Generation of scalar beams fully manipulated in amplitude and wavefront

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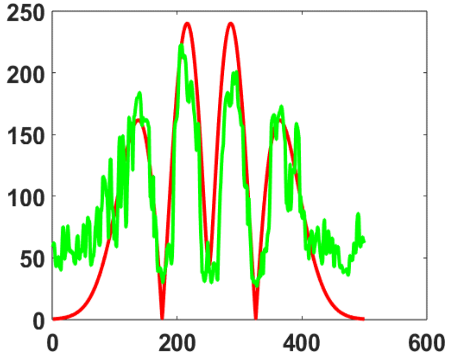
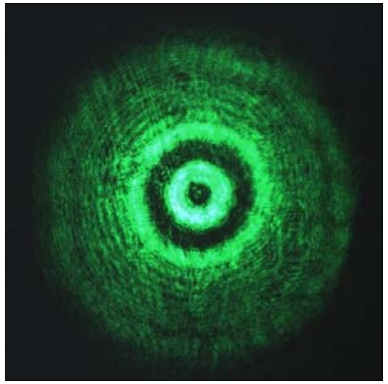
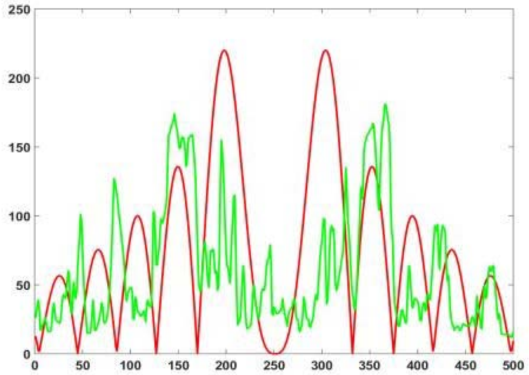


Laguerre-Gaussian Beam

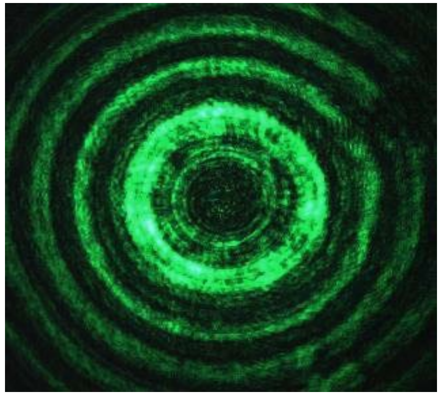


- LG beams are scalar beams varying spatially in amplitude & phase & have phase singularity at centre.
- LG modes with circular symmetry are exact paraxial solutions of Helmholtz wave equations in cylindrical coordinates.
- This $e^{il\varphi}$ gives spiral structure shift to planar wavefront of Gaussian beam, depending on *l* revolutions around propagation
  axis.
- Complex radial amplitude distribution of LG beams propagating along *z* direction can be expressed as,

$$A(x,y,l) = \sqrt{\frac{2p!}{\pi\left(p+|l|\right)!}}\left(\frac{1}{w(z)}\right)\left[\frac{r\sqrt{2}}{w(z)}\right]^{|l|} \exp\left[\frac{-r^2}{w^2(z)}\right] L_p^{|l|}\left[\frac{2r^2}{w^2(z)}\right]$$



Bessel-Gaussian Beam



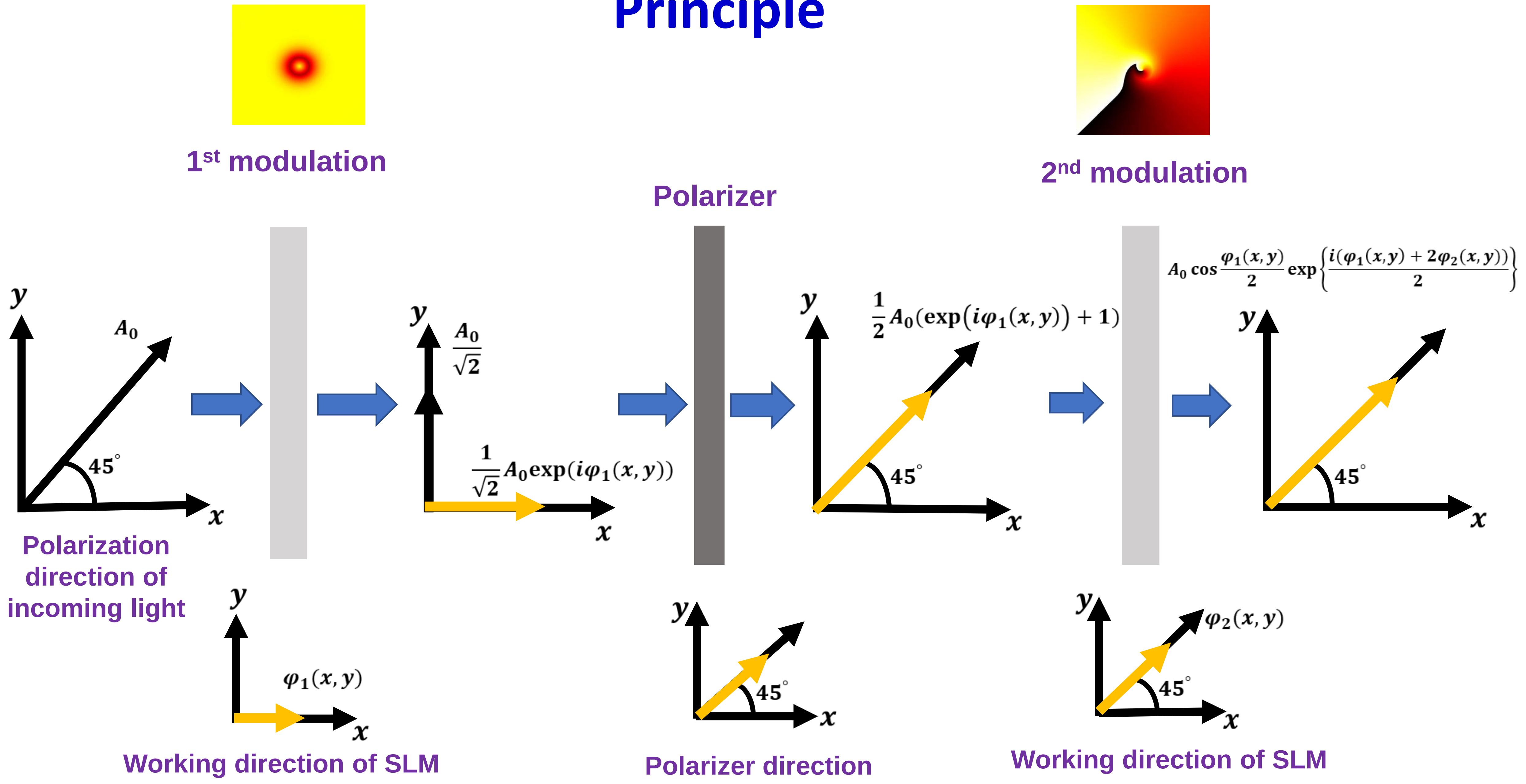
- **In 1987, Bessel beams were first studied by Durnin.**
- **Bessel beams carry OAM & are non-diffractive beams.**
- **They are well-known for reconstructing itself after encountering an obstacle.**
- **They are mainly controlled & characterized by radial wave vector k_r & azimuthal index *l*.**
- **Complex amplitude of *l*-order Bessel-Gaussian beam are exact solutions to Helmholtz wave equation in cylindrical symmetry. It is expressed as,**

$$E(r,\varphi,z) = A_l J_l(k_r r)\exp(ik_z z)\exp(il\varphi)\exp\left(\frac{-r^2}{w_0^2}\right)$$

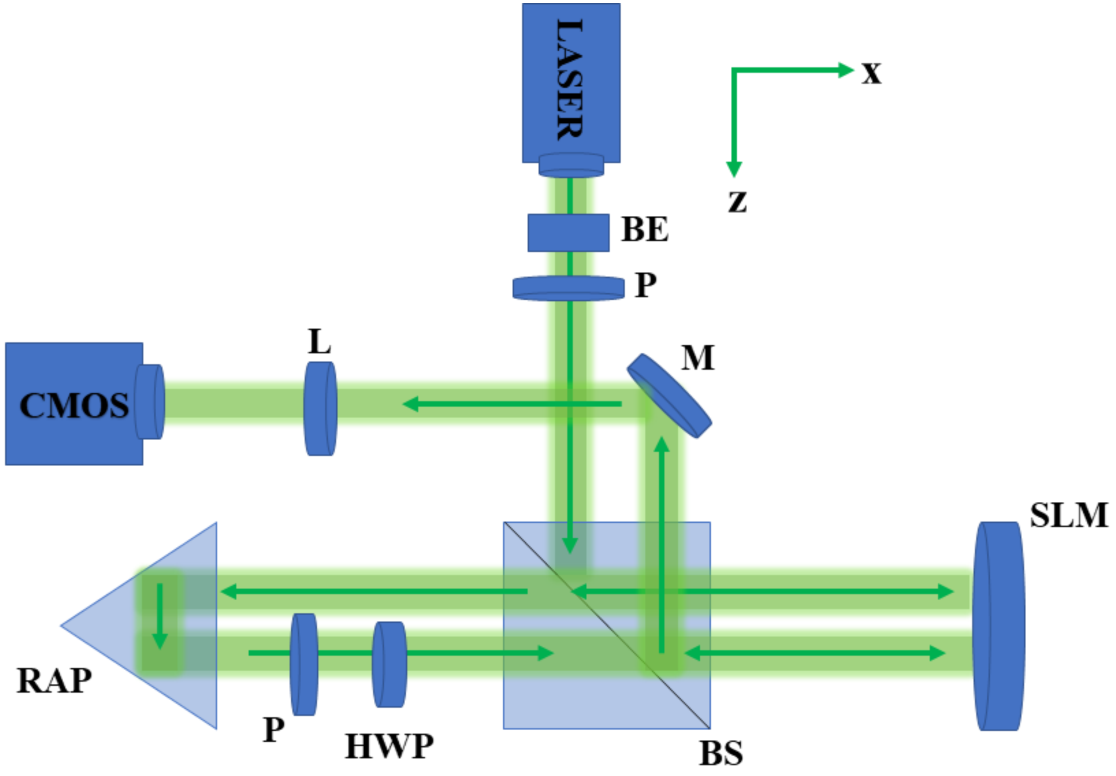
where $J_l(x)$ is Bessel function of order *l*, *k* is wave vector, k_t, k_z are transverse & longitudinal wave vector components, respectively.

[J. Durnin, “Exact solutions for nondiffracting beams. I. The scalar theory,” J. Opt. Soc. Am. A 4 (1987) 651]

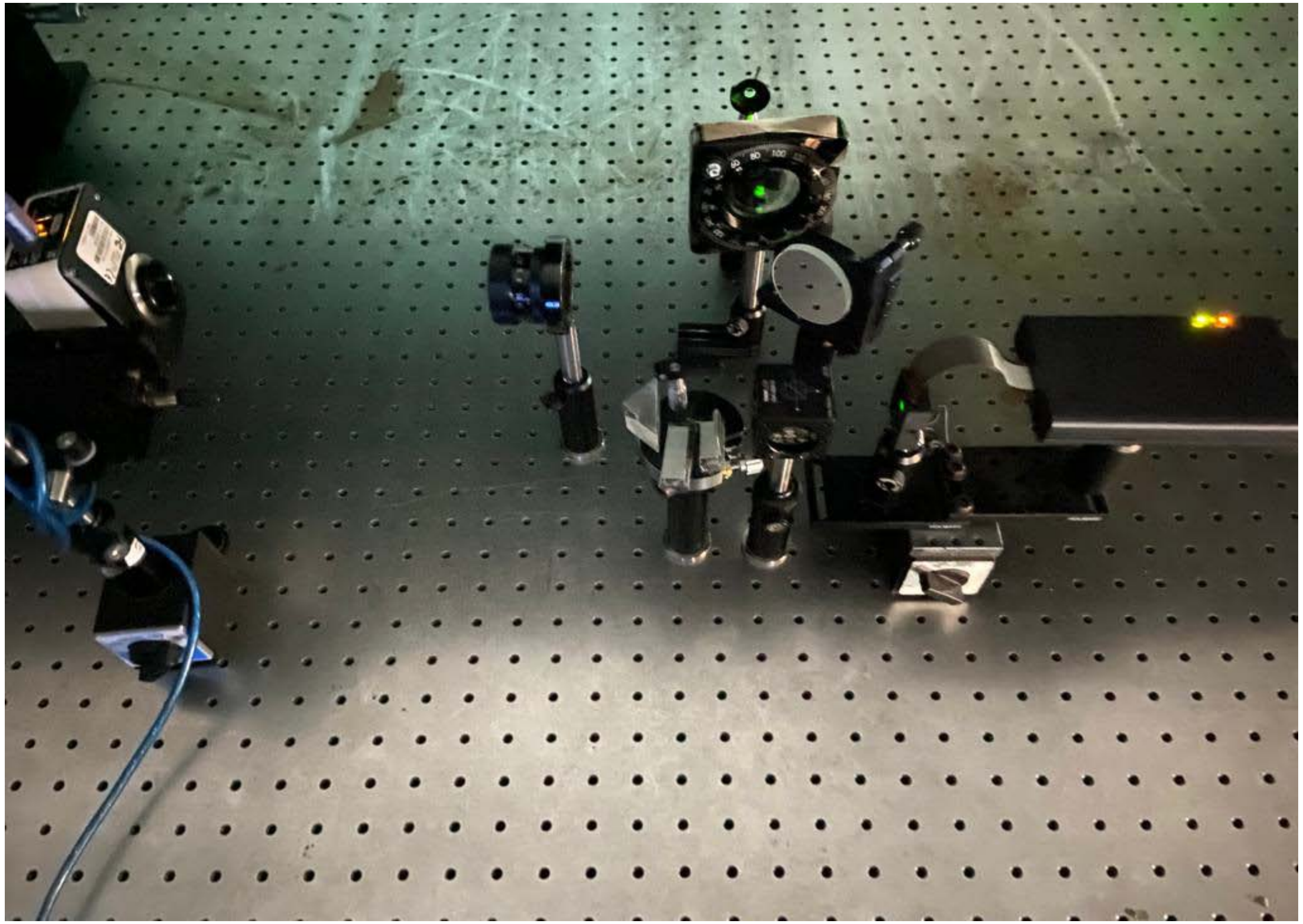
Principle


1st modulation
2nd modulation
Polarizer
y
x
A_0
45°
Polarization direction of incoming light
$\frac{A_0}{\sqrt{2}}$
$\frac{1}{\sqrt{2}}A_0\exp(i\varphi_1(x,y))$
$\frac{1}{2}A_0\left(\exp\left(i\varphi_1(x,y)\right)+1\right)$
$A_0\cos\frac{\varphi_1(x,y)}{2}\exp\left\{\frac{i(\varphi_1(x,y)+2\varphi_2(x,y))}{2}\right\}$
$\varphi_1(x,y)$
Working direction of SLM
Polarizer direction
$\varphi_2(x,y)$
Working direction of SLM

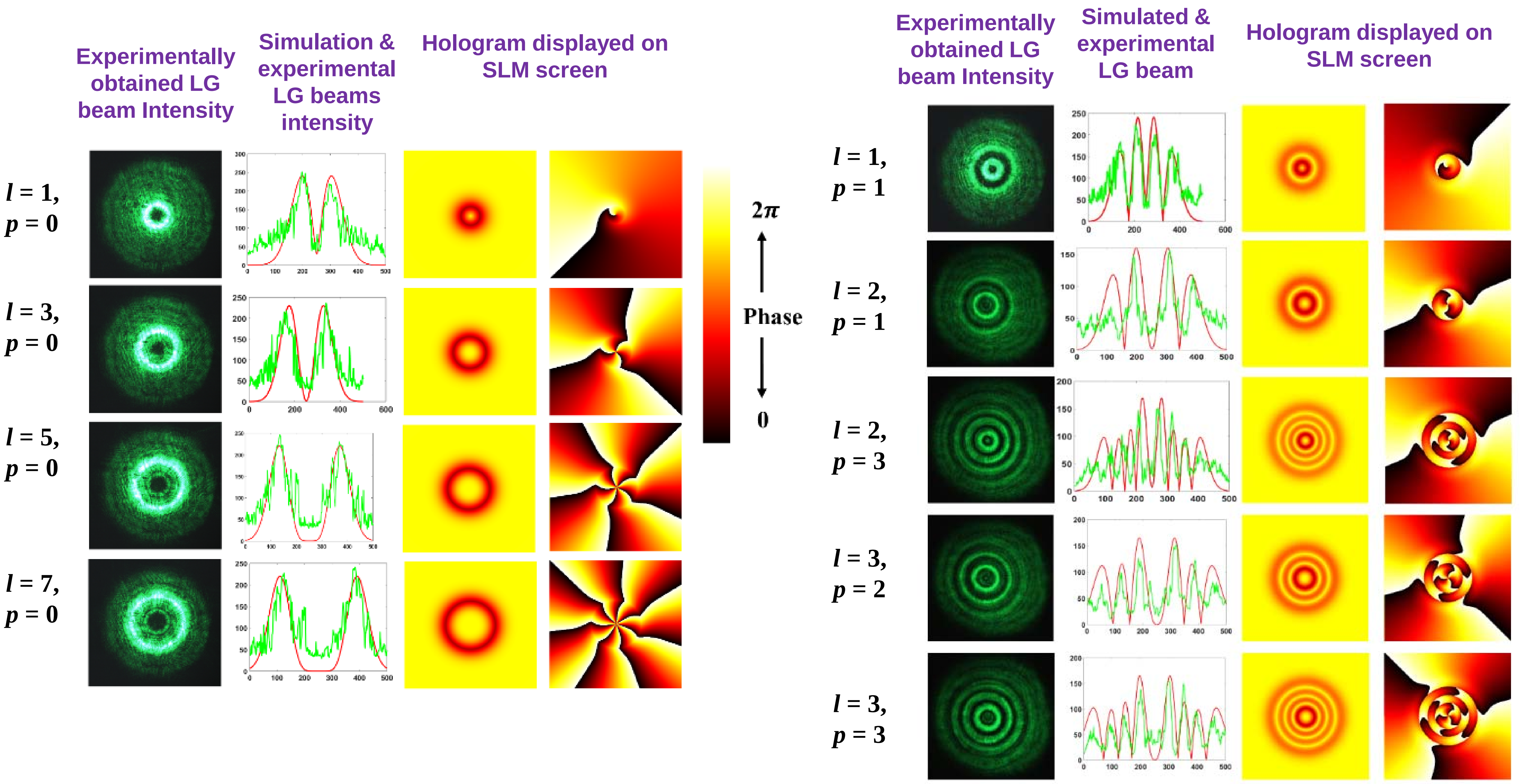
Experimental set-up for amplitude & wavefront modulated Laguerre-Gaussian & Bessel beams



Schematic of experimental set-up

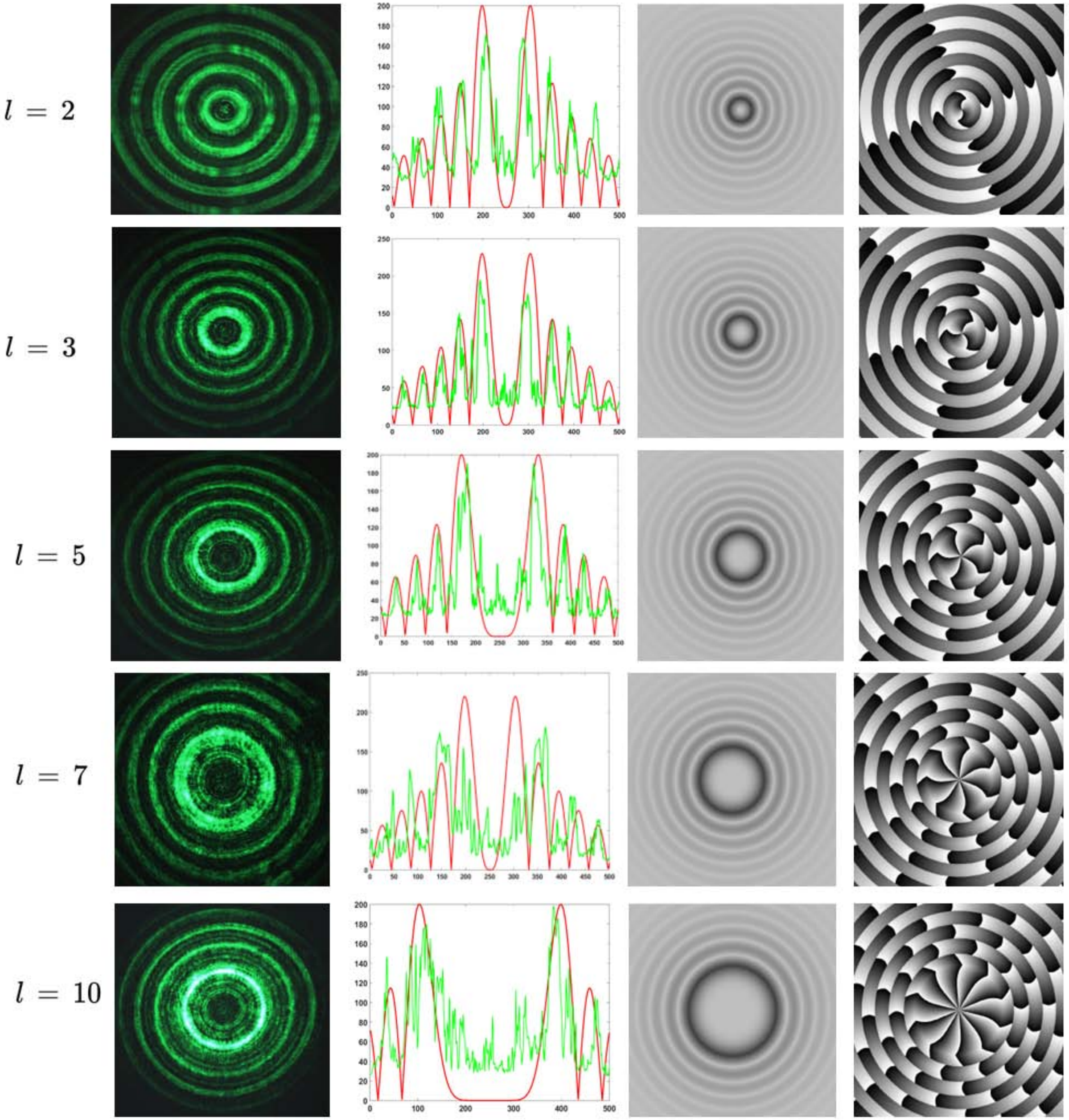


Experimental set-up used to generate scalar beams



Experimentally obtained LG beam Intensity
Simulation & experimental LG beams intensity
Hologram displayed on SLM screen
l = 1, p = 0
l = 3, p = 0
l = 5, p = 0
l = 7, p = 0
2π
Phase
0
Experimentally obtained LG beam Intensity
Simulated & experimental LG beam
Hologram displayed on SLM screen
l = 1, p = 1
l = 2, p = 1
l = 2, p = 3
l = 3, p = 2
l = 3, p = 3

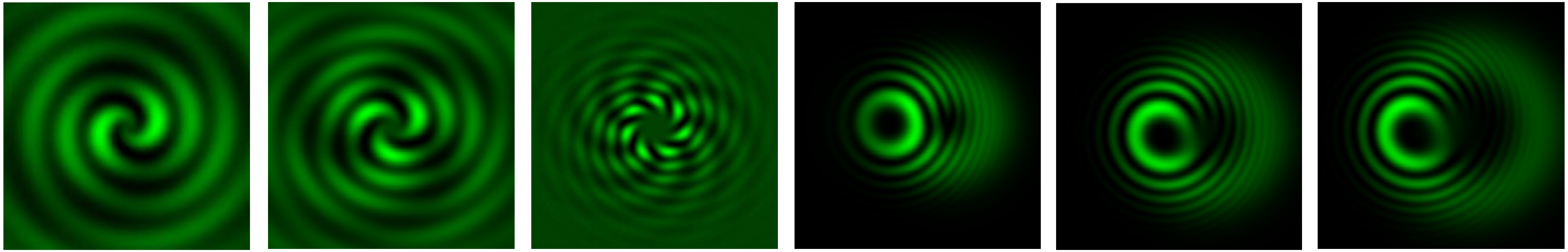
Experimentally obtained Bessel beam Intensity | **Simulated & experimental Bessel beams** | **Hologram displayed on SLM screen**



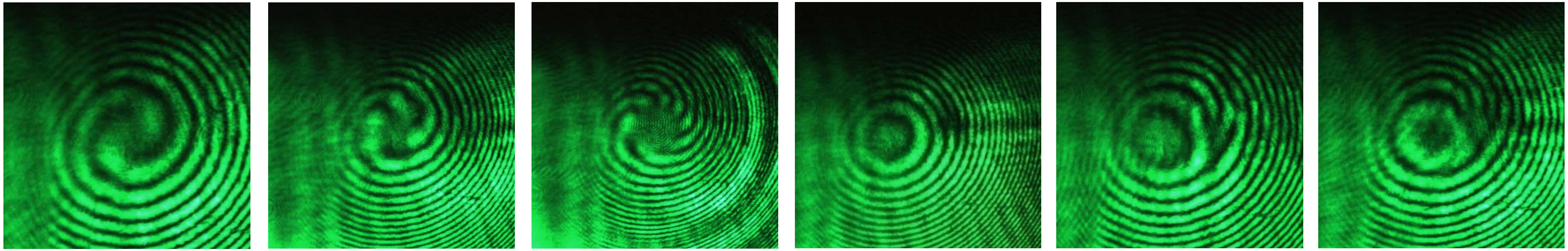
Simulation & Experimental Results: Wavefront Modulation

Bessel beam with Gaussian beam

Laguerre beam with Gaussian beam



Simulation results



l **= 2**	***l*** **= 3**	***l*** **= 7**	***l*** **= 1**	***l*** **= 2**	***l*** **= 3**

Experimental results

References

1. J. Durnin, “Exact solutions for nondiffracting beams. I. The scalar theory,” J. Opt. Soc. Am. A 4, 651-654 (1987)
2. Y. Shen, X. Wang, Z. Xie, C. Min, X. Fu, Q. Liu, M. Gong, and X. Yuan, "Optical vortices 30 years on: OAM manipulation from topological charge to multiple singularities," Light Sci. Appl. 8, 90 (2019).
3. P. G. Martinez, D. Marco, J. L. M. Fuentes, M. D. M. S. Lopez, and I. Moreno, “Efficient on-axis SLM engineering of optical vector modes,” Opt. Laser Eng. 125, 105859 (2020).
4. P. Kumar, S. K. Pal, N. K. Nishchal, and P. Senthilkumaran, “Non-interferometric technique to realize vector beams embedded with polarization singularities,” J. Opt. Soc. Am. A 37, 1043-1052 (2020).
5. L. Zhu and J. Wang, “Arbitrary manipulation of spatial amplitude and phase using phase-only spatial light modulators,” Sci. Rep. 95, 7441 (2014).

Acknowledgements

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