Nonlocally controlling of skyrmion topologies with spin-skyrmion entangled states

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Abstract: Photonic skyrmions constitute an emerging resource, promising stable quantum information encoding. We report spin–skyrmion entangled states where a single photon's local skyrmionic topology is remotely controlled through the spin of its entangled partner.

Skyrmions are a particle-like topology characterized by an integer-valued topological charge, known as the skyrmion number (n), which is associated with the wrapping of a spin or pseudospin field. These topological excitations have since been studied in many systems due to their robust nature to external environmental influence, including optical fields [1]. One such optical approach is structuring the spatial phase and polarisation in free-space paraxial beams [2]. This Stokes skyrmion is defined as a mapping between the tranverse spatial plane, R^2 and a polarization state space, S^2, represented by the Poincare sphere and offers the advantages that span from versatile platforms for investigating exotic topologies [3], to the promise of robust computing [4] and optical processing at the speed of light. It is only recently that these states have been explored in the quantum regime from single photons [5] to across the entangled photons [6] and both [7]. However, the topology in these systems has remained a well-defined feature of their underlying states. Here, we introduce spin-skyrmion entangled states, where the skyrmion topology of one photon is remotely controlled by its entangled twin [8]. We demonstrate these features through experimentally measured dual-wavelength entangled states that exhibit topological transitions between two different skyrmion numbers as shown conceptually in Fig. 1(a). To visualise this skyrmion number transition, we introduce the notion of a topological Bloch sphere, capturing the state of the skyrmion-photon given measurements the other photon's spin. This is shown with an experimentally realised example in Fig 1 (b). Notably, no well-defined spin texture or skyrmion number exists prior to measurement, underscoring the non-local character of the topology. Our approach opens new avenues for harnessing quantum skyrmions and multiskyrmions in non-locally steered configurations and quantum-information protocols.

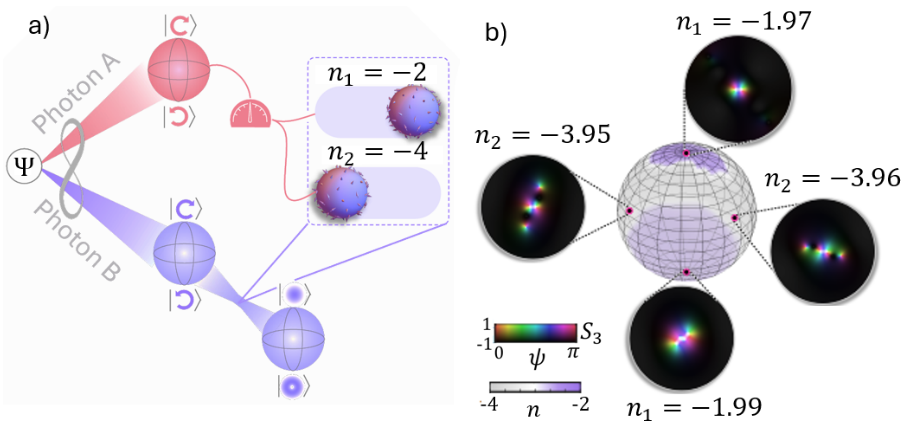

Fig. 1 a) Photons A and B can be engineered to form a spin-skyrmion entangled state such that a measurement made on the polarization of photon A will collapse photon B onto a defined topology, having a skyrmion number that can be switched between n1 and n2. b) Polarization measurements on photon A heralds topologies on photon B that can be visualised on a Poincarè sphere, giving one the freedom to traverse an entanglement-enabled topological landscape. A quantum multiskyrmion composed of quasiparticle-like distributions is revealed at the equator, having one skyrmion number (n1), while a higher order skyrmion is realised at the poles with another skyrmion number (n2). The topological states are represented as polarization vector plots where $\psi = \frac{1}{2} tan^{-1}\left(\frac{S_2}{S_3}\right)$ at exemplary points on the sphere.

Example References

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