Master 2 “Photonics, Complex and Quantum Systems (PhoCQS)”: Research Training 2023-2024

Supervisor: Guiseppe Patera

Topic: Nonlinear and quantum optics

## Multimode quantum light from microresonators

Integrated quantum photonics combine high-density and high-performance functions over small footprint chips. In recent years, a particular interest has been driven by the possibility of exploiting optical nonlinearities to generate on-chip multimode entanglement among frequency- time modes. Four-wave mixing (FWM) in silicon-based microresonators have been used to prove chip-scale sources of paired photons and low-dimension quantum frequency combs. More recently, experiments have started including a continuous variable (CV) regime with the demonstrations of two-color intensity and quadrature entanglement. A Si-based platform has also been validated to execute quantum algorithms that can exploit up to eight squeezed vacuum sources integrated on chip. At the same time, important applications inquantum metrology, quantum communication, and measurement-based quantum computing necessitate the ability to work with particularly large and complex entanglement structures. Our team has recently introduced *analytic Bloch-Messiah decomposition* [1] as a theoretical tool for unravelling the complex dynamics of the microresonators in terms of statistically independent observables called *morphing supermodes* [1] and characterizing their quantum properties. As a result we discovered [2] that the traditional characterisation based on homodyne detection is incomplete since part of the quantum properties (such as squeezing) remain hidden to this approach and we are currently developping the theory of interferometers with memory in order to access the whole quantum state.

The goal of this stage is a theoretical study of the classical solutions above threshold in the CW and pulsed pumping regime and the characterization of their quantum properties by the use of the morphing supermodes. In a second phase, the study will involve the investigation of possible strategies for the tailoring of quantum correlations in order to produce multimode states useful for quantum protocols.

[1] E. Gouzien, S. Tanzilli, V. D'Auria, and G. Patera, *Morphing Supermodes: A Full Characterization for Enabling Multimode Quantum Optics*, Phys. Rev. Lett 125, 103601 (2020).

[2] Élie Gouzien, Laurent Labonté, Jean Etesse, Alessandro Zavatta, Sébastien Tanzilli, Virginia D'Auria, and Giuseppe Patera, *Hidden and detectable squeezing from microresonators*, Phys. Rev. Research **5**, 023178 (2023).

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