Probing Quantum Nature of Gravity

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There appears to be two realms of reality, coexisting at all times. A classical realm where every physical outcome is deterministic and a quantum realm where "measurement" is a two step process and the outcome is a probabilistic connection between them[1]. On one hand, classical world, dominated by the gravitational force is well understood and tested, whereas in quantum mechanics, despite many experimental tests we don't quite understand some fundamental questions like - how to explain collapse of superposition of wave function, the measurement process. The line of distinction between these two worlds is also unclear as gravity has a fundamental length scale- the Planck's length and Quantum mechanics cease to be effective for masses above Planck's mass. Thus, in order to have the complete idea of the physical reality there has to be some connection between these two unconnected realms.

As an epistemological consequence of our understanding of fundamental interactions in terms of fields, we can look for a Quantum Field theory of Gravitation. Here, we are forced to believe that the physical reality has to be "quantum". We soon encounter problem of non-renormalizability in spite of adding higher order terms in the original Einstein-Hilbert action of gravity. Pure gravity is renormalizable at 1-loop level but we cannot remove divergencies when we include matter[2]. Non-renormalizability implies that the quantum field theory of gravity is not UV-complete; raison d'être we do not have a good understanding of gravity at high energies. This problem is obvious if we realise the fields we use in quantum field theory are local operators. Since UV-completeness does not lead to new predictions, we can still calculate quantum corrections to Newton's constant when gravity is treated as effective field theory in low energies[3]. Some of the theoretical techniques to solve the problem includes - Emergent gravity, String Theory, Loop-Quantum gravity etc. Nevertheless, detection of a graviton would be a direct evidence for the relation between two realms but, it has been shown that it may not be possible to either detect a single graviton[4] or to see a graviton induced excitation of an electron in a Hydrogen atom [5].

In the recent times, the semi-classical approach of "Gravitizing Quantum Mechanics" is being discussed as it not only provides us an opportunity to test if at all there is an interaction between the two realms but it might also solve some fundamental problems of Quantum Mechanics itself [6]. One of earliest model treats the gravitational effects as the background noise in a quantum mechanical experiment. Such a model is represented by Schrödinger equation with an additional term indicating Newtonian potential. Since the potential is state-dependent, Schrödinger-Newton Equation is non-linear. We can promote the states to stochastic variables such that Newtonian potential is a statistical correlation between such variables. The master equation now obtained with such quantities would be a stochastic equation with mass-dependent, off-diagonal, damping term which correspond to "Decoherence time-τ". The ratio of coefficients of unitary ($\hbar/2m$) and non-unitary ($G_N m^2/2\hbar$) parts of the Hamiltonian is a length scale parameter $R_D = \hbar/Gm^3$ at which we would expect effects of decoherence. Such a model would have normalization problems which is generic problem of semi-classical theories. It does not explain the nature of noise and moreover predictions depend on mass distribution.

Massive states in quantum superposition would also have corresponding curvature of spacetime metric associated with their energy[9]. Assuming the isometry of the metrics of the superposition up to an error term leads to an uncertainty in energy which in turn gives decoherence time parametrized by a length scale $R_P = G_N m^2/\hbar(\Delta t)$ which was put to test in the experiment[7]. Theoretically R_P represented the coherent size of the nucleus (Germanium) wavefunction which was used in the experiment (0.05x10^{-10}m). In this model there has to be a Brownian-like diffusion as a consequence of gravity induced wavefunction collapse. With careful measurement of background emissions, the lower bound for R_P was experimentally found to be 10% higher than the predicted value. This is still a test of a basic model and would not rule out the complete set of gravity induced collapse models. Yet another proposal to find whether gravity is a quantum entity is to look for gravity mediated entanglement[8] using microscopic diamond crystals. The idea is to build two adjacent mass interferometers, such that, we detect the gravitational interaction between the diamonds of mesoscopic masses (10^{-14}kg) which are far enough to avoid the Casimir forces. States evolve under mutual gravitational interaction which impart phases to components of superposition resulting in entanglement which can be only explained if gravity is a quantum entity. The seminar is aimed to present some of these new developments in theory and experiments with which we can now possibly probe the quantum nature of gravity.

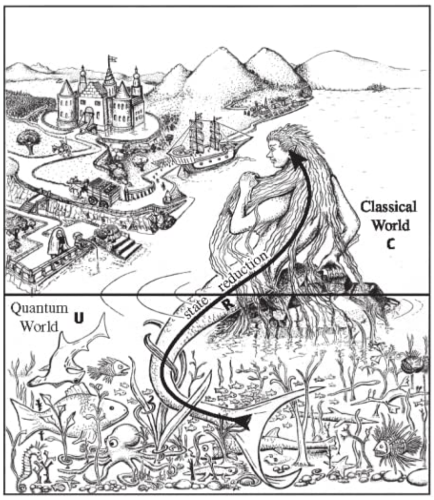

Figure 1: [10]

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