

INTERNSHIP PROPOSAL

Laboratory name: **C2N (Center for Nanoscience and Nanotechnology)**

CNRS identification code: **UMR 9001**

Internship director's surname: **LANCO Loïc**

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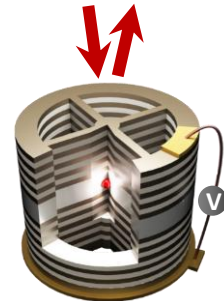
Internship location: **C2N, 10 Boulevard Thomas Gobert, Palaiseau**

Thesis possibility after internship: **NO**

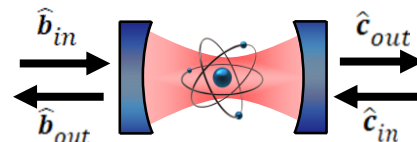
Theory of atom-photon and spin-photon interfaces: from cavity-QED to waveguide-QED

In the framework of optical quantum computing and communications, a crucial goal consists in **controlling the interaction between single atoms and single photons**. This has first led to the development of cavity-QED, where natural or artificial atoms efficiently interact with confined photons, in an optical or microwave cavity. Many practical demonstrations were also performed in the simplified framework of waveguide-QED, exploiting the direct coupling of atoms to photonic waveguides, fibers, and on-chip photonic circuits.

Our team in C2N has developed quantum-dot-based interfaces which can be used as efficient emitters¹ of single photons: this led to the creation of the company Quandela. A strong challenge remains: **developing quantum nodes that implement quantum logic operations on incoming photons**, using the interaction with a single stationary qubit. In such context, we use our light-matter interfaces as efficient *receivers* (and not just emitters) of quantum light: this allowed us, for instance, to demonstrate the first optical nonlinearity triggered at the single-photon level². We also develop spin-photon interfaces³, with which we could demonstrate the entanglement of a spin with several photons⁴, as well as giant polarization rotations induced by a single spin⁵.



During the last decade, we have also built a practical theoretical toolbox, allowing to simulate the cavity-QED effects in light-matter interfaces, in excellent agreement with experimental results. By doing so, we realized that a breakthrough can also be obtained on the theory side: **it becomes possible to exactly describe many complex cavity-QED phenomena, within the much simpler framework of waveguide-QED**. This allows implementing numerical and analytical strategies which were previously out of reach, to invent novel experiments and predict their results.



During this internship we want to explore the potential of this breakthrough, extending it to the study of spin-photon interfaces. We will derive analytical expressions describing spin-photon entanglement and explaining the measurement back-action, induced on a single spin qubit, by the detection of a single reflected photon. We will also explore the possibility to extend our formalism to the strong-coupling regime of cavity-QED.

Condensed Matter Physics: **NO**

Soft Matter and Biological Physics: **NO**

Quantum Physics: **YES**

Theoretical Physics: **YES**

¹ Somaschi *et al*, **Nature Photonics** 10, 340 (2016); Loredó *et al*, **Nature Photonics** 16, 374 (2022)

² De Santis *et al*, **Nature Nanotechnology** 12, 663 (2017)

³ Arnold *et al*, **Nature Communications** 6, 6236 (2015); Hilaire *et al*, **Phys. Rev. B** 102, 195402 (2020)

⁴ Coste *et al*, **Nature Photonics** 17, 582 (2023); Huet *et al*, **Nature Communications** 16, 4337 (2025)

⁵ Mehdi *et al*, **Nature Communications** 15, 598 (2024); Gundin *et al*, **Phys. Rev. Lett.** 134, 036902 (2025)