Time-frequency quantum information processing

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Scientific description:

The frequency degree of freedom of a single photon represents a continuous variable that serves as a powerful tool for encoding quantum information. It provides a high-dimensional encoding scheme, which in turn helps to reduce overall optical costs. Leveraging frequency as a continuous variable and subsequently discretizing it allows for the creation of qubits, which are essential for achieving fault- tolerance. These qubits demonstrate robustness against temporal or spectral broadening for the superposition of two frequency and time, and even small broadening in both the temporal and frequency domains, as for the time-frequency Gottesman–Kitaev–Preskill (GKP) states (Phys. Rev. A **102**, 012607). Errors can arise during the manipulation of single photons in logical operations and as they propagate through optical fibers. Additionally, errors may stem from cross-talk between classical and quantum signals within optical fibers, a particularly pertinent consideration in the development of cost-effective quantum communication infrastructure. What we will explore in this theoretical internship would be:

• **Studying the Propagation of Single Photons:** We will study the propagation of single photons with diverse spectral distributions through optical fibers. We will investigate the use of time- frequency GKP states and two-color (time-of-arrival) encoding schemes. We will then model and analyze noise that may affect these quantum states during their propagation, and we will simulate light-matter interactions and implement computational methods using tools like Qutip. We will assess the purity and coherence of the resulting quantum states, gaining valuable insights into their potential for quantum information processing**.**

• **Application in Quantum Key Distribution:** Once the errors of these encodings have been found studying the Quantum Bit Error Rate (QBER), and the secure key rate associated with these different encoding strategies. Participate in research aimed at enhancing the security and reliability of quantum communication protocols, including the renowned BB84 protocol with novel encodings.

• **References:**

[1] N. Fabre, A. Keller, and P. Milman, *Time and Frequency as Quantum Continuous Variables*, Phys. Rev. A **105**, 052429 (2022).

[2] N. Fabre et al., *Generation of a Time-Frequency Grid State with Integrated Biphoton Frequency Combs, Phys. Rev. A* ***102****, 012607 (2020).*

Techniques/methods in use: Theoretical Quantum optics, Quantum communication, Python
Applicant skills: Interest and understanding in quantum technologies and photonics, eager to develop international collaboration with theoreticians

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