Destruction and recovery of spiral vortex beams

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Beam model

In this paper, we consider a spiral beam with a quadrangular generatrix, where the generatrix is given in a complex parametric form:

$$\Psi\left(\mathbf{r}\,|\,\zeta(t), t\in[0,2\pi]\right) = e^{-r^2}\int_0^{2\pi}\left|\zeta'(t)\right|\exp\left\{2\zeta^*(t)\,r\,e^{i\varphi} - \left|\zeta(t)\right|^2 + i\,\Phi\left(t\,|\,\zeta\right)\right\}dt, \qquad (1)$$

where **r** - 2D vector and $\Phi(t|\zeta) = 2\int_0^t \mathrm{Im}\left\{\zeta^*(\tau)\zeta'(\tau)\right\}d\tau$. The perturbation of a spiral vortex beam means the perturbation of each Laguerre-Gaussian mode in its composition. Each m-th Laguerre-Gaussian mode becomes a source of secondary modes with different radial numbers p and ℓ topological charge of both signs:

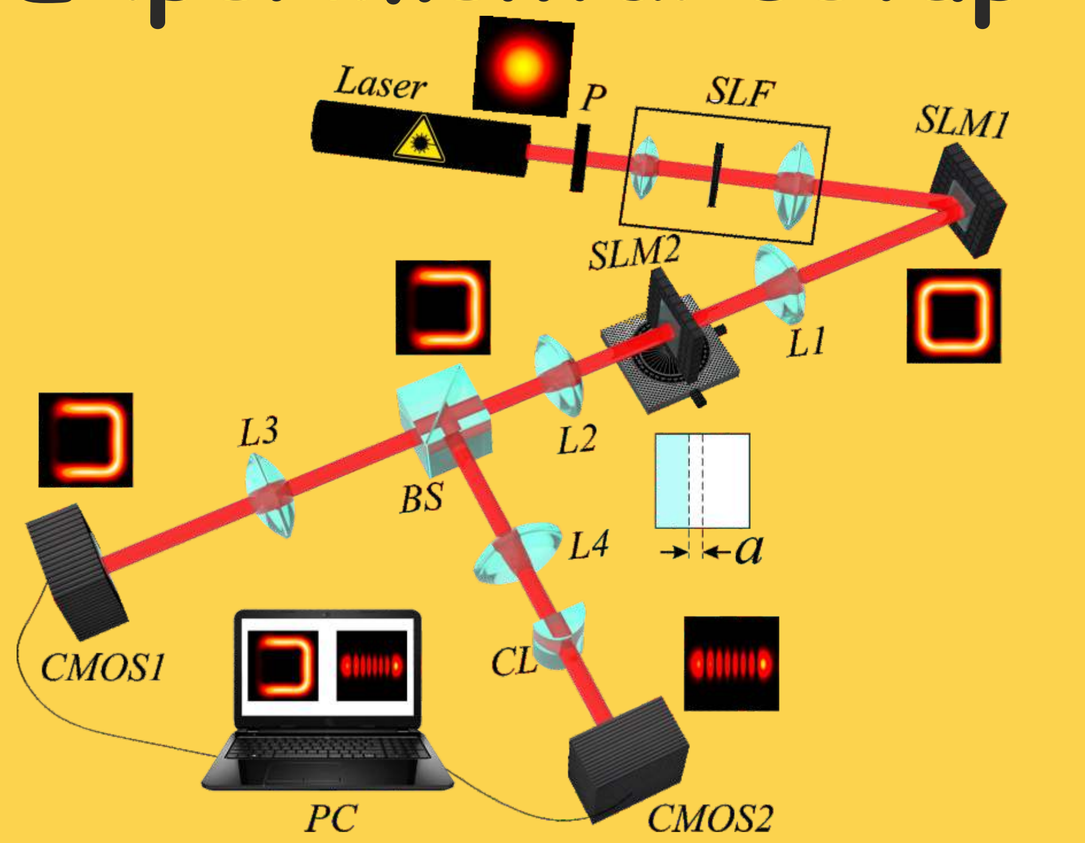
$$\Psi^{(\mathrm{pert})}\left(\mathbf{r}\,|\,\zeta\right) = \sum_{m\geq 0} c_m \sum_{p\geq 0}\sum_{\ell=-\infty}^{\infty} C_{p,\ell}^{(m)}\mathrm{LG}_{p,\ell}(\mathbf{r}) \qquad (2)$$

The amplitudes of the secondary modes depend on the type of external perturbation and are given by the relation

$$C_{p,\ell}^{(m)} = \frac{2^{|\ell|+1}\,p!}{\pi\left(p+|\ell|\right)!}\int_{\mathbb{R}^2} T(\mathbf{r})\mathrm{LG}_{0,m}(\mathbf{r})\mathrm{LG}_{p,\ell}^*(\mathbf{r})\,d^2\mathbf{r} \qquad (3)$$

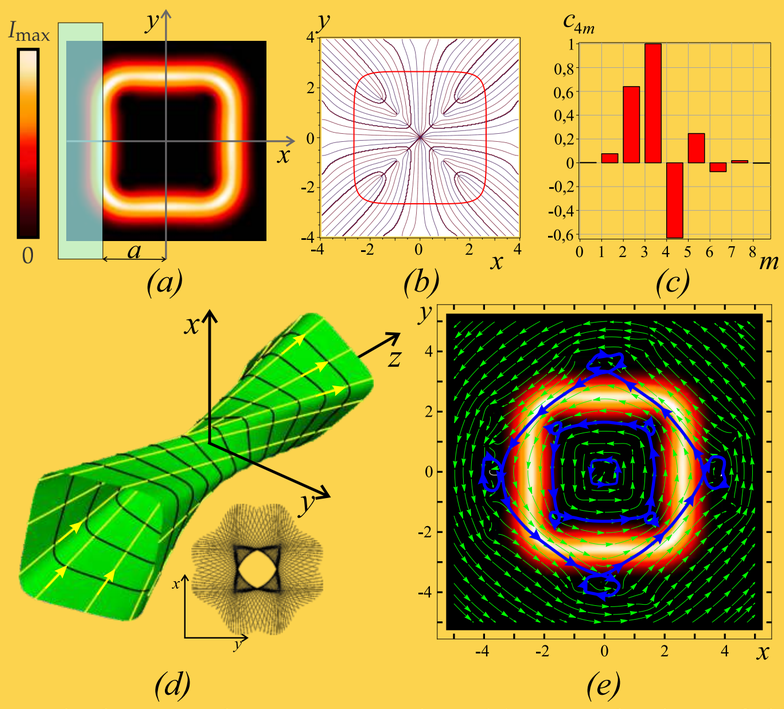
For computer simulation, it is necessary to limit the number of terms in three sums in expression (2). The first sum over the number m is limited by the quantization condition. For a quadrangular beam, it includes only 8 terms, where it is sufficient to use modes with . Restriction of the remaining two sums to p and ℓ requires numerical estimates and comparison with experiment.

Experimental setup

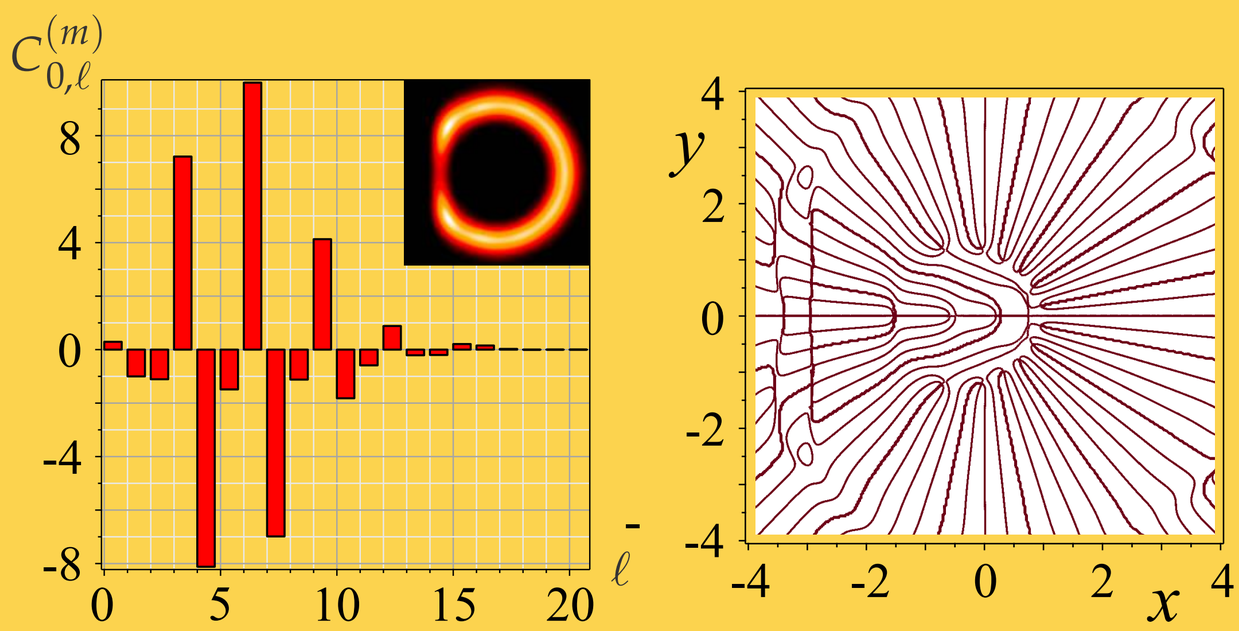


Experimental setup: laser 0.633 μm, *P*-polarizer, SLF – spatial light filter, L1-4 - lens, L3 lens has a focal length about f =20*cm*, CL – cylindrical lens (f =25*cm*), BS – beam splitter, SLM1,2 - spatial light modulator, CMOS1,2 – photodetector, PC - computer.

Experiment

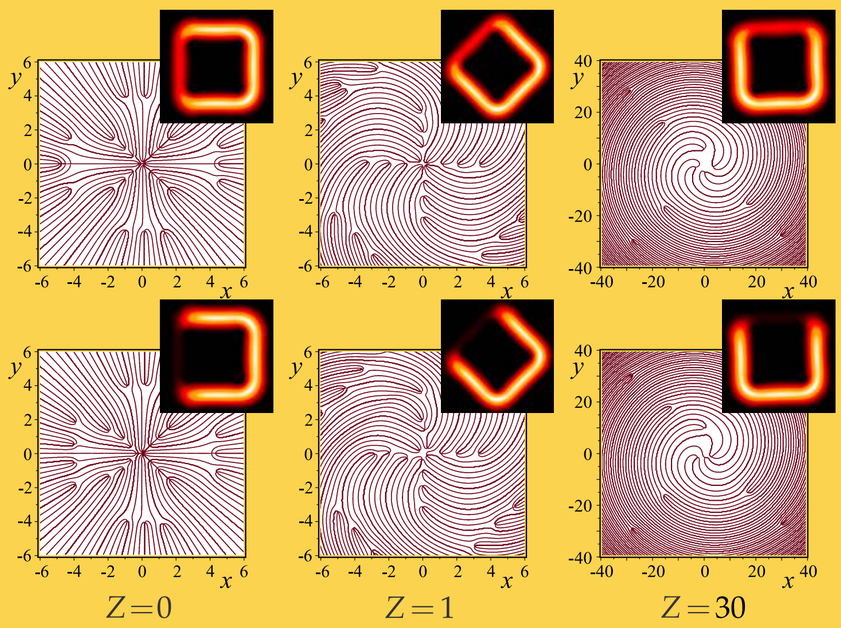


Tetragon spiral vortex beam properties: (a) perturbation of the beam by opaque screen; (b) phase pattern at plane z = 0 while the thick curveoutlines the caustic; (c) experimental mode spectrum; (d) stability surface with ray generatrices; (e) optical currents at the background of the intensity pattern. Solid blue lines are separatrices.



Spectra of secondary Laguerre-Gaussian modes and corresponding amplitude and phase patterns.

Reconstruction



Conclusion

Thus, we have analyzed the process of rearrangement of the structure of a quadrangular spiral beam caused by the action in the form of an opaque screen. At the same time, we used computer simulation methods together with experiment, considering the far zone of diffraction of a spiral beam. We found that an asymmetric perturbation in the form of screening of a part of the beam that does not affect the region of the maximum allows the spiral beam to partially restore its original shape. However, if the optical knife cuts off part of the maximum, then the perturbed spiral beam passes into a new stable state in the far diffraction zone through chains of dislocation reactions.