# MASTER 2 INTERNSHIP OFFER-Year 2023-24

## Microwave quantum optics in quantum Hall edge states

**Internship director**: Ines Safi (CRHC HDR CNRS)

**Laboratory name**: Laboratoire de Physique des Solides (UMR 8502), Université Paris - Saclay.
Email: ines.safi@universite-paris-saclay.fr

**Co-director:** Pascal Degiovanni (DR1 CNRS, ENS Lyon), Laboratoire de Physique (UMR 5672), ENS de Lyon.

**Funding**: Yes for the internship. Application to EDPIF for the thesis.
**Key words:** quantum optics, electronic quantum optics, quantum sensing, electron interferometry.
**Skills :** Analytical (majority) and numerical.

**Motivation and context of the project:** A novel research field has emerged in the last years by studying quantum electronic transport in its ultimate form, through manipulating single coherent electronic excitations in quantum conductors [1,2,3]. It has shown the ability not only to emit [4] them but also to characterize them finely. Chiral edge states of the quantum Hall effect (QHE) provide one of the favored conductors [4,5] for these achievements, being electronic analogues to optic fibers in photonics. Quantum point contacts (QPCs) formed by bringing closer two opposite chiral edges are the analogous of beam splitters under control.

Quite often, "light", thus electromagnetic fields, is used to probe properties of "matter". Inversely, our project consists in using electrons to probe the quantum states of electromagnetic fields. By exploiting the extreme sensitivity of electronic wavefunctions to such fields, we are developing novel quantum sensors of the latter at small length (sub-micron) and time (sub-nanosecond, or even pico-second).

Such an idea, explored beforehand within the european metrology project SEQUOIA [6], is that of an "electron radar ", which is at the heart of the QuSig4QuSense project funded by the National Agency for Research (ANR 10/2021-10/2025) and involving the groups of Pascal Degiovanni (ENS Lyon) and Inès Safi (LPS) for theory and that of G. Fève (ENS Paris) for experiments.

**Subject:** An important part of the project consists into manipulating and characterizing microwave quantum fields within systems based on edge states of the QHE. This would allow one to propose controlled on-chip sources of quantum radiation. In nano-circuits, the latter is indeed hybrid states of matter/light, and is associated with charge oscillation modes called « plasmons » whose propagation determines electrical current at finite frequency [1].

**The thesis** aims to use these plasmonic modes in the edge states of the QHE to perform microwave quantum optics. These are some the questions which can be addressed:

- Can one achieve non-linear components which would generate quantum states of radiation in the QHE?
- What is the radiation emitted by single electron sources, or by two-electron interference between two such sources through a QPC?
- What are the relations between the properties of the radiation and that of the electrons?

For the **internship of the spring 2024**, a first direction is proposed in connection with the first question above. It consists into studying the behavior of plasmonic cavities obtained by closing an edge state over itself, and their response to an ac excitation through capacitive coupling. We have made some progress on the theoretical level, involving our postdoctorate Giacomo Robera, and on the experimental level through their implementation and analysis by Gerbold Menard in the group of Gwendal Fève. Next we aim to introduce a QPC in the cavity, which can then yield a non-linear resonator for plasmonic modes. This project combines the standard approach of quantum optics (input/output theory) with a universal approach for non-linear and time-dependent transport developed by I. Safi [7,8,9].

A second direction consists into optimizing the generation of a specific quantum state of radiation, squeezed states, using a QPC in the QHE (both in the integer or fractional regime) subject to an ac voltage., the internship will exploit the approach in Refs.[7,8,9] which uses basic properties of Green's functions even though valid to describe non-equilibrium transport. Therefore, it requires minimal technical skills, while it provides a powerful unifying framework for a large family of strongly correlated conductors.

**Collaborations:** The proposal lies within the ANR project « QuSig4QuSense » associating « Laboratoire de Physique » at ENS Lyon (Pascal Degiovanni, coordinator), « Laboratoire de Physique » at ENS Paris (Gwendal Fève), and Laboratoire de Physique des Solides (Inès Safi). The project will be conducted in close collaboration with the two groups.

**References :**


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