Simulating the Interaction between Atom Clouds and Laguerre-Gaussian Laser Beams

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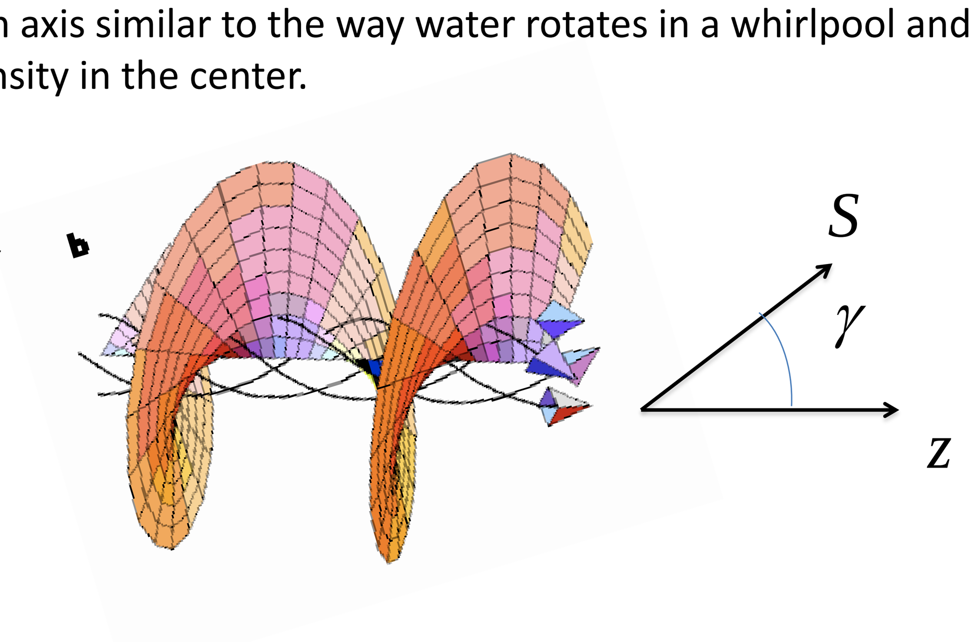
Abstract

Among certain atomic transitions is a class called electric quadrupole transitions, which require properties of the light field that conflict with those of ordinary laser beams. However, certain kinds of beams, including Laguerre Gaussian (LG) beams possessing orbital angular momentum (OAM), satisfy the needed conditions [1,2]. We simulate and experiment with obstructions, aiming to understand how these beams interact with clusters of atoms.

Introduction

The OAM comes about from the unique helical wave front of these LG beams [3]. The energy flow of the light (Poynting vector S) circulates around the beam axis similar to the way water rotates in a whirlpool and thus has no intensity in the center.

$$S = E \times H$$



The OAM is quantified by the "topological charge": the number of times the phase varies from 0 to 2π per wavelength.

The angle S is offset from the beam axis is called the Skew angle, written as

$$\bar{S} = C\frac{z_r}{z_r^{\,2}+z^2}\left(\frac{zr}{z_r^{\,2}+z^2}\hat{r}+\frac{\ell}{kr}\hat{\phi}+\hat{z}\right),$$

reducing to one term when collimated;

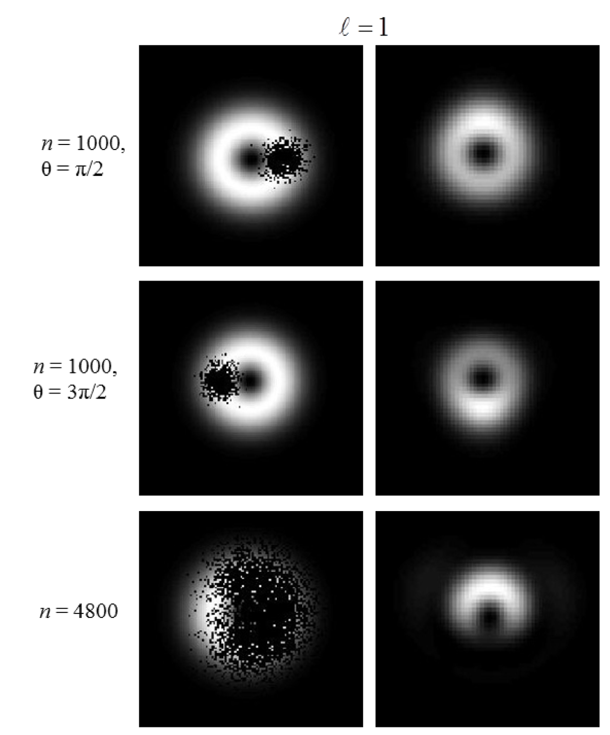
$$\bar{S} = \frac{\ell}{kr}\hat{\phi}.$$

This explains the rotation of intensity profiles we simulate.

Simulation

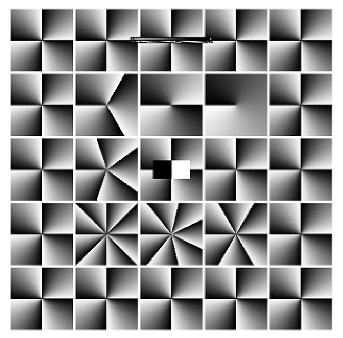
An LG beam with dark spots was computed in MATLAB, where *n* is the number of spots, and we vary the angular position *ϑ*. The beam is propagated into the far field. The dark spots simulating small obstructions rotate clockwise around the beam axis in agreement with the Skew angles and become smeared out as the beam propagates.

We simulate the far field of an LG beam with a charge of 1 using a Fourier transform function, equivalent to inspecting the beam waist after passing through a lens.

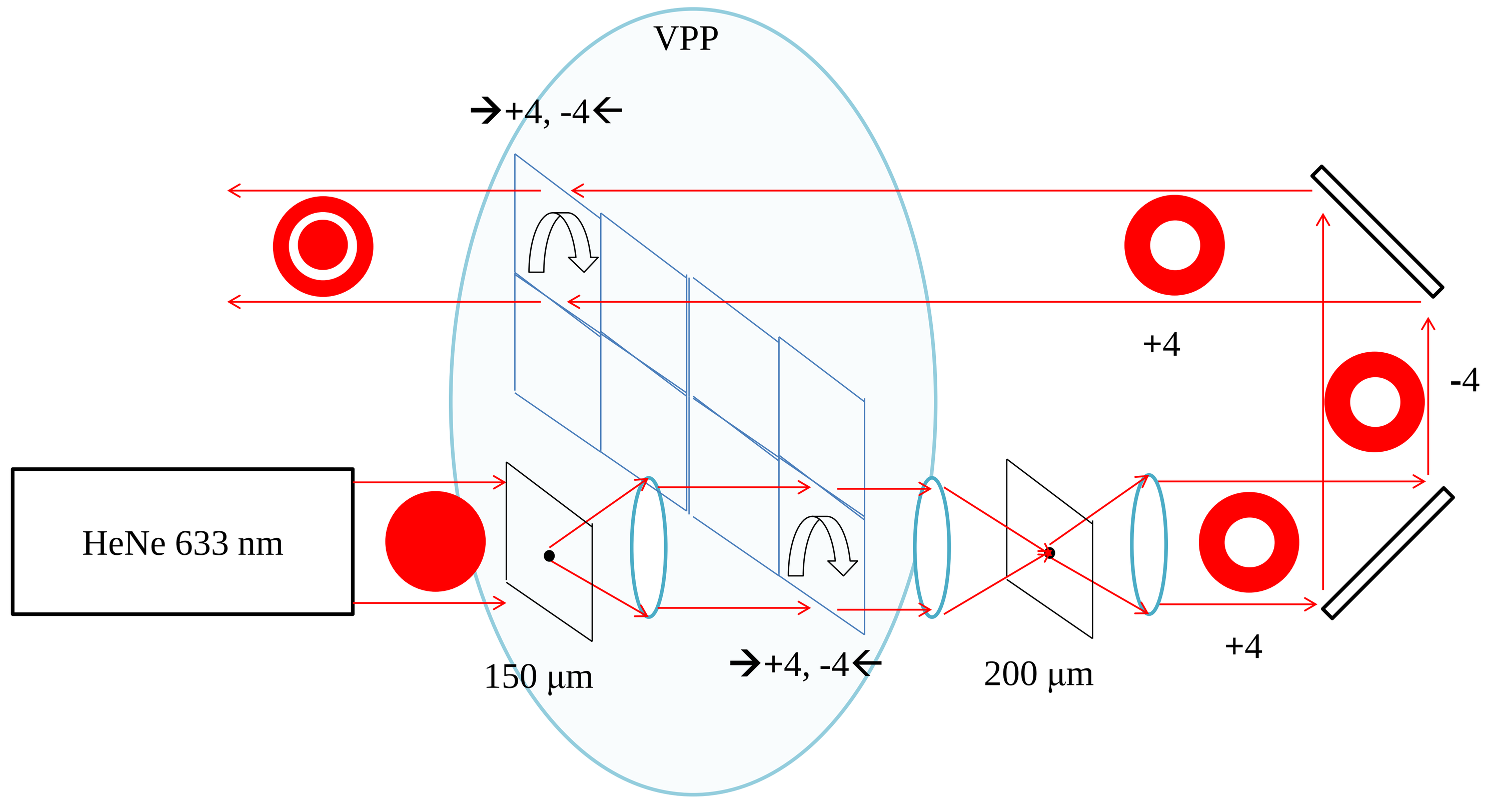


Setup

We generate LG modes using a vortex phase plate (VPP), a film varying in thickness around a center point so as to impose a helical wavefront. Our VPP has a series of such films, capable of generating charges from 1 to 8 (shown below).

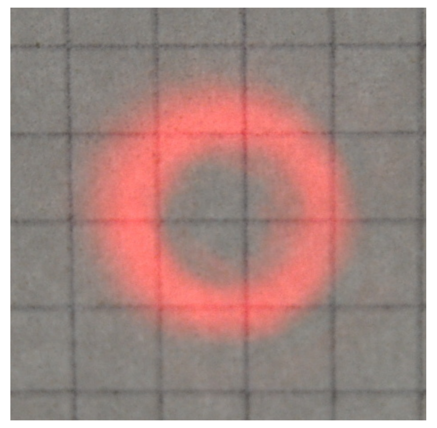


Our setup takes advantage of the fact that an opposite sign charge can be imposed simply by passing through the VPP from the reverse side.

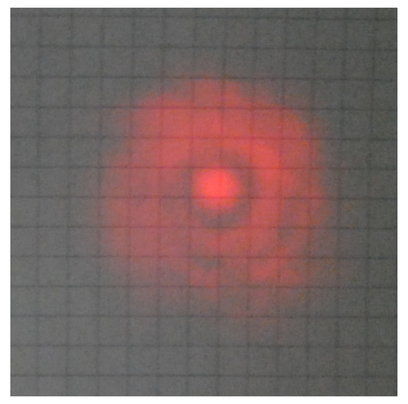


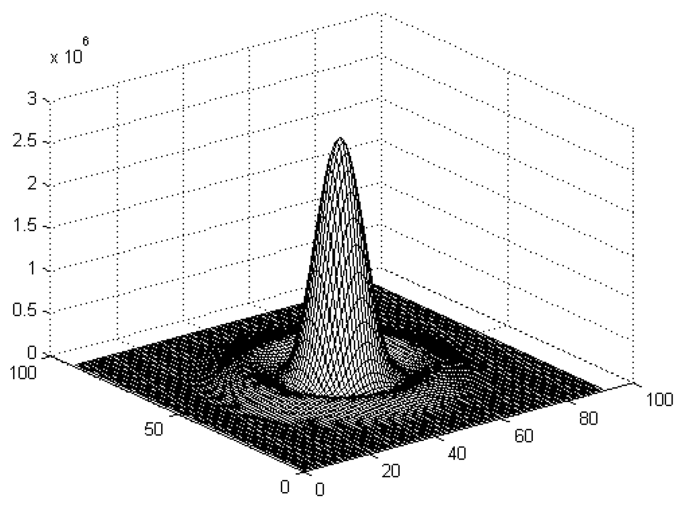
LG beams and Airy Patterns

We obtained high quality vortices after eliminating diffraction artifacts via spatial filtering (200µm pinhole).



We passed a order 4 vortex in the reverse direction to remove the helical phase pattern. In the far field we observed a ring of light with a bright center spot, similar to an Airy pattern. It is in agreement with our simulated far field of the corresponding LG beam with helical phase removed.





Our next experimental step is to observe the changes to a vortex beam as obstructions are placed in its path, considering the size and location of the obstructions, with the goal of experimenting on the atomic level.

References & Acknowledgements

[1] V. E. Lembessis and M. Babiker, "Enhanced Quadrupole Effects for Atoms in Optical Vortices," Phys. Rev. 110, 083002 (2013)

[2] L. Allen, M.W. Beijersbergen, R.J.C. Spreeuw, J.P. Woerdman, "Orbital angular momentum of light and the transformation of Laguerre-Gaussian laser modes," Phys. Rev. A 45 (1992) 8185.

[3] Basil S. Davis, L. Kaplan, and J.H. McGuire, "On Exchange of Orbital Angular Momentum Between Twisted Photons and Atomic Electrons," J. Opt. 15 (2013) 035403

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