Stable nonlinear vortices in self-focusing Kerr media with nonlinear absorption

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We have studied the stability properties of nonlinear Bessel vortices in self-focusing Kerr media with nonlinear absorption. Nonlinear Bessel vortices are propagation-invariant solutions of the nonlinear Schrödinger equation with cubic nonlinearity and nonlinear absorption. We have found that these vortices can be stable against perturbations, including the azimuthal perturbations that usually break the cylindrical symmetry of standard vortex solitons in self-focusing Kerr media. This property is seen to arise from the stabilizing effect of nonlinear absorption.

Our model is the nonlinear Schrödinger equation

(1) $\partial_z A = i\Delta_\perp A + i\alpha |A|^2 A - |A|^{2M-2}M$

where $\Delta_\perp = \partial_x^2 + \partial_y^2$, describing, for instance, light beam propagation in a self-focusing ($\alpha > 0$) Kerr medium with M-photon absorption.

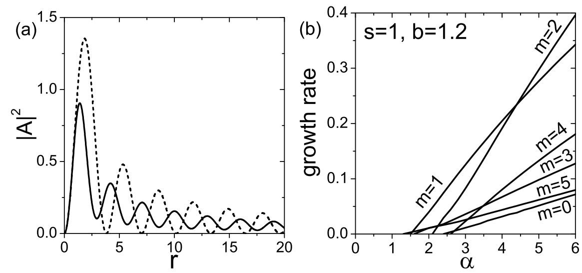

FIGURE 1. (a) Radial intensity profile of the nonlinear Bessel vortex beam with $M = 4$, $s = 1$, $b = 2$ and $\alpha = 1$ (solid curve) compared to the radial profile $b^2 J_s^2(\rho)$ of the linear Bessel beam with the same vortex core (dashed curve). (b) Growth rates of unstable azimuthal modes m of nonlinear Bessel vortices with $M = 4$, $s = 1$, $b = 1.2$ and different values of the Kerr nonlinearity α.

Localized solutions with z-independent intensity profile $|A|^2$ of the form $A = a(r)\exp[i\phi(r)]\exp(-iz)\exp(is\varphi)$, where (r, φ, z) are cylindrical coordinates and $s = 0, \pm 1, \pm 2, \ldots$ is the topological charge, do exist, and are nonlinear Bessel vortices, also called nonlinear unbalanced Bessel beams [**1, 2**]. These beams carry a vortex of the type $a(r)\exp[i\phi(r)] \simeq bJ_s(r)$ about the origin $r = 0$, where b is a constant. Figure 1(a) shows an example of radial intensity profile compared to that of the Bessel profile $b^2 J_s^2(r)$.

A linearized stability analysis of these beams reveals that they may be stable against all type of small perturbations, including the most dangerous azimuthal perturbations usually leading to azimuthal breaking of vortex solitons in self-focusing Kerr media. Figure 1(b) illustrates that the growth rate of unstable radial ($m = 0$) and azimuthal modes ($m > 0$) vanish at positive values of the Kerr nonlinearity coefficient α.

This result has important implications in actual applications of nonlinear light beams, as laser material processing for waveguide writing or micro-machining with vortex light beams [**2, 3**].

Keywords: spatial solitons, optical vortices, nonlinear optics

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