Pulse by pulse and frequency multiplexed quantum states for CV quantum information protocols

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Photonics quantum networks are essential resources for quantum information processing, as quantum states of light allow for the efficient distribution and manipulation of information. Here we explore continuous-variable (CV) entangled states, where entanglement correlations appear between quadratures of the electromagnetic field. Such states can be deterministically generated by mixing several squeezed optical modes via linear-optics operations or, more generally, via mode-basis changes.

Easily reconfigurable entangled networks have been demonstrated in frequency modes structure [1], while the largest entangled structures (with more than a million of nodes) have been demonstrated by exploiting temporal modes. We recently demonstrated the generation of both frequency-multiplexed and pulse-by-pulse multiplexed quantum states from a non-linear waveguide pumped by femtosecond pulsed laser [2,3].

The combination of two waveguides will allow to generate three-dimensional entanglement structures, that are both scalable and reconfigurable and that can be to be exploited for CV quantum information protocols.
In particular, the quantum networks will be used for implementing machine learning tasks, like quantum reservoir computing, a topic that we study in collaboration with the theory group of R. Zambrini at IFISC (Institute for Cross-Disciplinary Physics and Complex Systems). We have recently shown that Gaussian states provide universal reservoir computing and that quantum Gaussian resources, like squeezed state, provide a larger information capacity than classical states [4]. Also, we have recently implemented the classical optical version of a reservoir computing protocol via our femtosecond source [5]. Different quantum reservoirs will be then tested in this scenario: i) by directly testing the frequency and pulse-by pulse multiplexed states and ii) by using the three-dimensional entanglement structure in the form of cluster states.

When required, local operations like single-photon subtraction [6] will be added to the protocol in order to reach non-Gaussian statistics of quadrature, which is known to be needed in order to demonstrate quantum advantage.

The project is intended to be inserted in the initiative of the Quantum Information Center Sorbonne (QICS). It in fact covers instances concerning quantum reservoir computing.

Applicants should have a Master diploma in Physics. Familiarity with quantum information and/or experimental optics will be valuable.

[1] Y. Cai, J. Roslund, G. Ferrini, F. Arzani, X. Xu, C. Fabre, N. Treps, Nature Communication 8, 15645 (2017).
[2]T. Kouadou, F. Sansavini, M. Ansquer, J. Henaff, N. Treps, and V. Parigi, arXiv:2209.10678
[3]V Roman-Rodriguez, B Brecht, K Srinivasan, C Silberhorn, N Treps, Eleni Diamanti, V Parigi New J. Phys. 23 043012 (2021)
[4] J. Nokkala, R. Martínez-Peña, G. L. Giorgi, V. Parigi, M. C Soriano, R. Zambrini Communications

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[6] Y.-S. Ra, A Dufour, M. Walschaers, C. Jacquard, T. Michel, C. Fabre, N. Treps, Nature Physics 11, 1 (2019).