The Optical Vortex Soliton

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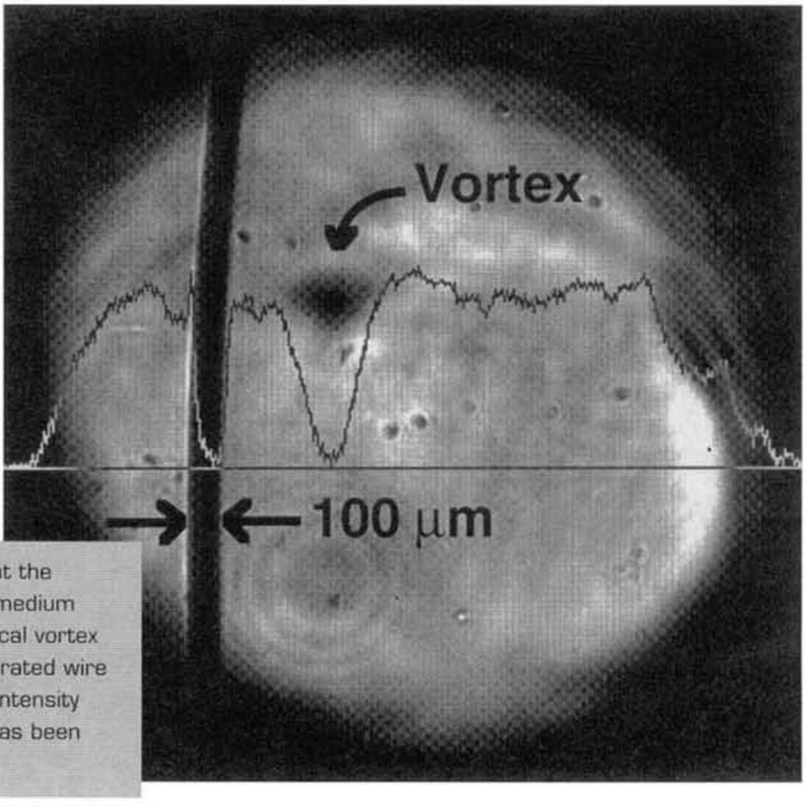
Until recently, optical solitons with two transverse degrees of freedom were not known to exist, and thus, nonlinear optical engineering often required the use of waveguides to constrain diffraction. Catastrophic beam collapse can occur once this constraint is relaxed in a self-focusing system. In a self-defocusing system, on the other hand, a new class of soliton phenomena, including dark soliton stripes and grids,[1] and optical vortex solitons,[2] have been observed. Because these effects occur in a bulk medium, without the constraints of a waveguide, new techniques may be possible, especially in the areas of planar spatial light modulation, image processing, optical switching, and optical interconnection.

A linear optical vortex is a fundamental wave that, like a plane wave, is characterized by a distinct phase profile; in this case, $\exp(\pm i\theta)$, where θ is the angular coordinate in a cylindrical system. Such a field produces a dark vortex core having zero intensity along the optical axis, z. The hydrodynamic nomenclature follows from the realization that the transverse phase velocity has circulation. When a vortex is introduced into a self-defocusing medium, the characteristic core size decreases, owing to the law of refraction. The opposing effects of refraction and diffraction result in a stationary core size in a Kerr nonlinear refractive medium[3] (the propagation is governed by the (2+1)-D nonlinear Schrödinger equation). Thus, the vortex forms a filament of constant radial size, which has been shown to serve as a self-induced graded-index optical fiber, capable of guiding a probe beam.[2]

Our investigations of the nonlinear optical vortex[2,4] indicate that the vortex is not only stationary, but also stable to severe perturbations; therefore it is a soliton. The intensity profile of a single optical vortex soliton is shown in the figure. The experiment was conducted using an argon ion laser (~1 W), a holographic vortex phase mask, and a 22 cm-long cell containing a slightly absorbing liquid. The figure is an image at the output face of the cell, where a 100 μm-diameter wire was placed to calibrate the half-intensity diameter of the vortex core, which we measured to be 170 μm.



Cross-sectional intensity profile at the output face of a self-defocusing medium showing the dark core of an optical vortex soliton. The dark stripe is a calibrated wire 100 μm wide. A line plot of the intensity profile through the vortex core has been superimposed on the image.

Recognizing that linear vortices may occur in cylindrical waveguides, vector vortex solitons have been proposed by Snyder *et al.*[5] On a quantum mechanical level, optical vortex solitons are analogous to vortices in a superfluid or superconductor, and may therefore exhibit striking quantum phenomena.[3] The ability to create optical vortex solitons opens an intriguing new frontier, and also allows exciting new opportunities to control light with light.

ACKNOWLEDGMENTS

This work was supported by the Advanced Research Projects Agency, the Pittsburgh Supercomputing Center, and the Naval Research Laboratory. We thank Mark Freeman (now at the Industrial Technology Research Institute, Taiwan) who fabricated this mask for us at the University of Colorado, Boulder. We also thank E. M. Wright, A. W. Snyder, and A. E. Kaplan for helpful discussion.

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