Quantum frequency conversion driven by classically nonseparable light

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Quantum frequency conversion (QFC) is the process of coherently changing the color of an optical signal while preserving its quantum state [1]. Applications of QFC are many, ranging from single-photon detection[2] to the interfacing of photons with quantum memories [3]. Here we investigate the QFC of photons driven by strong classical fields that are non-separable in the polarization and the spatial degrees of freedom. We show that the classical non-separability in the QFC process enables what we call the spin-orbit quantum frequency conversion (SO-QFC), i.e., the transduction of a quantum state encoded in the polarization of a single photon to the spatial profile of a photon of shorter wavelength.

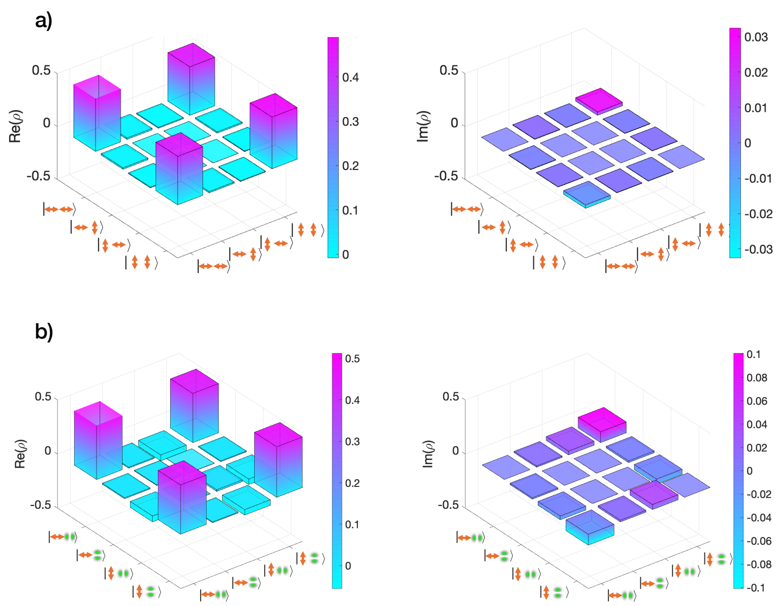

FIG. 1. Experimental results for the SO-QFC process. a) real and imaginary parts of the density matrix of the initial polarization-entangled state of the pair of photons. b) real and imaginary parts of the density matrix of the quantum state after SO-QFC.

In our experiment we generate a pair of polarization-entangled Telecom photons (1560 nm) via spontaneous parametric downconversion, one of which undergoes SO-QFC to visible (520 nm). We then characterize the SO-QFC by performing full quantum state tomography on both photons and compare the final two-color quantum state with the input state, as shown in Fig.1. Our results show that the SO-QFC driven by a fully non-separable classical field (local) successfully preserves the entangled state (non-local) of the photon pair, witnessed by the fidelity higher than 97% between the quantum state before and after QFC. Furthermore, by changing the degree of classical non-separability of the drive field, we verify that the concurrence of the upconverted entangled state is bounded from above by the classical concurrence of the drive field, consisting of a rare case where classical non-separability is a necessary (not sufficient) condition for entanglement.

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