PhD Proposal: Quantum Neural Networks of Excitons-polaritons

Abstract: This project aims at exploring a novel approach for sensing and generating quantum states of light. The project idea places itself at the frontier between quantum physics and applied artificial intelligence, targeting the realization of a novel device based on strongly interacting photons (exciton-polaritons) that, using principles of neuromorphic computing, is able to recognize, characterize, and generate a variety of quantum states.

Context: Photons are the best particles to use for quantum application giving their robustness to decoherence and for their relatively easy generation of quantum states. However, one of the major drawbacks is the very small nonlinearities that photons can feel in standard nonlinear media. In this project we will make use of a hybrid state of light and matter, the exciton-polariton, that keeps the long coherence time while possessing strong χ^3 nonlinearity, reaching more than 3 orders of magnitude what usually obtainable in standard photonic nonlinear crystals. This advantage has led to the observation of an interesting phenomenology, spanning from superfluidity to ultra-efficient four-wave mixing and they have been proposed for optical switching, transistors and ultra-low threshold lasers. More recently polaritons have also entered the quantum regime, demonstrating entanglement and quantum coherence.

Objectives: In this project, we propose to exploit the properties of a quantum neural networks (QNN) of polariton nonlinear nodes, using state-of-the-art interactions, to identify and generate quantum states: this strongly innovative idea relies on the resonant injection of states as excitations of the QNN, which physically realizes–rather than simulates–a massively parallel computing task. Indeed, based on recent theoretical advancements, prompting the feasibility of quantum neural networks with presently achieved polariton interactions and modal volumes, we propose to implement a polariton platform to solve one of the most interesting problems of quantum mechanics: the recognition of quantum states of photons, like Fock states or entangled pairs, without the need of correlation measurements (like those in quantum tomography). Moreover, we will explore the idea of converting classical light from a classical source into a quantum state.

Impact: this proposal will have a huge impact both in the field of artificial neural networks and quantum information. Apart from offering a new way of recognizing and eventually also generating complex quantum states, this idea could revolutionize the way a quantum state is measured, leading to a clear technological advance with a useful quantum device.
Indeed, one of the main needs in Quantum Optics and Quantum Information field is the ability to fully characterize and manipulate arbitrary quantum states generated both in discrete and continuous variable domains. These non-classical states are then exploited as quantum resources for a large variety of applications, ranging from quantum computing to quantum sensing and quantum communications.

PhD program: During the PhD, the candidate will implement a quantum neural network using a planar semiconductor microcavity, where polaritons are arising from the strong coupling between exciton and photons. In the first year the candidate will use advanced numerical simulations to identify the optimal parameters and the optimal sample characteristics for the implementation of the polariton network. In parallel (month 6 – month 18), the candidate will develop different sets of quantum states to be injected into the polariton network, for the training procedure. Standard detection techniques will also be implemented to characterize the states and benchmark the performances of the polariton network in identifying unknown quantum states. In the second and third years, the objective will be to construct the final polariton neural nework. The device will be trained and benchmarked for the task of the characterization of quantum states with known properties, measured independently using standard tomographic techniques. Finally, the Polariton neural network will be tested against classical signals to obtain non-conventional quantum states at its output.