Compact Spectrometers for the Orbital Angular Momentum of Light
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Orbital angular momentum (OAM) is one of the intrinsic properties of light, with eigenvalues of $l\hbar$ per photon, where $l$ is any integer. Therefore, the OAM degree of freedom can be utilized to construct qu-dit (d-dimensional) quantum systems, as opposed to qu-bit (two dimensional) systems, for quantum computing in higher-dimensional Hilbert spaces and quantum communication with high information capacities. To determine the OAM spectrum of an unknown state, a few methods have been developed. However, all these schemes map different OAM states to spatially separated modes at the output. As a result, complexity and size of the experimental setups increase with the highest measurable OAM state. Fidelity of the detection is often limited by the complexity of the experimental setup. We demonstrate here schemes that resolve different OAM state temporally, instead of spatially, and thus require only one compact optical-loop for detection of arbitrarily high OAM states with high fidelity.

The first scheme comprises of one interferometer nested within an optical loop (Fig. 1a). It uses a Quantum Zeno Interrogator (shaded region in Fig. 1a) to perform counterfactual measurements on the OAM state, and thus maps different OAM components of an arbitrary input light pulse into different time bins at the output. It can achieve very high extinction ratios between different OAM states (Fig. 1b) and can work for arbitrarily high OAM orders limited mainly by the loss of the optics.

The second scheme further simplifies the spectrometer to make it simple, practical, and economical experimentally, at the sacrifice of transmission efficiency. As shown in Fig. 1c, the second scheme consists of simply an optical loop that converts an input pulse into a sequence of pulses equally spaced in time, a vortex phase plate that decreases the OAM value by 1 per pass, and a single-mode fiber that filter out states with non-zero OAM and passes the state with zero OAM. Given an arbitrary incident pulse, the OAM=0 component exits the spectrometer first, at time $t = 0$, and the component with OAM value $l\hbar$ exits at $t = lT$ after the first pulse. We tested the spectrometer using light with a dominant OAM component, created by diffracting a Gaussian laser beam off fork-patterns printed on a transparency. Extinction ratios of 44-9 were measured for $l = 1-3$, mainly limited by the purity of the test input state. Including reasonable mis-alignment, we estimate an extinction ratio of >150 for $l$ up to 5.

References: