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A Minimal Length Uncertainty Approach to Cosmological Constant Problem

Based on quantum mechanical framework for the minimal length uncertainty, we demonstrate that the generalized uncertainty principle (GUP) parameter - on one hand - could be best constrained by recent gravitational waves observations, and - on other hand - suggest modified dispersion relations (MDRs) to calculate the difference between the group velocity of gravitons and that of photons. Utilizing features of the UV/IR correspondence and the obvious similarities between GUP (including non-gravitating and gravitating impacts on Heisenberg uncertainty principle) and the discrepancy between the theoretical and the observed cosmological constant (apparently manifesting gravitational influences on the vacuum energy density), we suggest a possible solution for the cosmological constant problem.

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Cosmological Constant Problem

$$\frac{\Lambda_{QFT}}{\Lambda_{Obs}} = 10^{121}$$

Experimental observation (PLANCK 2018)

The Cosmological Constant is related to the Hubble parameter (H_0) and the dark energy density (Ω_Λ) as $\Lambda = 3H_0\ \Omega_\Lambda$.

$$\Lambda_{Obs} = 10^{-47}\ GeV^4/(\hbar c)^3$$

Theoretical estimation (Quantum Field Theory)

$$\Lambda = \frac{1}{(2\pi\hbar)^3}\int d^3p\left(\frac{\hbar}{2}\sqrt{(pc)^2 + \left(m_g c^2\right)^2}\right)$$

$$\Lambda_{QFT} = 10^{+74}\ GeV^4/(\hbar c)^3$$

The disagreement is one of the greatest mysteries in physics and known as the cosmological constant problem.

Approach: Generalized Uncertainty Principle (GUP)

GUP is extended version of Heisenberg uncertainty principle (HUP), where a correction term included the gravitational effects. Various experiments and theories confirmed this approach.

$$(\Delta x)(\Delta p) \geq \frac{\hbar}{2}\left[1 + \beta(\Delta p)^2 + \beta\ < p >^2\right]$$

$$\left[\hat{x}_i\,,\hat{p}_j\right] = i\hbar\,\delta_{ij}\left(1 + \beta\,p^2 + 2\beta\hat{p}_i\hat{p}_j\right)$$

Instead of violating Lorentz invariance form quadratic GUP we intend to investigate the speed of the graviton from the GW170817 event.

$$v_g = c\left\{\left[1-\left(\frac{mc^2}{\omega_g}\right)^2\right]^{1/2} + 4\beta\frac{\omega_g^2}{c^2}\left[1-\left(\frac{mc^2}{\omega_g}\right)^2\right]^{3/2}\right\}.$$

We present a novel estimation for GUP parameter from event GW170817.

$$\beta_0 \lesssim 8.89 \times 10^{60}.$$

The cosmological constant

$$\Lambda_{\mathrm{GUP}}(m=0) = \frac{c}{4\pi^2\hbar^3}\int \frac{p^3}{(1+\beta p^2)^3}\,dp = \frac{c(M_p^2 c^2)^2}{16\pi^2\hbar^3\beta_0^2}$$

$$= 1.78\times 10^{-48}\ \mathrm{GeV}^4/(\hbar^3 c^3).$$

Conclusion

the possible matching between the estimation of the upper bound on the GUP parameter deduced from the gravitational waves, GW170817 event, and the one estimated from the PLANCK 2018 observations seems to support the conclusion about the great importance of constructing a theory for quantum gravity.

Bibliography

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