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The transformation of an edge dislocation in atmospheric turbulence

Jinhong Li [a,*], Baida Lü [b]

[a] School of Applied Science, Taiyuan University of Science and Technology, Taiyuan 030024, China
[b] Institute of Laser Physics and Chemistry, Sichuan University, Chengdu 610064, China

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ABSTRACT

The explicit expression for the cross-spectral density of partially coherent elliptical Gaussian beams carrying an edge dislocation propagating through atmospheric turbulence along a slant path is derived, and used to study the transformation of the edge dislocation in atmospheric turbulence. We find that the edge dislocation disappears and transforms to a noncanonical coherence vortex, when partially coherent elliptical Gaussian beams with edge dislocation propagate through atmospheric turbulence. The inversion of the topological charge of the coherence vortex may take place. The ellipticity of the beam and slope of the edge dislocation play a dominant role in the evolution of the coherence vortex. In the coherent limit the coherence vortex in turbulence becomes an intensity vortex, however, differing from the case in free-space propagation, the position of the intensity vortex depends on the choice of the reference point. The results are illustrated analytically and numerically.

1. Introduction

Considerable interest has been exhibited recently in the optical beams carrying phase singularities (wavefront dislocations) due to their theoretical importance and potential applications in micron-sized particle manipulations, atom trapping and optical communications, etc. [1,2]. There exist two different kinds of pure dislocations, i.e., the longitudinal screw dislocation (optical vortex) with spiral phase and transverse edge dislocation with π-phase jump located along a line in the transverse plane [3]. The propagation dynamics of optical vortex beams and vortex-edge dislocation interaction in a linear medium, a nonlinear defocusing medium and in the presence of an astigmatic lens have been studied extensively [3–12]. The vortex evolution and decay of high-order optical vortices in media with an anisotropic nonlocal nonlinearity were analyzed in [13,14]. The generation of an optical vortex from the instability of a dark soliton stripe in a saturable defocusing medium was observed experimentally in [15]. More recently, the dynamical evolution of an edge dislocation nested in a general elliptical Gaussian beam through aligned and misaligned paraxial ABCD systems was analyzed in [16].

The laser beam propagation through atmospheric turbulence is a topic that has been of particular theoretical and practical interest for a long time [17,18]. It was found both theoretically and experimentally that partially coherent beams are less sensitive to the effect of turbulence than fully coherent ones [19–21]. For some practical applications the propagation of laser beams through atmosphere along a slant path is required [18,22,23]. By using the average structure constant $\overline{C}_n^2$, the propagation of multi-Gaussian beams through slant atmospheric turbulence was investigated in [23]. The propagation of optical vortex beams through weak-to-strong atmospheric turbulence was dealt with by using multiple phase screen simulation in [24], and the results showed that the topological charge could be used as an information carrier in optical communications.

Interesting is to ask: what will happen when optical beams carrying an edge dislocation propagate through atmospheric turbulence? The purpose of the present paper is to study the transformation of an edge dislocation in atmospheric turbulence. In Section 2 the theoretical model of the propagation of partially coherent elliptical Gaussian beams carrying an edge dislocation through atmospheric turbulence along a slant path is formulated. The transformation of an edge dislocation in atmospheric turbulence and dependence on the edge dislocation, beam and atmospheric-propagation parameters are analyzed in Section 3. Finally, in Section 4 a summary of the main results obtained in the paper concludes this paper.

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[*] Corresponding author.
E-mail addresses: sculijh@yahoo.cn (J. Li), baidalu0@tom.com (B. Lü).

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2. Theoretical model

The field at the source plane $L=0$ of elliptical Gaussian beams carrying an edge dislocation reads as [3,16]

$$E(\boldsymbol{\rho}, L=0) = \left(p\rho_x - \rho_y + d\right) \exp\left(-\frac{\rho_x^2}{w_{0x}^2} - \frac{\rho_y^2}{w_{0y}^2}\right), \tag{1}$$

where p and d denote the slope and off-axis distance of the edge dislocation, w_{0x}, w_{0y} are the waist widths of elliptical Gaussian beams in the x and y directions, respectively. $\boldsymbol{\rho} \equiv (\rho_x, \rho_y)$ is the two-dimensional (2D) position vector at the plane $L=0$. Fig. 1 gives (a) the three-dimensional (3D) normalized intensity distribution $I(\boldsymbol{\rho}, 0)/I(\boldsymbol{\rho}, 0)_{\max}$ ($I(\boldsymbol{\rho}, 0)_{\max}$—the maximum intensity), (b) the contour plot of the intensity, and (c) the contour lines of the phase of an elliptical Gaussian beam carrying an edge dislocation at the source plane $L=0$, respectively. The calculation parameters are $w_{0x}=3$ cm, $w_{0y}=5$ cm, $p=2$, and $d=1$ cm. Fig. 1(a) and (b) indicates that there exist two intensity peaks whose maximum is unequal. From Fig. 1(c) we see that an edge dislocation with slope $p=2$ appears.

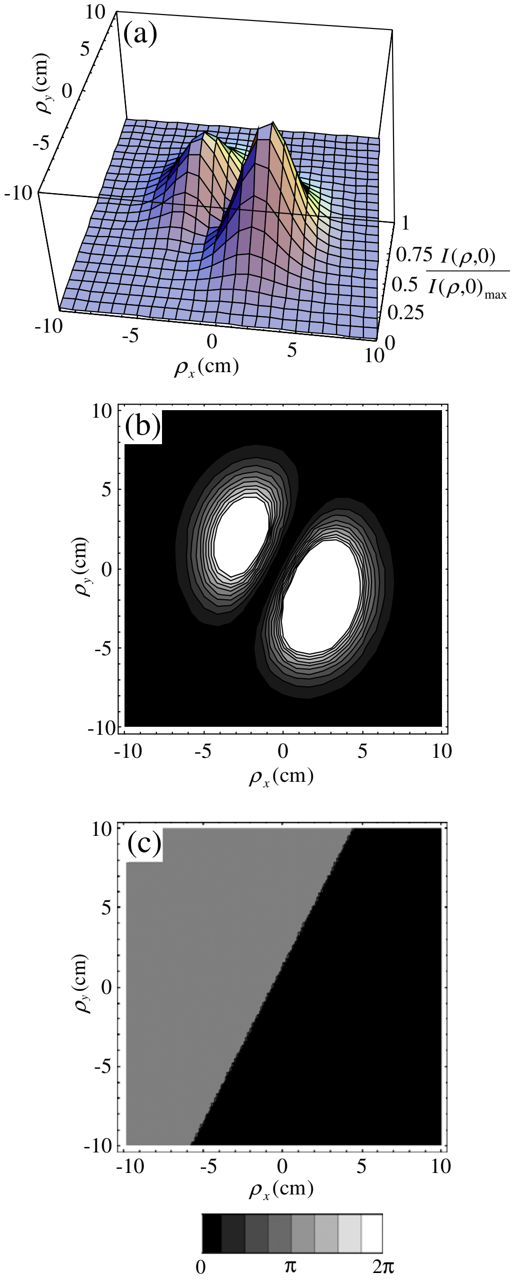

Fig. 1. (a) 3D normalized intensity distribution, (b) contour plot of intensity, and (c) contour lines of phase of an elliptical Gaussian beam carrying an edge dislocation at the plane $L=0$.

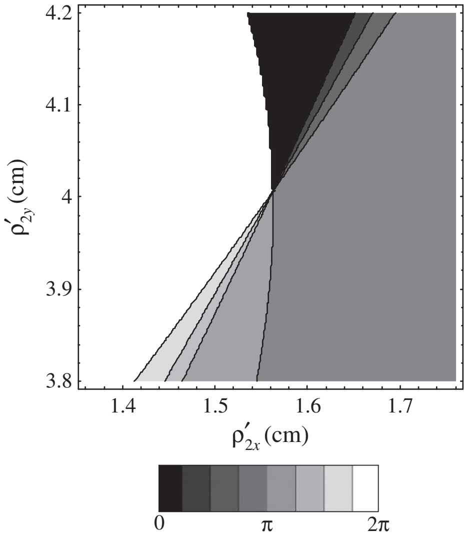

Fig. 2. Contour lines of the phase at $L=1$ km of a partially coherent elliptical Gaussian beam with edge dislocation propagating through atmospheric turbulence.

Introducing a Schell-model correlator [25], the cross-spectral density of partially coherent elliptical Gaussian beams with edge dislocation at the plane $L=0$ is written as

$$\begin{aligned} W^{(0)}(\boldsymbol{\rho}_1, \boldsymbol{\rho}_2, 0) &= \langle E^*(\boldsymbol{\rho}_1, L=0) E(\boldsymbol{\rho}_2, L=0)\rangle \\ &= \left[p^2\rho_{1x}\rho_{2x} - p\left(\rho_{1x}\rho_{2y} + \rho_{2x}\rho_{1y}\right) + dp(\rho_{1x}+\rho_{2x}) - d\left(\rho_{1y}+\rho_{2y}\right) + \rho_{1y}\rho_{2y} + d^2\right] \\ &\quad \times \exp\left[-\left(\frac{\rho_{1x}^2+\rho_{2x}^2}{w_{0x}^2} + \frac{\rho_{1y}^2+\rho_{2y}^2}{w_{0y}^2}\right)\right] \exp\left[-\frac{(\boldsymbol{\rho}_1 - \boldsymbol{\rho}_2)^2}{2\sigma_0^2}\right], \end{aligned} \tag{2}$$

where σ_0 denotes the spatial correlation length and $\boldsymbol{\rho}_j \equiv (\rho_{jx}, \rho_{jy})$ ($j=1, 2$ unless otherwise stated).

Based on the extended Huygens–Fresnel principle [18], the cross-spectral density of partially coherent elliptical Gaussian beams with

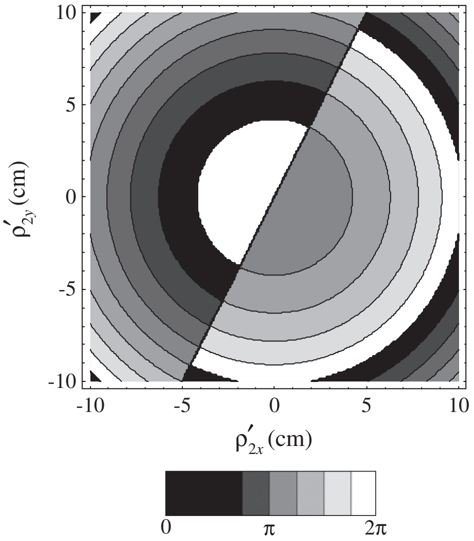

Fig. 3. Contour lines of the phase of a fully coherent Gaussian beam with edge dislocation at $L=1$ km in free space.