Optical Vortex Streets

Gabriel Molina-Terriza, Dmitri V. Petrov
and Lluis Torner

Singular light beams that contain topological wave-front dislocations are ubiquitous in optics.[1] Screw dislocations, or vortices, are a common type of dislocation. They are dark holes nested in light beams that feature a helical phase ramp around a core where the light intensity vanishes. The phase of the field changes by $2\pi m$ (m being the topological charge of the vortex) along any closed loop around the vortex core. Vortices abound in nature and thus appear spontaneously in many optical settings, including speckle fields, optical cavities and doughnut laser modes. They can also be readily generated, e.g., with phase masks, and nested in host beams. Light beams with nested vortices have widespread, far-reaching applications in fields as diverse as the biosciences, laser cooling and trapping, micromechanics and quantum information.

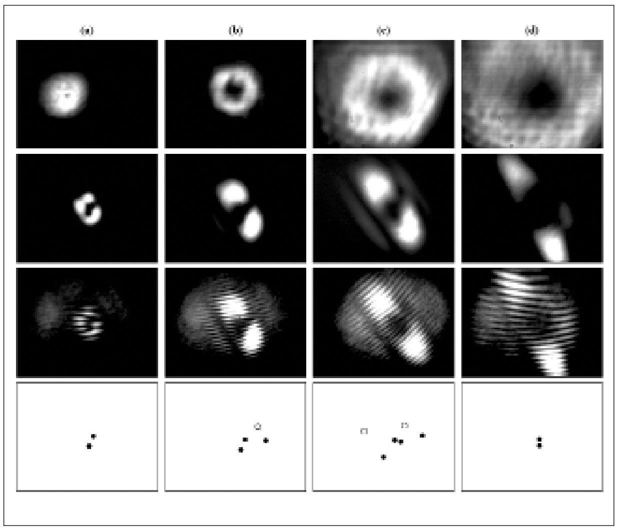

Figure 1. Observed light distribution. Upper row: FF pump beam; second row: SH beam; third row: Interferogram of the SH beam with a tilted plane wave; lower row: Location of the optical vortices observed in the SH beam. Positive (negative) vortices are shown with filled (open) circles. Images were taken by a CCD camera placed 25 cm behind the LBO crystal. The actual scale of the figures is 8 mm x 6 mm. Conditions suitable for the formation of a small vortex street occur only in file (c). See Ref. 4 for details.0

Since the number and location of the vortices existing in a light beam at different observation planes are dictated by the evolution of the host beam, parametric mixing of waves opens the door to a variety of new phenomena. Because of the parametric interaction, the waves exchange not only energy with each other but also nonlinear phase shifts, thus wave fronts. For this reason, new vortices and vortex trajectories are created in the new fields that are generated. Charge-doubling in second-harmonic generation schemes, and arithmetic charge operations in three-wave processes, have been observed with wide beams. However, the combined effects of diffraction and Poynting vector walk-off introduce a new range of possibilities, including the spontaneous nucleation of multiple vortex twins whose subsequent explosion under appropriate conditions yields quasi-aligned patterns of single-charge vortices, or *vortex streets*.[2,3]

We recently reported what is believed to be the first experimental observation of such phenomena.[4] The experiments were conducted in a 25-mm-long lithium triborate crystal cut for phase-matching for second-harmonic generation pumped at 1064 nm. In this geometry, the fundamental wave propagates as an ordinary beam, the second-harmonic wave at 532 nm propagates as an extraordinary beam, and both beams experience a moderate Poynting vector walk-off with angle $\rho = 0.4$ degrees. To pump the crystal, we used 8-ns pulses from a Q-switched Nd:YAG laser. Screw-phase dislocations were nested in the pump beam by use of high-diffraction efficiency computer-generated off-axis holograms. Figure 1 illustrates a typical outcome of the observations.

Vortex streets appear in a variety of natural phenomena.[5] For example, in aerodynamics, periodic pressure and density fluctuations produced by so-called von Kármán vortex streets are responsible for the familiar whistling of thin wires in the wind, or the whistling sound made when a thin stick is waved briskly in the air. Similarly, vortex streets generated by ocean drift currents, e.g., the Gulf Stream interacting with Cozumel Island off the Yucatán coast, have been recorded. Such vortex streets are formed by physical effects absent in our setting, where the vortices are generated by the interference of multiple walking beams. Yet our observations add to previous evidence to stress that the analogy existing between singular optics and fluid dynamics is a continuously inspiring source for the discovery of new phenomena involving light.

References

1. Y. S. Kivshar, E. A. Ostrovskaya, Opt. Photon. News, **12**(4), 26-31 (2001).
2. J.T Malos, *et al.*, Opt. Lett. **22**, 1056-9 (1997).
3. G. Molina-Terriza, *et al.*, Opt. Lett. **24**, 899-901 (1999).
4. G. Molina-Terriza, *et al.*, Opt. Lett. **27**, 625-7 (2002).
5. H.J. Lugt, Vortex Flow in Nature and Technology (Krieger, Malabar, Florida, 1995).

Gabriel Molina-Terriza, Dmitri V. Petrov and Lluis Torner (torner@tsc.upc.es) are with the Institute of Photonic Sciences, Universitat Politècnica de Catalunya, Barcelona, Spain.