Interacting Photons

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Research theme: We investigate physics emerging from photon interactions in tunable optical micro-cavities. Our fundamental interests include quantum simulation, critical phenomena, noise-assisted transport, and cavity-enhanced materials. We are also interested in applications of interacting photonic systems, e.g. optical memories, switches, isolators, sensors, and quantum networks.

Master's projects & Internships: To give you a flavor of research projects available in our group, we propose 3 projects below. All projects involve experimental work in state-of-the-art setups, and accompanying theoretical work depending on your interests and skills.

Project 1. *Light-induced superconductivity*
Supervisors: David van der Flier and Said Rodriguez

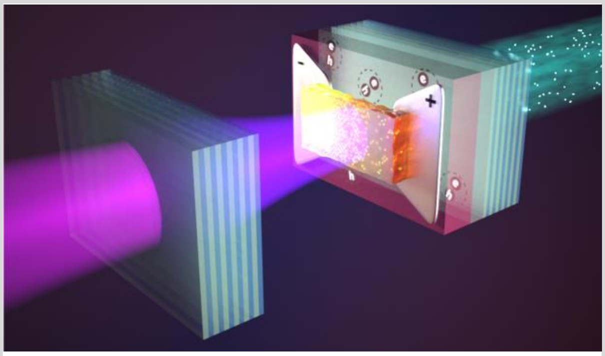

Figure 1. An optical cavity contains 2 semiconductors, one hosting excitons (under the electrodes) and another conducting charges. Light-induced superconductivity has been predicted for this system.

In this project you will explore how to dynamically and locally enhance (up to infinity) the electrical conductivity of materials inside an optical cavity. Recently, it was predicted that the coupling between a two-dimensional electron system and an excitonic system (i.e., a semiconductor) inside a cavity can enable electrical current to flow without resistance. This transition to a superconducting state depends on the number of photons in the cavity, which can be controlled with a laser. To explore this effect, you will measure the electrical conductivity of two-dimensional (2D) materials inside a laser-driven tunable cavity. For this purpose, you will first fabricate micron-scale electrodes to contact 2D materials; this part of the research will be done in collaboration with the group of E. Garnett at AMOLF. Next, you will measure conductivities while varying the cavity length and the laser power. You will perform these experiments across a wide range of temperatures, from ambient down to 4K. To achieve this, you will use a new closed-cycle cryostat (see Fig. 2) specially designed for experiments demanding extremely high mechanical stability; this is the first system of its kind in Europe.

Project 2. *Quantum nonlinear optics in a tunable micro-cavity at 4K*
Supervisors: David van der Flier and Said Rodriguez

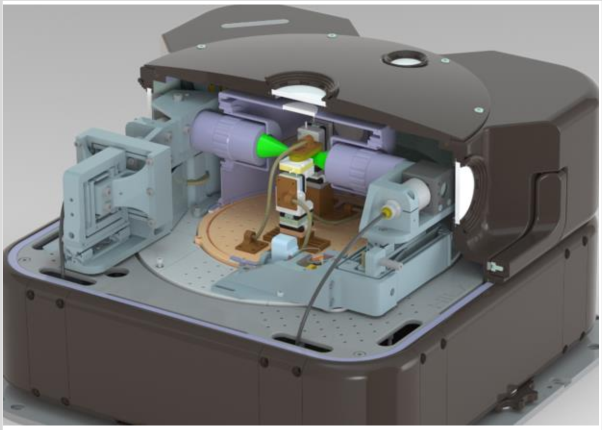

Figure 2. Our tunable cavity in a closed-cycle cryostat with free-space optics.

In this project you will probe the quantum nonlinear dynamics of a tunable optical micro-cavity containing 2D materials. For these experiments you will cool the sample to 4K using our state-of-the-art stabilized closed-cycle cryostat (Fig. 2). At low temperatures we expect to observe the formation of excitons with high principal quantum number, i.e. Rydberg excitons. These Rydberg excitons are associated with an extremely strong optical nonlinearity, which is promising for accessing the quantum regime of single-photon nonlinearity. Your goal will be to strongly couple Rydberg excitons in 2D materials to micro-cavity modes, and to measure the linear and nonlinear optical response of the hybrid exciton-photon system. This project involves collaborative work with the group of E. Garnett, who is fabricating the 2D materials you will use.

Project 3. *Spontaneous symmetry breaking in coupled nonlinear optical micro-cavities*
Supervisors: Zhou Geng and Said Rodriguez

Spontaneous symmetry breaking (SSB) occurs when a symmetric system ends up in an asymmetric state. SSB is one of the most fundamental processes in physics, underlying for example the Higgs mechanism, Bose-Einstein condensation, and the laser. In this project, you will explore the SSB phase transition of two coupled nonlinear optical micro-cavities. To evidence this effect, you will use a state-of-the-art tunable cavity setup which our group recently constructed. The system already enjoys a strong optical nonlinearity (necessary for SSB), and we can measure the cavity dynamics across ~5 orders of magnitude in time. In this project, you will extend the capabilities of the setup so that you can measure the cavity-resolved dynamics of two strongly coupled micro-cavities simultaneously. You will model your experiments with a system of coupled nonlinear stochastic differential equations. Our group is already experienced with nonlinear stochastic differential equations. On the theory side, your task will be to build upon our recent efforts by extending our model to deal with coupled systems and apply it to the SSB problem, i.e. to model your experiments.