Study finds semiclassical gravity counterintuitive, but on the horizon of testability

May 8 2013, by Lisa Zyga

(Phys.org) —One of the more controversial theories of quantum gravity, which attempts to unify quantum mechanics and general relativity, is semiclassical gravity, which was proposed in the 1960s. As its name suggests, semiclassical gravity involves a combination of quantum and classical components. Specifically, matter obeys the rules of quantum mechanics while gravity and the spacetime structure obey classical laws. Many physicists think that integrating quantum and classical systems in this way creates physical contradictions and mathematical inconsistencies. However, in a new paper, physicists have closely analyzed exactly how classical gravity might affect the quantum properties of macroscopic objects, and found that the effects of semiclassical gravity may be experimentally detectable with state-of-the-art technology.

The physicists, Huan Yang, et al., at the California Institute of Technology in Pasadena, California, and the National Dong Hwa University in Hua-Lien, Taiwan, have published their paper, called "Macroscopic Quantum Mechanics in a Classical Spacetime," in a recent issue of *Physical Review Letters*.

Most theories of quantum gravity predict that gravity should be quantized. However, as Richard Feynman once said, "Quantum theory does not absolutely guarantee that gravity has to be quantized. ... I would like to suggest that it is possible that quantum mechanics fails at large distances and for larger objects." Since concrete, unambiguous experimental signatures of the quantum nature of gravity still do not exist (other than when assuming the "many-world" interpretation of quantum mechanics), the physicists here thought it would be worthwhile to investigate if a theory of quantum gravity could involve classical gravity.

"Semiclassical gravity is one of the existing models which tries to unify quantum mechanics and general relativity," Yang told *Phys.org* on behalf of his coauthors. "Instead of trying to quantize space and time (as in string theory, loop quantum gravity, etc.), in this model the spacetime is assumed to be a classical entity, although the matter particles in the spacetime are quantum. Our findings show the imminent possibility of verifying or falsifying the semiclassical gravity experimentally. More importantly, we point out that both self-gravitational effects and quantum effects are important for macroscopic objects—the only regime accessible by table-top experiments so far. This opens up the possibility for testing other models that try to unify quantum mechanics and general relativity, as well: gravity decoherence models, stochastic gravity models, emergent gravity models, etc. We don't necessarily believe any of these models, but we believe it is important to test signatures/predictions of these models experimentally and let nature tell us what the true physics is, as we don't have a conclusive theory of quantum gravity yet."

Combining gravity and quantum mechanics

In their paper, the scientists used a non-relativistic version of a semi-classical gravity model, which describes how the quantum state of a system changes over time under the influence of classical gravity, called the Schrödinger-Newton (SN) equation.

Although physicists have extensively used the SN equation to study the quantum states of single particles, in the new paper the physicists use the equation to study the quantum states of macroscopic objects consisting of many particles. They show that the SN equation can be used to describe the quantum evolution of a macroscopic crystal's center of mass, the point at which the object's weight is perfectly balanced. The center-of-mass gives information on the self-gravitational effect that depends on the object's internal structure, which enables physicists to investigate how the object's quantum properties may be affected by classical gravity.

The physicists' calculations revealed several unique signatures of classical gravity on macroscopic quantum mechanics. Most interestingly, they found that the center-of-mass motion of a crystal is found to deviate slightly from standard quantum mechanics, obeying the SN equation where the center-of-mass wave function evolves nonlinearly due to self-gravitating effects.

The calculations also revealed other interesting insights. For instance, the classical gravity of a single macroscopic crystal is much stronger in relation to itself than it is between two separate crystals. The physicists explain that this effect arises because the mass of a macroscopic crystal is concentrated near its lattice sites. Another signature of classical gravity acting on macroscopic quantum objects is that classical gravity cannot be used to transfer quantum uncertainties between two objects. In addition, the scientists discovered a unique signature regarding the evolution frequency of expectation values of position and momentum.

Searching for semiclassical signatures

Although these effects are extremely weak, the physicists predict that one or more effects may induce visible signatures that are detectable with state-of-the-art optomechanics experiments. This kind of experiment could monitor and manipulate a macroscopic object's center-of-mass at quantum levels. Although the individual particles in a macroscopic object cannot be accessed separately, a light beam could probe the average displacement of the atoms in the first few layers of a reflective coating on a macroscopic object. Since the motion of these surface atoms is related to the center-of-mass motion of the entire object, the experiment could potentially probe some of the unique effects hinting at semiclassical gravity.

"If the future experiment sees the effects predicted by the SN equation, this means gravity/spacetime is classical, and previous attempts for quantizing gravity were on the wrong track, which is unlikely but nevertheless possible," Yang said. "However, if the experiment shows null results, it is highly possible that gravity is quantum. The third possibility is that the experiment sees some non-null result which is not consistent with SN prediction either. This may inspire physicists to formulate new theories of quantum gravity, given the experimental results."

Overall, the results show that semiclassical gravity involves effects that are counterintuitive, but not necessarily contradictory. Although experimentally detecting such effects is unlikely, their detection would open up many new opportunities in the search for quantum gravity.

"We talked to several experimental groups, including Nergis Mavalvala's group at MIT, Thomas Corbitt's group at Louisiana State Universiity, Markus Aspelmeyer's group at the University of Vienna, and Michael Tobar's group at Western Australia University," Yang said. "They were very excited about the idea and the possibility of doing the experiment. We will collaborate with experimentalists in performing such an experiment in the future."

More information: Huan Yang, et al. "Macroscopic Quantum Mechanics in a Classical Spacetime." *PRL* 110, 170401 (2013). DOI:

10.1103/PhysRevLett.110.170401