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Exploring and optimizing the limits of nano-optomechanical coupling using quantum information-driven wavefront shaping

Description of the scientific project:
Optomechanics investigates the reciprocal interactions between light and mechanical motion. The field has recently completed major advance, including breaking into the quantum regime of the optomechanical interaction, with the demonstration of the preparation and detection of quantum macroscopic motional states. The premises of these milestones are to be found in the breakthrough of nano-optomechanical systems in the early 2010, which have demonstrated the ability to harness large light-matter interactions at the nanoscale for ultra-high sensitivity optomechanical purposes. So far, the sensitivity limits of these systems has been treated along an approach similar to that developed for their macroscopic counterparts, assuming both Gauss conditions and unitarity. **These hypotheses, however, must be revised with nano-optomechanical systems, which may presently be operated orders of magnitude away from their sensitivity potential**. Indeed, theoretical considerations for the Cramér-Rao bound, which defines the ultimate limit of precision for parameter estimation, suggest that these systems are far from reaching their optimal performance.
This internship is part of a project aiming at addressing the fundamental limits of nano-optomechanical coupling using quantum information theory-driven wavefront shaping. Briefly, our experimental concept relies on interfacing a nano-optomechanical system consisting of a tapered nano-optomechanical capillary illuminated by a strongly focused laser probe (see Fig. 1(b)) with multimode imaging devices, to be fed to information-theory trained algorithms (see Fig. 1(a)) enabling to identify the nature and reach the fundamental motion detection limits. Early results using this method have enabled an enhancement of the sensitivity of above 25 dB compared to traditional motion detection methods (see Fig. 1(c)).

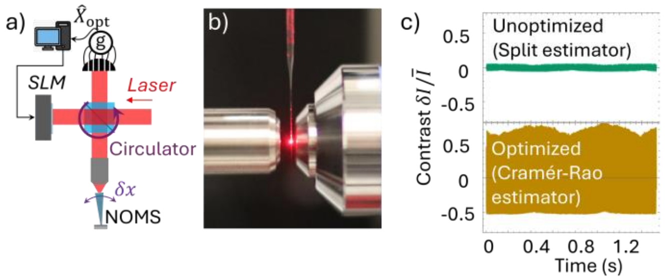

Figure 1. (a) Schematic of the experimental setup. The NOMS is measured using a laser beam whose wavefront is shaped using a SLM operated in reflexion. The laser output is fed to a CCD camera, whose signal is processed for optimizing the motion sensitivity. **(b)** Photograph of a zoomed area of the experiment, including the NOMS used in LuMIn (tapered nanomechanical capillary). **(c)** Motion estimator obtained from the split detection in the unoptimized case (top), and from the computation of the Cramér-Rao estimator in the optimized case (bottom).

The internship will be based in the 505 building of the LuMIn lab, and may be continued in the frame of collaborative project jointly funded with CEA Pheliqs and the CNRS NPSC group (Grenoble), with one of the aims being to adapt this new technology of multimode optomechanical wavefront shaping to optimizing quantum dot optomechanical transducers.

Methods and techniques: Nano-optomechanics; wavefront shaping; Quantum Estimation theory; Quantum noise

Possibility to continue as a PhD student ? YES
PhD grant available ? YES