Master 2 Internship

Title: Ground-state cooling of multiple nanoparticles in optical levitation

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PhD funding (if any): Yes (ANR-funded 3-year PhD)

Project: **Optical levitation** is a subfield of optomechanics, in which a nanometer-size particle is trapped in a vacuum chamber at the focal spot of a laser focused through a microscope objective. The laser beam produces an optical force equivalent to a mechanical spring and the system can be regarded as a simple mass-spring resonator displaying pristine vibrational oscillations in the kHz regime. Because levitated systems outperform other resonators, they are currently exploited to achieve high-sensitivity metrology, detect gravitational waves or search for dark matter. Yet, above all, levitation offers the tantalizing prospect of investigating **quantum mechanics at the mesoscale** (i.e., at the quantum to classical transition) to confirm (or rule out) fundamental hypotheses of quantum physics.

To display quantum properties, the nanoparticle must be **cooled down close to its motional ground state** (i.e., down to a few quanta of vibrational energy). In other words, one must reduce the amplitude of its oscillations that are fueled by the collisions with residual air molecules in the vacuum chamber. Cooling is typically achieved through the constant monitoring of the nanoparticle's displacements and a subsequent modulation of the laser's intensity.

Currently, the most exciting and challenging **endeavor in the field lays in performing levitation with many-body systems**. Many-body levitation could offer the fascinating opportunity of observing many-body quantum physics at the mesoscale, which would (amongst other things) enable the **first mesoscopic motional entanglement** of particles or the formation of **quantum simulators**. Sadly, conventional cooling techniques, cannot be multiplexed and fail badly to cool several elements in parallel.

Throughout this internship, the candidate will experimentally implement a new cooling technique intended to achieve the **first-ever cooling of a many-body system** composed of multiple nanoparticles in levitation. Compared to former strategies, here, a spatial light modulator is used to spatially shape the wavefront of the laser beam. Such a modulation enables to exert simultaneously adapted optical forces on all the nanoparticles in order to reduce their individual vibrational motions, which ultimately leads to the cooling of the many-body system. The student will be closely guided by the advisor and will acquire both theoretical and experimental skills on **optomechanics** and **levitation**, **quantum** and **many-body physics** as well as in **spatial modulation techniques**. A funding is already available to continue and expand this internship through a PhD.