Master in Photonics – "PHOTONICS BCN"
Master ERASMUS Mundus "EuroPhotonics"

MASTER THESIS PROPOSAL

Dates: April – September 2023

Laboratory: Optoelectronics group
Institution: ICFO – Institut de Ciències Fotòniques
City, Country: Castelldefels, Spain

Title of the master thesis: High-dimensional spatial entanglement distribution using custom-made optical fibres

Name of the master thesis supervisor and co-supervisor: Valerio Pruneri and Adam Vallés
Email address: adam.valles@icfo.eu
Phone number: +34 935534137
Mail address: Av. Carl Friedrich Gauss, 3. 08860 Castelldefels (Barcelona), Spain

Keywords: Entanglement distribution, structured light, few-mode optical fibres

Summary of the subject (maximum 1 page):

The successful distribution of spatial entanglement over long optical fibres is to become an important operational toolbox in quantum information. With the arrival of commercially available quantum computers will come the need to connect them through quantum channels, i.e. the quantum Internet. There is an obvious limitation in the capacity and security that these quantum channels can provide if only qubits are considered. Many experiments have been performed using different degrees of freedom of a single-photon over optical fibres, mainly using polarisation and energy-time/time-bin [1]. The spatial degree of freedom, a discrete series of transverse spatial modes forming an orthogonal high-dimensional basis (such as the Laguerre-Gaussian basis), has the potential to exponentially increase the capacity of the quantum communication links, especially in transoceanic links formed by few-mode optical fibres, for example, operating in the so-called third telecom window centred on silica loss minima (between 1.5 – 1.6 μm).

For many years the distribution of spatial entanglement over optical fibres has been out of reach. This has been mainly due to the fact that single-mode fibres, by their very nature, do not support more than one spatial mode; and mode coupling scrambles the multi-mode spatial state during propagation. Nevertheless, significant progress has been made recently using both custom-made and standard commercially available optical fibres. In common, all experiments

employ fibres that support only three-dimensional states (qutrits) or spin-orbit hybrid states [2,3], in order to minimise significant mode coupling.

The proposed master thesis aims at characterizing the high-dimensional spatial correlations in the Laguerre-Gaussian basis generated in an entanglement photon source (EPS) working in the shortwave infrared (SWIR) region, between 0.9 - 1.7 µm, and control its propagation through different custom-made few-mode optical fibres. The student will learn how to reduce the core size of a multi-mode fibre to turn it into a few-mode fibre; and to characterize the spiral bandwidth of the EPS by means of a spatial light modulator (SLM) and a single photon detector, also known as avalanche photodiode (APD).

Objectives:

- Look for related seminal work to discuss the expected performance of the proposed high-dimensional quantum communications link.
- Perform simulations assessing the required specifications of the few-mode optical fibres.
- Manufacture, in-house and with the help of a supervisor, the different few-mode fibres that will be used to characterize the propagation performance of each high-dimensional spatial state.
- Design and implement optical systems to characterize the orbital angular momentum degree of freedom of a photon pair, and participate in the experimental measurements.

Additional information:

It is desirable that the student has basic knowledge of experimental optics, Python and Comsol programming.

References

[1] G.B. Xavier, and G. Lima, “Quantum information processing with space-division multiplexing optical fibres,” *Commun. Phys.* **3**, 9 (2020).

[2] H. Cao, S.-C. Gao, C. Zhang, J. Wang, D.-Y. He, B.-H. Liu, Z.-W. Zhou, Y.-J. Chen, Z.-H. Li, S.-Y. Yu, J. Romero, Y.-F. Huang, C.-F. Li, and G.-C. Guo, "Distribution of high-dimensional orbital angular momentum entanglement over a 1 km few-mode fiber," *Optica* **7**, 232-237 (2020).

[3] J. Liu, I. Nape, Q. Wang, A. Vallés, J. Wang, and A. Forbes, “Multidimensional entanglement transport through single-mode fiber,” *Sci. Adv.* **6**, eaay0837 (2020).