4) The modified quantum vacuum fluctuations next to a mass will also have an effect (modification) on the vacuum fluctuations at some distance further away from the mass. These in turn will also modify the quantum fluctuations further away, at infinitum. So, the presence of a mass will disturb the surrounding vacuum in a gradual way up to infinity.

5) The disturbed vacuum energy "field" is identified with the curvature of spacetime in GR [7]. The vacuum energy density changes according to $\rho(r) = \rho_V \left(1 - \frac{G\,M}{c^2 r}\right)$ in which ρ_V is the unperturbed vacuum energy density.

6) The force on a test particle is calculated by considering the corresponding vacuum pressure on a particle of equivalent volume $V_M = Mc^2/\rho_V$, resulting in the known Newtonian gravitational force. In this concept, the value of ρ_V drops out of the equation of the force.

In this view of gravity, the presence of a uniform large vacuum energy will be no source of gravitation. Also, it is clear from this that unconnected Feynman diagrams cannot contribute to gravity. Only the gradient of the ZPE matters and the gradient is induced because of the boundary imposed by real particles. Also, a modified vacuum energy density can impose a “boundary” and be important as a source of gravitation, in the same way as gravity itself gravitates in GR. Whether or not this theory is correct, it shows that in a quantum theory of gravitation, ZPE does not necessarily need to be a source of gravitation. In this respect I would like to quote Feynman. In an interview on Superstrings, while talking about gravity, he said [8]: ‘In the quantum field theories, there is an energy associated with what we call the vacuum in which everything has settled down to the lowest energy; that energy is not zero-according to the theory. Now gravity is supposed to interact with every form of energy and should interact then with this vacuum energy. And therefore, so to speak, a vacuum would have a weight-an equivalent mass energy-and would produce a gravitational field. Well, it doesn’t! The gravitational field produced by the energy in the electromagnetic field in a vacuum-where there’s no light, just quiet, nothing-should be enormous, so enormous, it would be obvious. The fact is, it’s zero! Or so small that it’s completely in disagreement with what we’d expect from the field theory. This problem is sometimes called the cosmological constant problem. It suggests that we’re missing something in our formulation of the theory of gravity. It’s even possible that the cause of the trouble-the infinities-arises from the gravity interacting with its own energy in a vacuum. And we started off wrong because we already know there’s something wrong with the idea that gravity should interact with the energy of a vacuum. *So, I think the first thing we should understand is how to formulate gravity so that it doesn’t interact with the energy in a vacuum.*’.

In the foregoing concept of quantum gravity [5], this is exactly what we did.

Note that other ongoing theoretical developments (such as Loop Quantum Gravity) still seem to lead to gravity coupling to all energies, including the vacuum zero-point fluctuations.

3. Cosmological Constant as a Curvature Effect

The Einstein Field equations are given by

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\,\pi G}{c^4}\, T_{\mu\nu} \tag{1}$$

In which $G_{\mu\nu}$ is the Einstein tensor, Λ is the cosmological constant, G is Newton’s gravitational constant, c is the speed of light and $T_{\mu\nu}$ is the stress-energy tensor. In this equation, Λ has the unit m^{-2}.

For a homogeneous and isotropic universe, the EFE yield the Friedmann equations from which the effect of the cosmological constant on the expansion of the universe can be inferred.

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

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3p) + \frac{\Lambda c^2}{3} \tag{3}$$

Where a is the scale factor, $H = \dot{a}/a$ is the Hubble parameter, ρ is the total energy density, p is pressure, and k is the curvature parameter.

The first equation determines the expansion rate of the universe, while the second equation governs the acceleration (or deceleration) of that expansion.

After sufficient time, the scale factor will grow exponentially as given by

$$a(t) = a_0 e^{\sqrt{\frac{\Lambda c^2}{3}}(t-t_0)} \quad (4)$$

In which t_0 is the present time, a_0 is the present scale factor. It is conceivable though that this exponential growth can be tamed within a quantum theory of gravity.

Rather than interpreting Λ as vacuum energy, we propose that it is a curvature effect arising from the global gravitational structure of the universe. Specifically, we suggest:

$$\Lambda \approx \frac{c^4}{G^2 M_{\text{universe}}^2} \approx \frac{1}{R_S^2} \quad (5)$$

Where M_{universe} represents the total mass of the universe, including *all* forms of matter and the equivalent matter corresponding to all forms of radiation and fields. R_s is the Schwarzschild radius of the observable universe. This approach eliminates the need for an arbitrary fine-tuning of vacuum energy and directly links Λ to large-scale gravitational properties.

Interestingly, since the cosmological constant can be expressed as $1/R_s^{2,}$ where R_s is the Schwarzschild radius, one might draw an analogy between the universe's accelerated expansion and the geometric behavior inside a white hole [9]. Just as space-time within a black hole is structured to inevitably lead toward collapse, a white hole, its time-reversed counterpart, naturally leads to expansion.

The mass of the universe is obtained by

$$M_{universe} = \rho_c V \quad (6)$$

In which ρ_c is the critical density, given by

$$\rho_c = \frac{3\,H_0^2}{8\,\pi G} \approx 8.5\ \cdot 10^{-27} kg\ m^{-3} \quad (7)$$

In which $H_0 = 2.18\ 10^{-18}\ s^{-1}$ [11].

The observable volume V is given by

$$V = \frac{4\pi}{3}\left(\frac{c}{H_0}\right)^3 \quad (8)$$

Resulting in

$$M_{universe} = \frac{c^3}{2GH_0} \quad (9)$$

Note that this equation coincides with the general expression found in [10] as based on a dimensional analysis. The dimensionless factor (1/2) is however uncertain, and the factor is in [10] described as a “dimensionless parameter of the order of magnitude of a unit”.

Plugging in known values, we obtain

$$M_{universe} = \frac{(3.0 \cdot 10^8)^3}{2\,(6.67 \cdot 10^{-11})(2.18 \cdot 10^{-18})} = 9.21\;10^{52}\;kg \tag{10}$$

This value of about 10^{53} kg corresponds to the value given in [10] and coincides with the Carvalho formula [12] for the mass of the observable universe.

Then, equation (1) becomes $\Lambda \approx 2.11\;10^{-5}\;\; m^{-2}$ which is, within a factor 2, equal to the presently accepted value for $\Lambda \approx 1.07\;10^{-52}\;\text{m}^{-2}$, which is obtained as

$$\Lambda = 3\;\cdot \frac{\Omega_\Lambda \cdot H_0^2}{c^2} \tag{11}$$

In which $\Omega_\Lambda = 0.67$ and $H_0 = 2.18\;10^{-18}\;\text{s}^{-1}$ (or 67.4 km/s/Mpc).

Here we also assume that $M_{universe}$ is a constant, thus assuming energy conservation on a global scale (something which is not really required by fundamental principles of physics). Thus, Λ remains a geometrical term in the EFE and should not be interpreted as an energy density related to the ZPE. In this way, the concept of dark energy is removed.

This is in line with the failure to directly observe and relate quanta or fields like the chameleon particle or the symmetron theory to dark energy, in a laboratory setting, failed to detect a new force [13]. Inferring the presence of dark energy through its interaction with baryons in the cosmic microwave background has also led to a negative result [14].

The "cosmological constant problem" ceases to exist, since one was comparing completely unrelated values.

Reinterpreting the cosmological constant as a purely geometrical factor has no effect on the evolution of the size of the universe.

Conclusion

It has been shown that that the cosmological problem, which has been around for more than 60 years, has its origin in an unjustified belief that gravitation has to be coupled to the zero-point energy fluctuations of the vacuum. Einstein's theory did not provide any mechanism to explain the curvature of space by matter and assuming that gravitation would couple to all kinds of zero-point vacuum fluctuations was never guaranteed.

By reconsidering the gravitational role of vacuum fluctuations, we provide a natural resolution to the cosmological constant problem.

If Λ is a curvature effect rather than an energy density, then the fine-tuning issues of dark energy disappear. Furthermore, this perspective offers a direction for developing a quantum theory of gravity that is consistent with GR without requiring exotic new physics.

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