Master 1 or Master 2 Internship

Title: Theoretical study of a quantum speed meter for optically trapped particles

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Project:

The precise measurement of motion at the quantum scale is a central challenge in modern quantum optics and optomechanics. Conventional position measurements are limited by quantum back-action: the very act of measuring a particle's position disturbs its momentum, leading to the standard quantum limit (SQL). A promising approach to overcome this limitation is the **quantum speed meter**, in which the observable is not the position itself but the **velocity**(or a time derivative of the position). Since successive velocity measurements commute more favorably than position measurements, this scheme offers the potential to suppress back-action noise and improve sensitivity [1,2].

In this project, the student will carry out a theoretical study of a quantum speed-meter setup applied to an **optically trapped nanoparticle**. Optically levitated systems are excellent candidates for exploring macroscopic quantum effects: they can be isolated from thermal environments, controlled with high precision, and cooled close to their motional ground state [3,4]. The aim of the project is to analyze, within a simplified optomechanical model, how a speed-meter–type measurement can be implemented in such a system, what quantum limits it faces, and how it compares to conventional position readout.

The work will involve developing the Hamiltonian description of the optically trapped particle, identifying the relevant measurement operators, and calculating noise spectral densities. The results may help clarify whether speed-meter protocols can enhance the sensitivity of levitated optomechanics experiments, which are of growing interest both for fundamental tests of quantum mechanics and for applications in precision sensing. Funding for a PhD thesis is available for the continuation of the project.

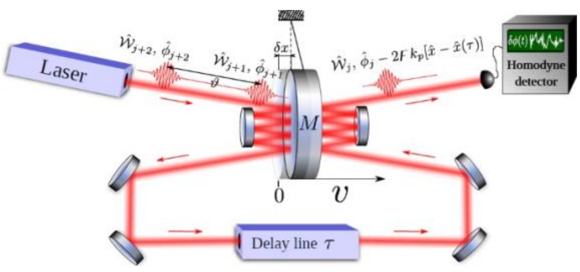

Figure: *Scheme from Ref. [2] of the speed meter.*

References

[1] V. B. Braginsky and F. Ya. Khalili, *Quantum Measurement* (Cambridge University Press, 1992).

[2] S. L. Danilishin and F. Ya. Khalili, "Quantum Measurement Theory in Gravitational-Wave Detectors," *Living Rev. Relativ.* **15**, 5 (2012).

[3] O. Romero-Isart, “Quantum superposition of massive objects and collapse models,” *Phys. Rev. A* **84**, 052121 (2011).
[4] M. Aspelmeyer, T. J. Kippenberg, and F. Marquardt, “Cavity optomechanics,” *Rev. Mod. Phys.* **86**, 1391 (2014).