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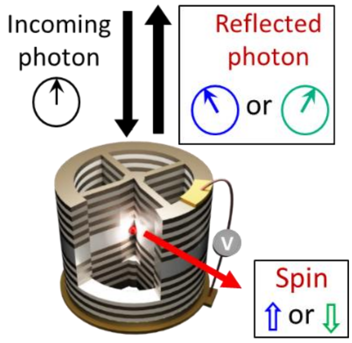
# M2 internship: a spin-photon interface for quantum entanglement & quantum logic operations

## Objectives

This project aims at controlling the interaction between light and matter at the most fundamental level: *qubits*. To this purpose, we recently developed **an efficient interface between a single material qubit** (the spin of a single charge) and a **single photonic qubit** (the polarization of a single photon). Our interface uses the spin qubit carried by a semiconductor hole, confined in a nanometer-scale InAs quantum dot (QD), deterministically-coupled to an electrically-contacted microcavity. This technology, invented in C2N, has already allowed developing high-efficiency sources of quantum light[1], and demonstrating the first optical nonlinearity at the single-photon level[2].




As we demonstrated, a photon reflected by such a QD-cavity structure experiences a drastically-enhanced rotation of its polarization, clockwise or counter-clockwise, depending on the spin state (see figure)[3]. Using deterministically-coupled spin-photon interfaces[4], and polarization state tomography experiments[5], we demonstrated the full reversal of the photon polarization state, controlled by a single spin[6]. Recently, we **demonstrated the optical probing of a single spin using single photons[7]**. In such experiment every single detected photon leads to a measurement back-action on the spin qubit.

In the proposed internship and the following PhD thesis offer, we want to explore the perspectives of such spin-photon interfaces for quantum information. A final objective will be to demonstrate **new forms of spin-photon entanglement and photon-photon entanglement**, and develop **logic gates mediated by the spin-photon interaction**. On the way, we will also perform **fundamental quantum measurements**, and study the interaction between a spin and its solid-state matrix.

All the technological, experimental and theoretical expertise of the C2N group will be available to successfully lead this project. We welcome highly-motivated applicants with excellent background in quantum physics, optics, and/or solid state physics, and with a taste for theory and numerical simulations.

## Methods and techniques:

**Experimental techniques:** photon-photon correlations, resonant laser spectroscopy, qubit tomography, and microphotoluminescence experiments, performed on single nano-objects in cryogenic environments (4K) and with intense magnetic fields (up to 9T)

**Theory/simulations**: Simulations of open quantum systems including quantum optics, cavity quantum electrodynamics, and solid-state physics phenomena

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[1] Somaschi *et al,* Nature Photonics **10,** 340 (2016); Coste *et al*, Nature Photonics **17**, 582 (2023);
[2] De Santis *et al,* Nature Nanotech. **12**, 663 (2017)
[3] Arnold *et al,* Nature Commun**. 6,** 6236 (2015)
[4] Hilaire *et al*, Phys. Rev. B **102**, 195402 (2020) ; Ollivier *et al*, ACS Photonics **7**, 1050-1059 (2020)
[5] Anton *et al*, Optica **4,** 1328 (2017); Hilaire *et al*, Appl. Phys. Lett. **112**, 201101 (2018)
[6] Mehdi *et al*, Nature Commun. **15**, 598 (2024)
[7] Coste *et al*, Quantum Science & Technology **8**, 025021 (2023); Gundin *et al*, arXiv:2401.14976 (2024)