Measurement of motion beyond Heisenberg uncertainty bound in a negative mass reference frame of atomic spin

Eugene S. Polzik

Niels Bohr Institute, University of Copenhagen, Denmark

A continuous measurement of a position of an object imposes a random quantum back action (QBA) perturbation on its momentum. This randomness translates with time into position uncertainty, thus leading to the well known uncertainty of the measurement of motion. As a consequence, and in accordance with the Heisenberg uncertainty principle, the QBA puts a limitation—the so-called standard quantum limit—on the precision of sensing of position, velocity and force. In this talk I will first present the results of the experiment [1] where motion of a mechanical oscillator is tracked with the precision not restricted by the QBA. This is achieved by measuring the motion in a special reference frame linked to an atomic spin system with an effective negative mass. The spin system is a hot atomic Cesium vapor placed in magnetic field. The spin oscillates in magnetic field with the frequency tuned to the mechanical oscillator frequency. A suitable orientation of the spin with respect to magnetic field makes it an inverted oscillator, equivalent to an oscillator with a negative mass. Light sent though the spin oscillator acquires quantum back action noise which interferes distractively with the quantum back action noise written on light by the mechanical oscillator. This results in back-action-free measurement on the hybrid system. I will end the talk with outlining a proposal for employing this principle for reaching beyond the Standard Quantum Limit precision with Gravitational Wave Detectors [2], such as LIGO and the Hannover 10m prototype.

[1] Quantum back action evading measurement of motion in a negative mass reference frame. C. B. Møller, R. A. Thomas, G. Vasilakis, E. Zeuthen, Y. Tsaturyan, K. Jensen, A. Schliesser, K. Hammerer, and E. S. Polzik. Nature, 547, 191 (2017).
[2] Overcoming the standard quantum limit in gravitational wave detectors using a spin system with a negative effective mass. F. Khalili and E. S. Polzik. arxiv.org/1710.10405.