Structuring light via Pancharatnam-Berry Phase: preparing and manipulating qudits

Recent advances in quantum photonics have demonstrated the pivotal role of liquid-crystal (LC) devices in enabling the generation, manipulation, and detection of structured light through the Pancharatnam–Berry (PB) phase. LC-based geometric-phase optics, including PB lenses, deflectors, and spin–orbit converters, now provide high-efficiency, polarizationdependent control of optical wavefronts and mode structures, offering a scalable platform for high-dimensional quantum state engineering. In particular, Corona-Aquino et al. [Phys. Rev. Appl. 21, 034030 (2024)] experimentally demonstrated the reliable preparation and remote topological control of heralded single photons whose polarization, intensity, and phase profiles are inherited from a shaped pump beam via a voltage-tunable spin-to-orbital angular momentum converter. Complementary developments in LC-based planar PB devices [Opt. Express 32, 544628 (2024)] highlight their capacity for dynamic and reconfigurable beam shaping, enabling tailored spatial and polarization structures with exceptional fidelity and efficiency. Together, these advances establish LC Pancharatnam– Berry optics as a versatile and reconfigurable hardware platform for quantum photonic technologies, supporting non-separable spin–orbit states, tunable mode conversion, and topological class switching at the single-photon level—key functionalities for next-generation quantum communication, computation, and measurement systems. Novel perspectives are finally presented.