Topological states of light

A coherent optical vortex (OV) features a helical phase, with the electromagnetic energy circulating around a vortex core which is a line of zero field intensity and indeterminate (singular) phase. A garden variety OV exhibits a characteristic intensity null on its axis (vortex core) which is surrounded by a bright ring with the radius scaling with the magnitude of its longitudinal orbital angular momentum (OAM). In addition to OVs carrying longitudinal OAM along their propagation direction, which have been extensively studied to date, spatiotemporal optical vortices (STOVs), supported by dispersive optical media and endowed with transverse OAM, have recently piqued researchers' curiosity. The spatial and temporal degrees of freedom of such STOVs are inextricably entangled. In this connection, we have recently discovered a new class of STOVs, the so-called perfect STOVs, whose space-time intensity distribution is independent of their OAM content [1]. We exhibit the intensity and phase distribution, as well as the electromagnetic power flow around vortex cores of such perfect STOVs in Fig.1 below. The perfect STOVs can facilitate neutral particle guiding and tweezing along prescribed trajectories in space and time.

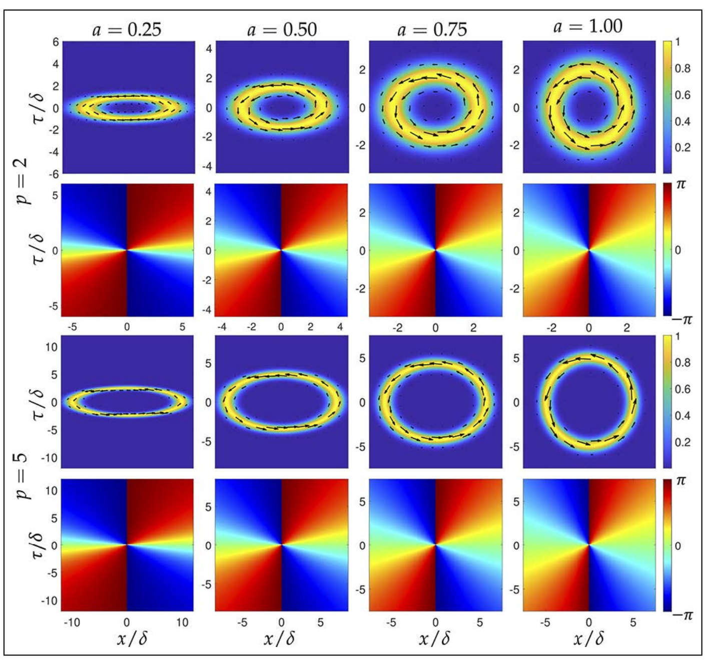

FIG. 1. Intensity (top and third from the top rows) and phase (second from the top and bottom rows) profiles of PSTVs with l = 2 and variable p and a in the focal plane of a space-time lens. The power density flow is indicated by the arrows.

At the same time, the correlation functions of random optical fields can also be endowed with vortices. In particular, we have recently discovered a class of such random vortices, perfect correlation vortices (PCV), with the degree of coherence (normalized field autocorrelation function) of any such vortex at the source being nearly statistically homogeneous and independent of the OAM of the vortex. We have demonstrated that while slowly diffracting in free space, perfect correlation vortices maintain their "perfect" vortex structure; they are capable of preserving said structure even in strong atmospheric turbulence [2] (see also Fig.2). Structural resilience to diffraction and turbulence makes the discovered PCVs suitable for free-space optical communications.

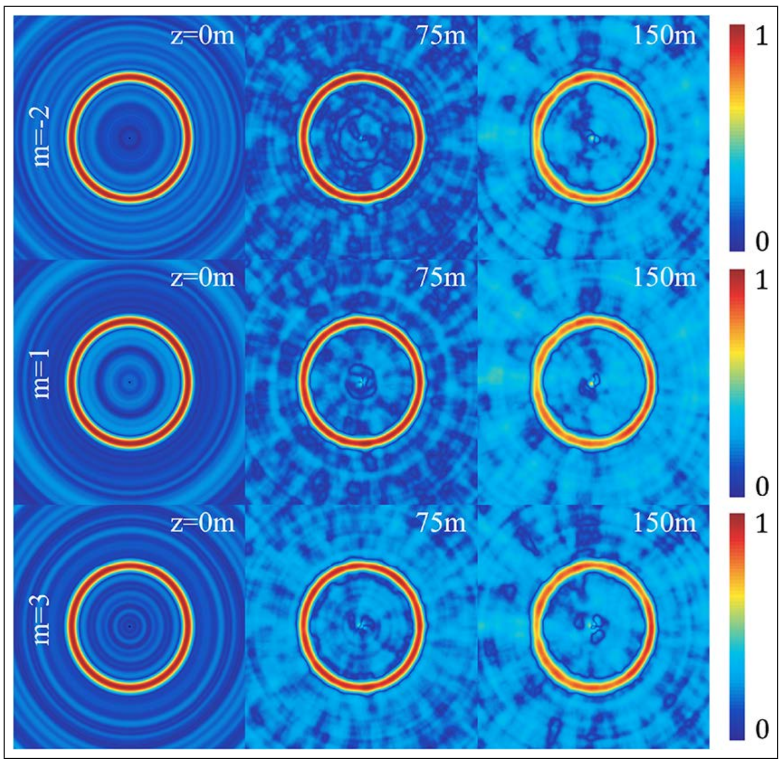

FIG. 2. Evolution of the magnitude of the PCV degree of coherence through a 150 m long stretch of the turbulence atmosphere in the strong turbulence regime with $C_n^2 = 10^{-13}$ m$^{-2/3}$.

[1] S. A. Ponomarenko, and D. Hebri, "Perfect space-time vortices," Opt. Lett. **49**, 4322 (2024).

[2] X. Li, S. Bashiri, Y. Ma, C. Liang, Y. Cai, S. A. Ponomarenko, and Z. Xu, "Perfect correlation vortices [**Editor's Pick**]," Opt. Lett. **49**, 4717 (2024).