Breakup of Ring Beams Carrying Orbital Angular Momentum in Sodium Vapor

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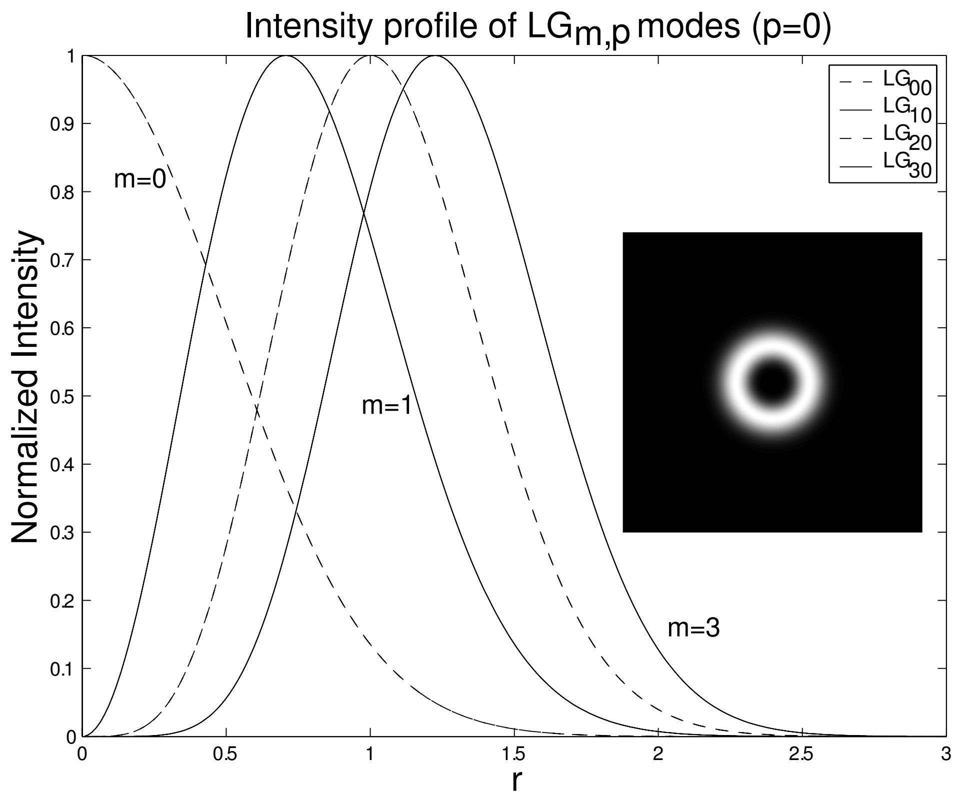
Introduction



- Laguerre-Gaussian beams $(LG_{m,p})$ have ring-shaped intensity pattern and an $e^{im\phi}$ field dependence.
- Carry orbital angular momentum (OAM) of $m\hbar$ per photon

Background

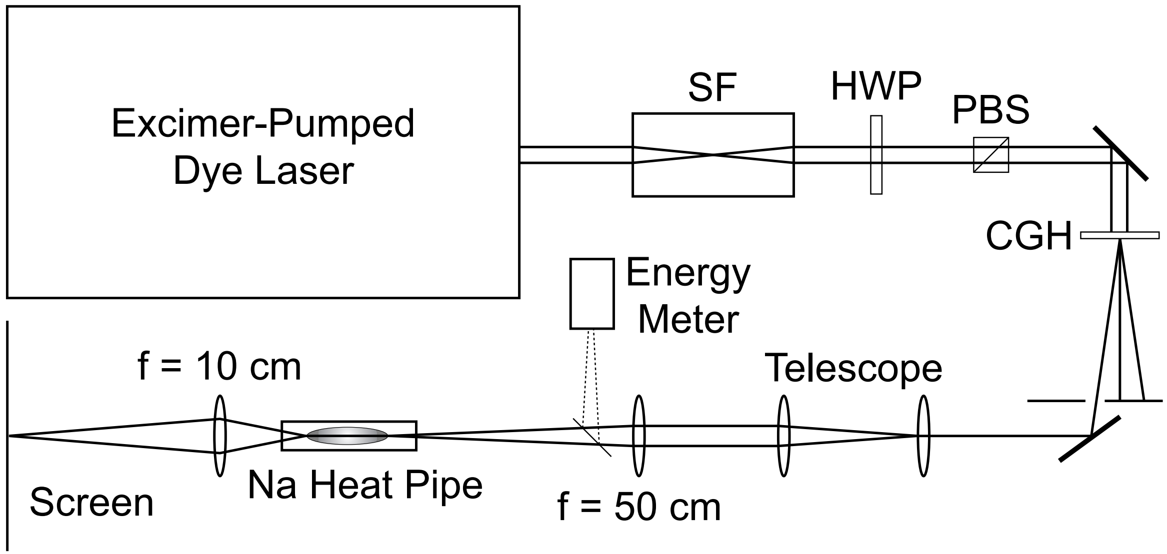
- Rings with $m \leq 2$ studied in different media experimentally
- Possible to stabilize high-power solitons ($m = 1, 2$) in competing cubic-quintic and quadratic medium [1, 2]
- In all nonlinear models, it's believed that any $(2 + 1)$D solitons with $m \geq 3$ are unstable [3]
- Ring-shaped solitons are shown to suffer from strong azimuthal instability in saturable self-focusing media
- Break up into $2m$ filaments and drift away tangentially from the original ring [4]

1. M. Quiroga-Teizeiro and H. Michinel, J. Opt. Soc. Am. B, **14**, 2004 (1997)
2. I. Towers *et al*, Phys. Lett A **288**, 292 (2001)
3. D. Mihalache *et al*, Phys. Rev. E **66**, 016613 (2002)
4. W. J. Firth and D. V. Skryabin, Phys. Rev. Lett., **79**, 2450 (1997)

Motivation

- The objective for doing the experiment was two-fold:
  - To study experimentally the azimuthal modulational instability suffered by ring beams which carry orbital angular momentum in a fully saturable medium (hot, dense sodium vapor).
  - To study the stability of high-power Laguerre-Gaussian modes which carry orbital angular momentum in sodium vapor.

Experimental setup



- FWHM $\sim$ 15 ns
- Conversion efficiency of the computer-generated hologram (CGH) into the first diffraction order $\sim$ 5%
- Beam diameter $\sim$ 50 μm
- Typical number density $\sim 8 \times 10^{14}$ cm^{-3}, effective interaction length ~ 5 cm

Numerical simulation

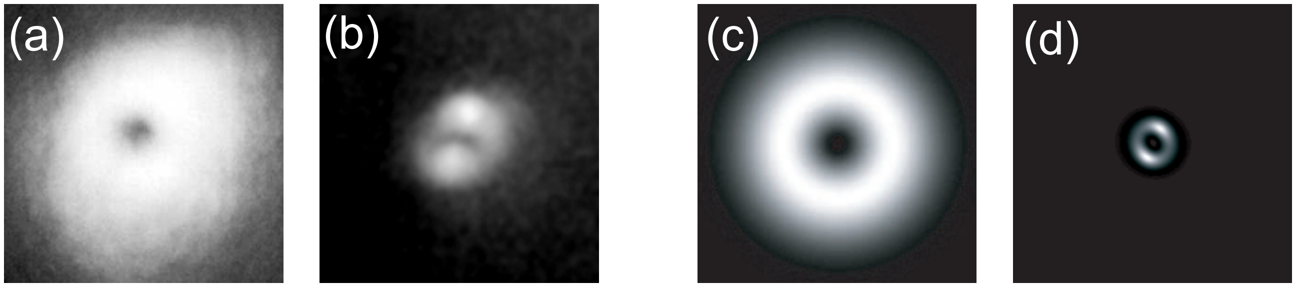
Propagation Equation

$$\frac{\partial A(x,y,z)}{\partial z} = \frac{i}{2k}\nabla_\perp^2 A(x,y,z) + (-\alpha + ik\Delta n)A(x,y,z).$$

- Laser wavelength detuning $\Delta \approx 40 - 47$ GHz from the D_2 resonance line of sodium.
- The susceptibility χ is given by

$$\chi = -\frac{\alpha_0(0)c}{4\pi\omega_{ba}} \frac{\Delta T_2 - i}{1 + \Delta^2 T_2^2 + |E|^2/|E_s^0|^2}$$

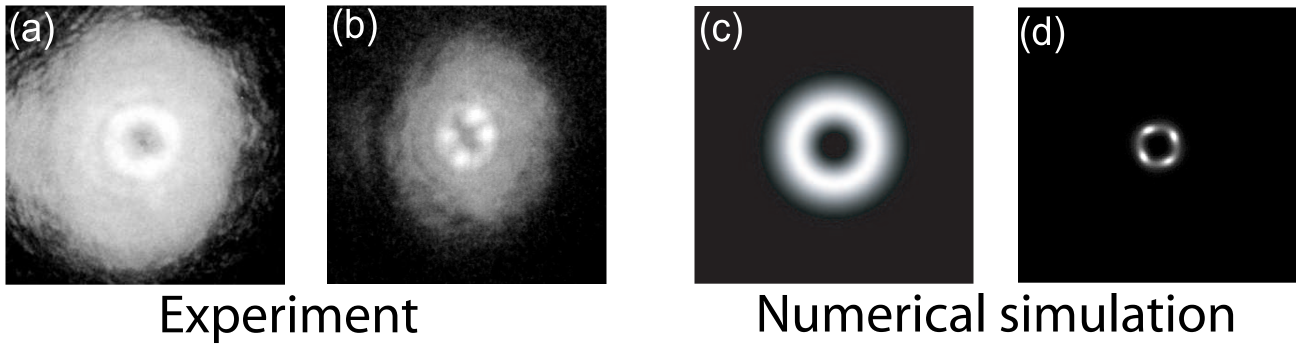
$m = 1$ case



Experiment   Numerical simulation

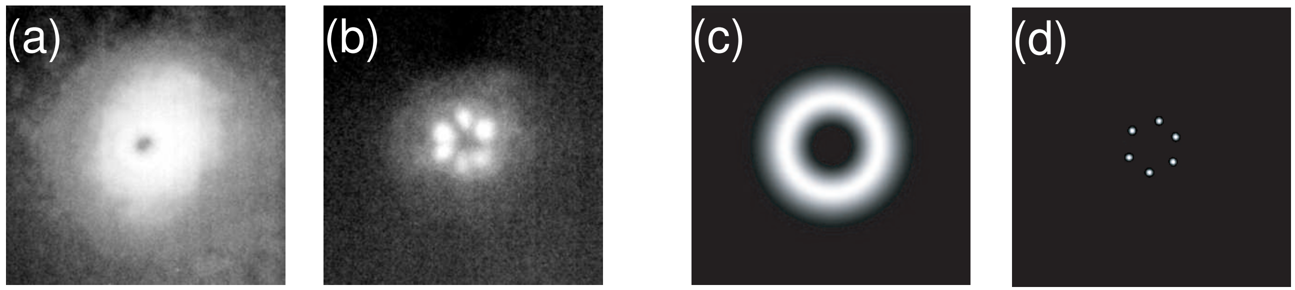
- Input beam $A_{1,0}$
- 40.6 GHz detuned to the blue side of D_2
- Input energy $= 76$ nJ (beam filaments at a relatively low energy due to large nonlinearity)
- Two spots over pulse energies: $65 - 710$ nJ
- No intentional perturbation put on the beam experimentally
- 1.5% random amplitude noise (numerical simulation)

$m = 2$ case



- Input beam $A_{2,0}$
- 46.7 GHz detuning, Input energy $= 234$ nJ
- Input beam breaks up into four filaments
- Result repeatable over pulse energies: $0.2 - 1.3\ \mu$J
- 1.5% random amplitude noise
- Poor beam quality could lead to other than **four** spots

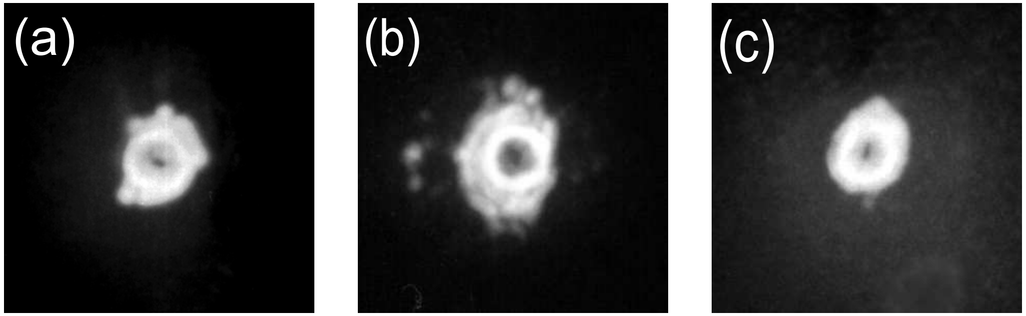
$m = 3$ case



Experiment Numerical simulation

- Input beam $A_{3,0}$
- 46.7 GHz detuned to the blue side (D_2 line)
- Input energy $= 359$ nJ
- Six spots over pulse energies: $0.35 - 2.5$ μJ
- 1.0% random amplitude noise
- Occasional **five** or **seven** spots seen due to misalignment of optics/light scattering off dust on optical surfaces

Higher power beam propagation



- (a) $m = 1$, input energy = 9.1 μJ
- (b) $m = 2$, input energy = 24.1 μJ
- (c) $m = 3$, input energy = 6.63 μJ

- Beam almost completely saturating the nonlinearity, and filamentation suppressed

Conclusion and future work

- Ring beams with orbital angular momentum $m\hbar$ tend to break up into $2m$ filaments
- $2m \pm 1$ filaments seen for imperfect input beam
- Numerical propagation of (randomly) perturbed Laguerre-Gaussian input beams through (Doppler broadened) two level atom gives good agreement with experimental results
- Stable beams observed at higher input power levels
  - Stability of vector solitons carrying equal but opposite OAM through sodium vapor [5]
- Work published in Phys. Rev. Lett **92**, 083902 (2004)

5. M. Bigelow, Q-Han Park, R. Boyd, Phys. Rev. E **66**, 046631 (2002)