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Few-photon interactions: from conditional phase to quantum vortices

Imagine dragging a plate across the surface of a tranquil water pool. Quite excitingly, you would form a pair of swirling vortex and antivortex, propagating steadily across the surface. In optics, vortices materialize as phase twists of the electromagnetic field. While traditionally optical vortices arise from interactions between light and matter, we have recently reached a new extreme regime of optical nonlinearity where quantum vortices –phase dislocations in the few-photon wavefunction –form due to effective, strong interactions between the photons themselves. These interactions are realized in a ‘quantum nonlinear optical medium’ based on ultracold Rydberg atoms. Analogous to the water pushed by the plate, the excess phase accumulating due to the photon-photon interaction gives rise to pairs of quantum vortices, vortex lines, and rings, within the photonic wavefunction. The two-photon and three-photon bound states dominate the formation of these vortices, and the ‘conditional’ phase flip localized between them can be used for deterministic quantum logic operations.

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