INTERNSHIP PROPOSAL

Laboratory name: **Laboratoire Kastler Brossel – Quantum Networks Team**
CNRS identification code: UMR 8552
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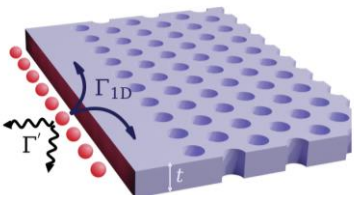
Internship location: Sorbonne Université, Campus P. et M. Curie, 4 Place Jussieu, Paris
Thesis possibility after internship: YES
Funding: YES, Doctoral school/group funding/ERC

Waveguide-QED - combining cold atoms and nanophotonics (2 internships)

Controlling light-matter interaction at the single-quantum level is a long-standing goal in optical physics, with applications to quantum optics and quantum information science. However, single photons usually do not interact with each other and the interaction needs to be mediated by an atomic system. Enhancing this coupling has been the driving force for a large community over the past two decades.

In contrast to the cavity-QED approach where the interaction is enhanced by a cavity around the atoms, **strong transverse confinement in single-pass nanoscale waveguides** recently triggered various investigations for coupling **guided light and cold atoms**. Specifically, a subwavelength waveguide can provide a large evanescent field that can interact with atoms trapped in the vicinity. An atom close to the surface can absorb a fraction of the guided light as the effective mode area is comparable with the atom cross-section. This **emerging field known as waveguide-QED promises unique applications to quantum networks, quantum non-linear optics and quantum simulation.** Recently**,** the LKB team pushed the field for the first time into the quantum regime by creating an entangled state of an array of atoms coupled to such a waveguide. **Two experiments are dedicated to this waveguide-QED effort and internships/PhD projects are proposed on both of them**. An ERC Advanced grant is starting on this research direction.



Nanofiber. Using a 400-nm diameter nanofiber and a few thousand atoms trapped around, the team demonstrated the very efficient reflection of single photons by an ordered one-dimensional array of trapped atoms controlled by as few as 30 photons, and the heralding of single-collective atomic excitation in this platform. The goal is now to implement a **high efficiency quantum memory protocol** in this platform, taking advantage of the atom trapping for large storage time, and of the periodic ordering, harnessing **cooperative effects** for improved efficiency.

Slow-mode waveguide. The team has been developing a **new experimental setup to trap atoms close to nanofabricated photonic-crystal waveguides** with low group velocities for the guided modes. This will increase the atom-photon coupling by a few orders of magnitude, enabling to reach the **strong coupling regime where one atom is enough to reflect incoming photons**, paving the way for implementing quantum gates for quantum information processing or simulating Hamiltonians with exotic quantum phases of matter.

This research involves cold-atom trapping, light shaping for atom transport, nanophotonics, single-photon detection, quantum state generation and characterization… The team is a member of three national and European consortia gathering experts in nanostructure design, light-matter interfaces, quantum networks.

A few references:
Large Bragg reflection from 1D arrays of trapped atoms near a nanoscale waveguide, PRL 117, 133603 (2016).
Waveguide-coupled single-collective excitation of atomic arrays, Nature 566, 359 (2019).
Reduced volume and reflection for bright optical tweezers with radial LG beams, PNAS 117, 26109 (2020)
Nanotrappy: an open-source versatile package for cold-atom trapping, PRResearch 4, 013079 (2022)
Systematic design of a robust half-W1 photonic crystal waveguide for interfacing slow light and trapped cold atoms, NJP 26, 023026 (2024)

Condensed Matter Physics:	YES	Soft Matter and Biological Physics:	NO
Quantum Physics:	YES	Theoretical Physics:	YES