Prospect of Verifying Gravity-Induced Collapse of Macroscopic Quantum Coherence Using a Schroedinger Cat Atom Interferometer

S.M. Shahriar, T.L. Kovachy, R. Fang, R. Sarkar and J. Li
Northwestern University, Evanston, IL, USA

Microscopic particles, such as electrons or atoms, are routinely shown to be in linear superpositions of two wave-packets that are separated in space. However, we never observe such a superposition in the macroscopic world. Thus, quantum mechanics in its current form is an incomplete theory. In recent years, a new model of quantum mechanics has been developed that eliminates this incompleteness, reproducing conventional quantum mechanics for microscopic particles, while preventing spatially separated quantum superpositions for macroscopic particles, and providing a physical mechanism that collapses superpositions during measurement. The underlying mechanism behind this model is gravity-induced collapse of quantum superpositions\(^1\),\(^2\). This collapse would only be observable for macroscopic objects with masses of \(~10^{10}\) to \(~10^{12}\) amu, far exceeding the masses of molecules for which matter wave interferometry has been carried out so far. On the other hand, creating such a quantum superposition of more massive objects, such as cantilevers, has proven to be impossible\(^3\), due to the complexity of the objects.

In this talk, we will describe the prospect of testing this Penrose-Diosi Model (PDM) by realizing a scheme developed by us\(^4\),\(^5\) for atom interferometry with spatially separated Schroedinger Cat (SC) states of \(N^{87}\text{Rb}\) atoms, with \(N\) ranging from \(10^8\) to \(10^{10}\) (corresponding to \(~8.7*10^9\) to \(~8.7*10^{11}\) amu). A confirmation of this theory would represent a revolutionary advancement in our understanding of nature and reveal a fundamental interplay between gravity and quantum mechanics that must be considered in developing any theory of quantum gravity. The scheme will use \(^{87}\text{Rb}\) atoms and non-linear interaction in an optical cavity to produce an SC atom interferometer. Consisting of \(N\) atoms, the SC state would behave as a single particle, in a superposition of two states with a spatial separation between the centers of mass. The effect of gravity-induced collapse would manifest as a reduction of the visibility of the interference fringes. \(N\) will be varied from \(10^8\) to \(10^{10}\) to determine the dependence of the visibility reduction as a function of the mass of the SC state and compared with the prediction of PDM. We will discuss how the use of a white light cavity\(^6\) can enhance the optomechanical coupling to produce the degree of squeezing needed to produce the SC state. We will also show that use of co-propagating Raman excitations to make an SC atomic clock\(^5\), which is considerably simpler that the SC atom interferometer, is expected to produce enough spatial separation for testing the PDM.

---