INTERNSHIP PROPOSAL

(One page maximum)

Laboratory name: Laboratoire Matériaux et Phénomènes Quantique
CNRS identification code: UMR 7162
Internship director'surname: Pérola Millman & Arne Keller
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Internship location: 10, rue Alice Domon et Léonie Duquet 75013 Paris

Thesis possibility after internship: YES
Funding: YES (concours) If YES, which type of funding: EDPIF (concours), Programme QuanTedu-France, DIM QuanTIP

Quantum information in quantum optics and superselection rules

Quantum information can be encoded in the quantum electromagnetic field in various ways. For example, non-classical superpositions of photon number states, such as Schrödinger cat states, provide one form of encoding. Alternatively, the degrees of freedom of single photons, such as polarization, can be used to encode qubits. An intriguing question arises: is there a way to relate these two types of quantum information encoding—one based on particle statistical properties and the other on mode/particle entanglement? Can one be mapped onto the other while adhering to physical principles, such as energy conservation, or informational principles, such as providing the same advantage over classical encodings? Our goal is to design common quantifiers for these quantum optical encodings. In a previous result [1], we developed a method to characterize the non-classical nature of a superposition of photon number states by assessing its computational power in a quantum computer composed of single photons, where qubits are encoded in the polarization states of each photon. This work is based on a representation of quantum optical states that respects superselection rules, which prohibit the existence of superpositions with different particle numbers.

During this internship, we will extend this approach to the field of quantum metrology, which aims to achieve quantum-enhanced precision in parameter estimation. As demonstrated in [2, 3, 4], using single photons in different frequency modes results in the same type of precision enhancement as that achieved with photon number state superpositions, such as Schrödinger cat states. Our objective is to develop a unified formalism that describes all quantum optical encodings capable of achieving quantum-enhanced precision.

[1] E. Descamps et al. arXiv 2407.03138 (2024).
[2] E. Descamps et al. Phys. Rev. Lett. 131, 030801 (2023). See also: https://www.inp.cnrs.fr/fr/cnrsinfo/la-metrologie-quantique-prend-des-couleurs
[3] E. Descamps et al. Phys. Rev. A 013797 (2023).
[4] O. Meskine et al. Phys. Rev. Lett. 132, 193603 (2024).

Theoretical internship requiring a background in quantum mechanics and a keen interest in quantum information and quantum optics. Possible (and encouraged) collaboration with experimentalists (Sara Ducci's team, MPQ).

Please, indicate which speciality(ies) seem(s) to be more adapted to the subject:

Condensed Matter Physics: YES/NO
Soft Matter and Biological Physics: YES/NO
Quantum Physics: YES/NO
Theoretical Physics: YES/NO