Manipulating Structured Light

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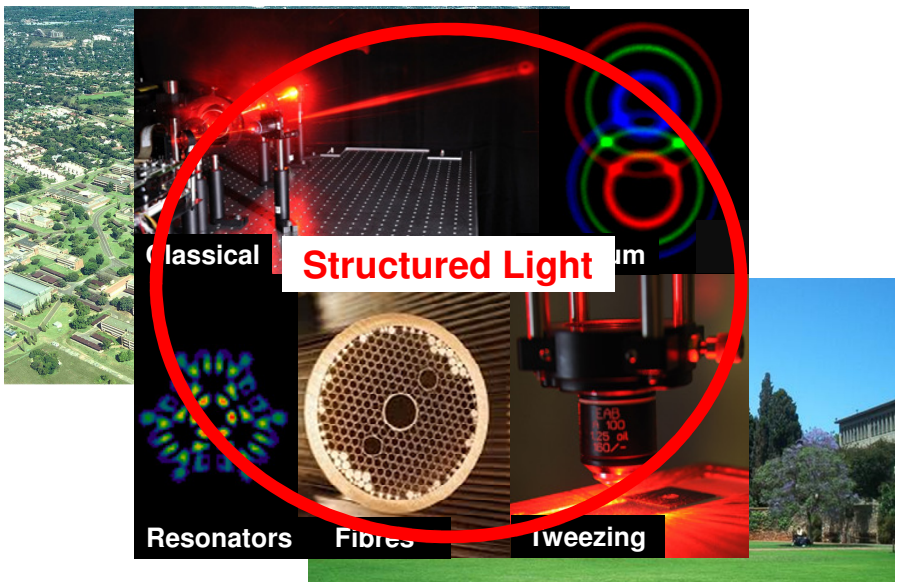
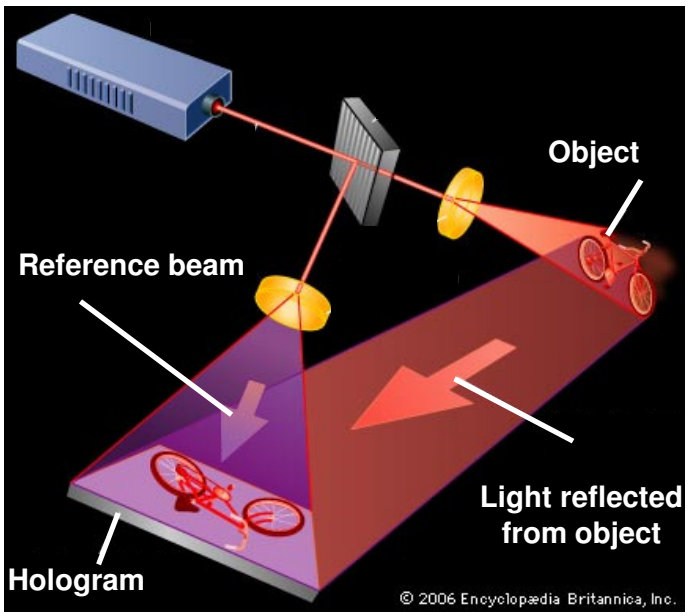
The City College of New York, New York, USA
5 July 2016

our future through science

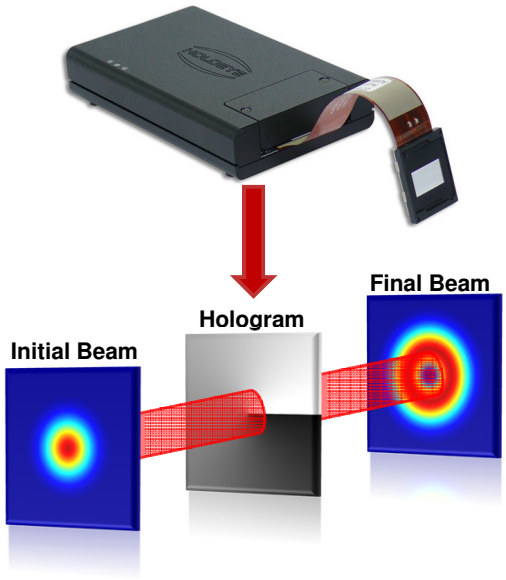
We are tied together by *Structured Light*

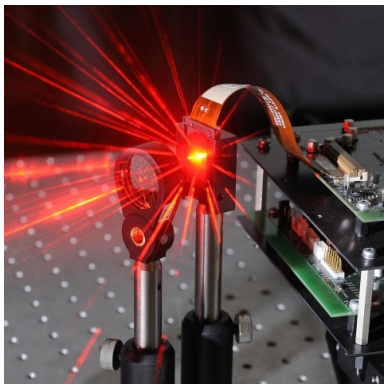


Conventional holography requires that both the laser and object physically exist

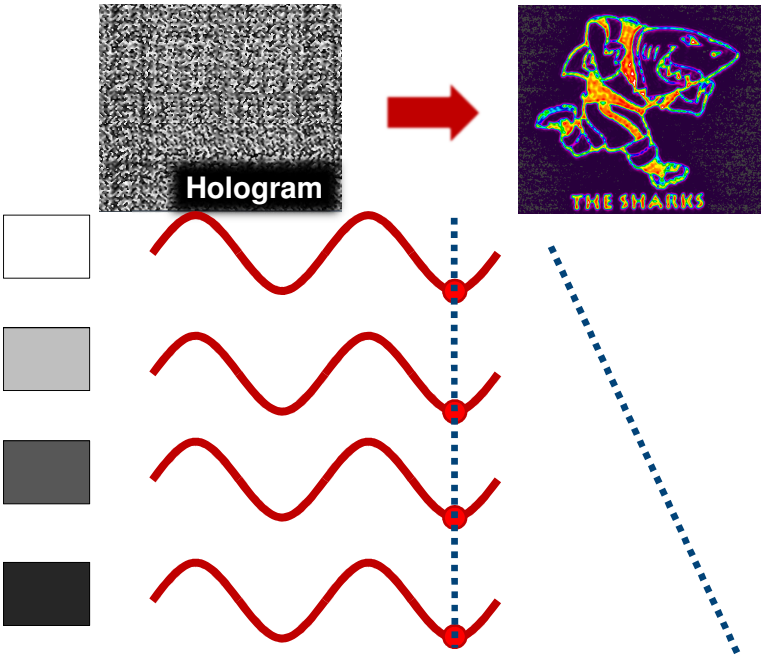


SLMs allow us to dynamical change the spatial profile of an optical field

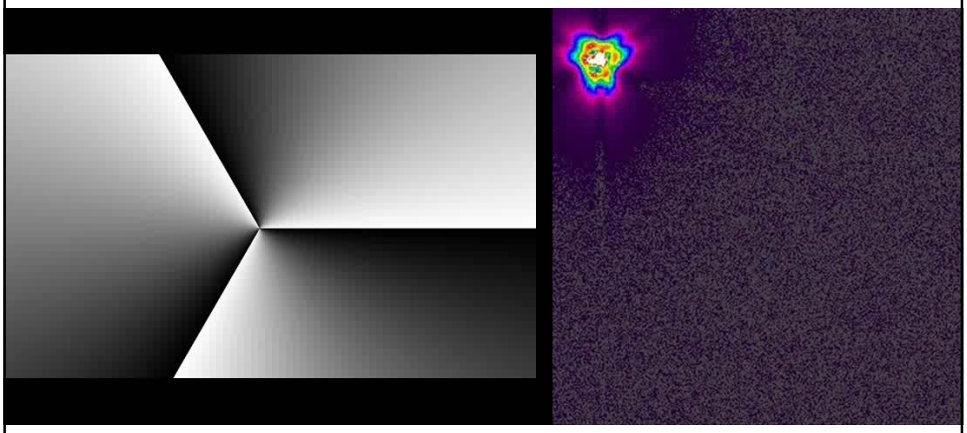




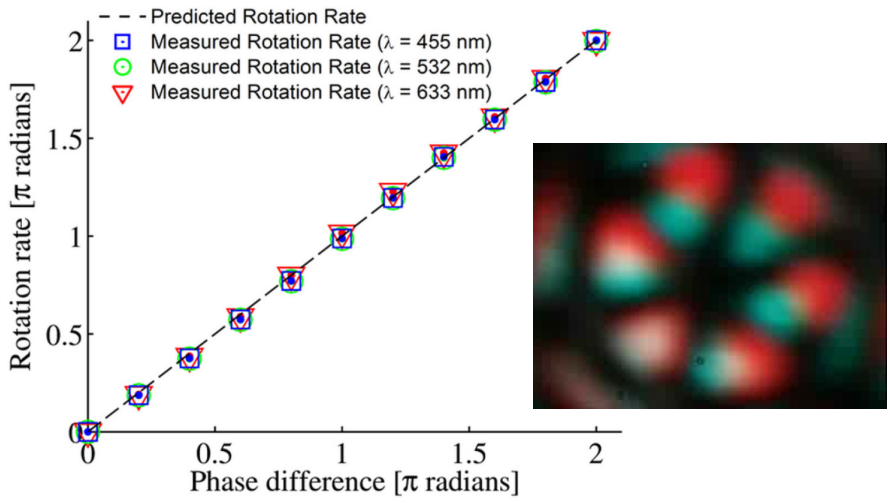
The phase shift is dependant on the grayscale of the hologram



These holograms can be refreshed at a rate of 60 Hz

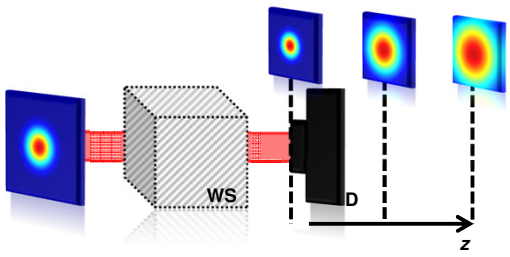


… they can even be wavelength independent

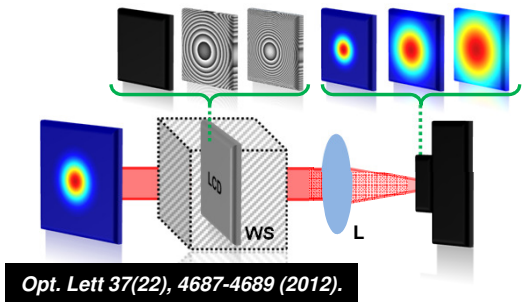


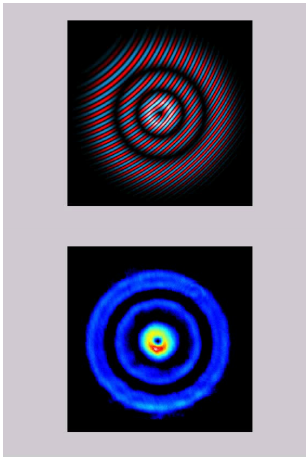
Opt. Express 22, 13870 (2014).

… and mimic free space propagation



$$U(\mathbf{r},z) = \mathcal{F}^{-1}[\mathcal{F}[U(\mathbf{r},0)]\exp(ik_z z)]$$

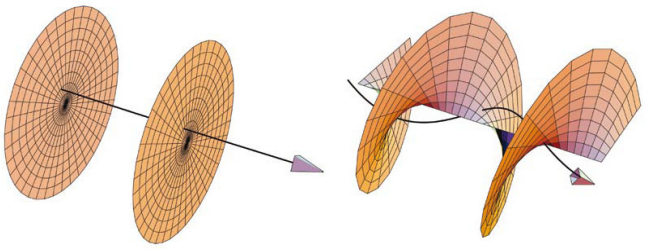




Opt. Lett 37(22), 4687-4689 (2012).

Our favorite structured light field – has a helical wavefront

$u(r,\theta,z) = u_0(r,z)\exp(il\theta)$

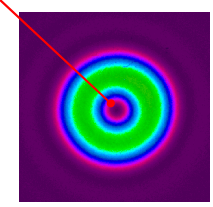


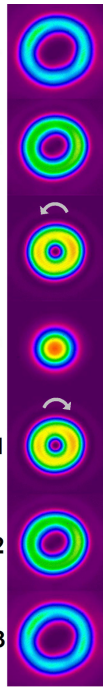
GAUSSIAN BEAM

LAGUERRE-GAUSSIAN BEAM

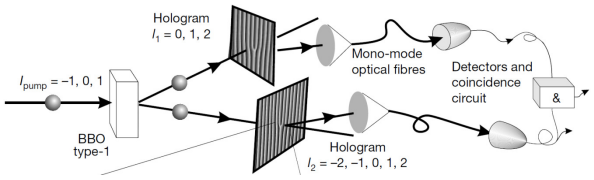
PHASE SINGULARITY

ZERO INTENSITY

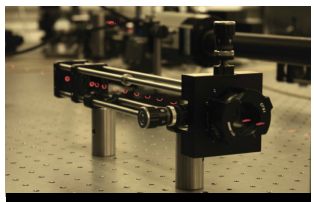




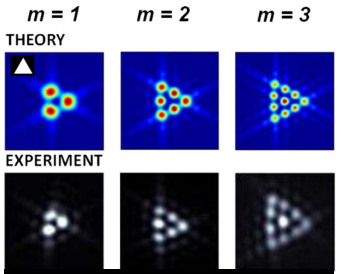
Many unique measurement techniques are available for structured light



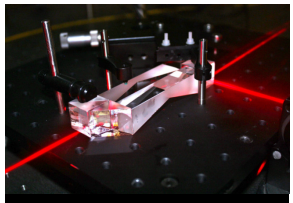
Nature 412, 314-316 (2001).



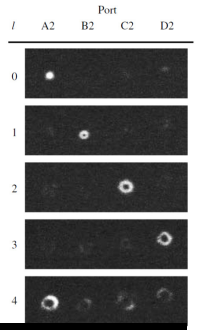
PRL 105(15), 153601 (2010).



PRL 105(5), 053904 (2010).



NJP 13, 093014 (2011).



PRL 88(25), 257901 (2002).

Modal decomposition expands an unknown field into an orthonormal basis to find the unknown coefficients

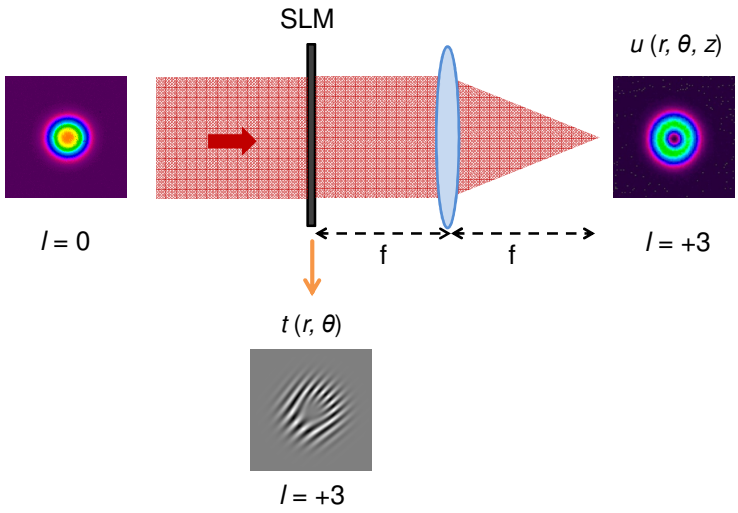
$$U = \sum_{n=0}^{\infty} c_n \Psi_n$$

$$c_n = \rho_n \exp(i\phi_n) = \langle U, \Psi_n \rangle = \int\int U \Psi_n^* dxdy$$

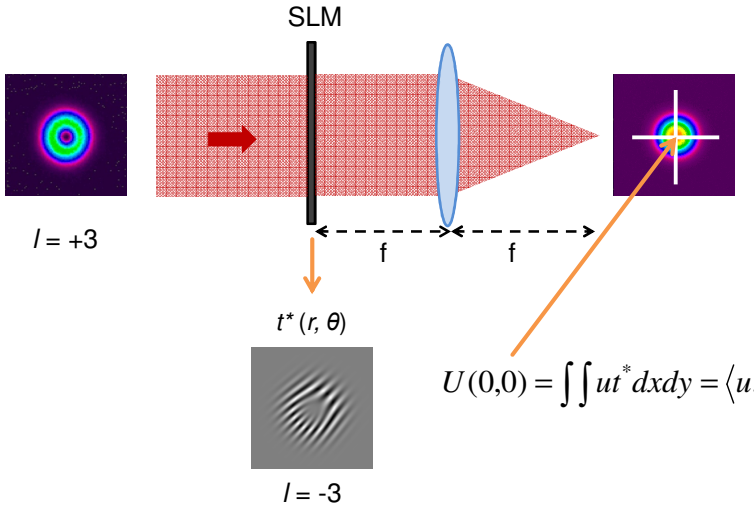
Perform this integral

Create these modes

We know how to create any laser beam with digital holograms

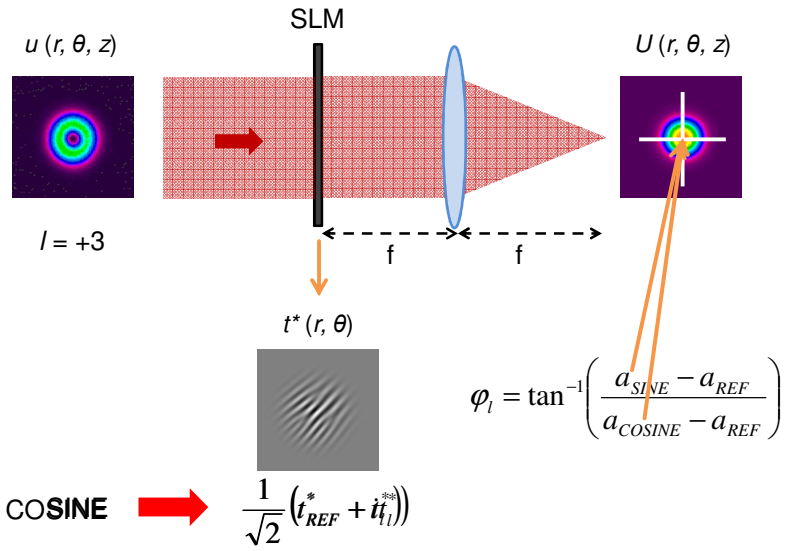


In reverse: we can pass an unknown field through a match filter to find the inner product

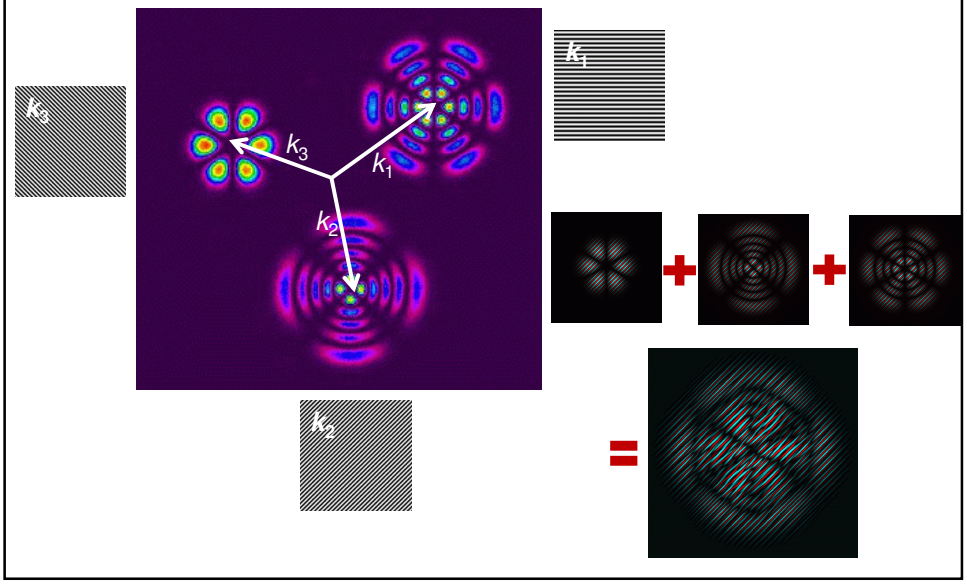


$$U(0,0) = \int\int ut^* dxdy = \langle u, t \rangle$$

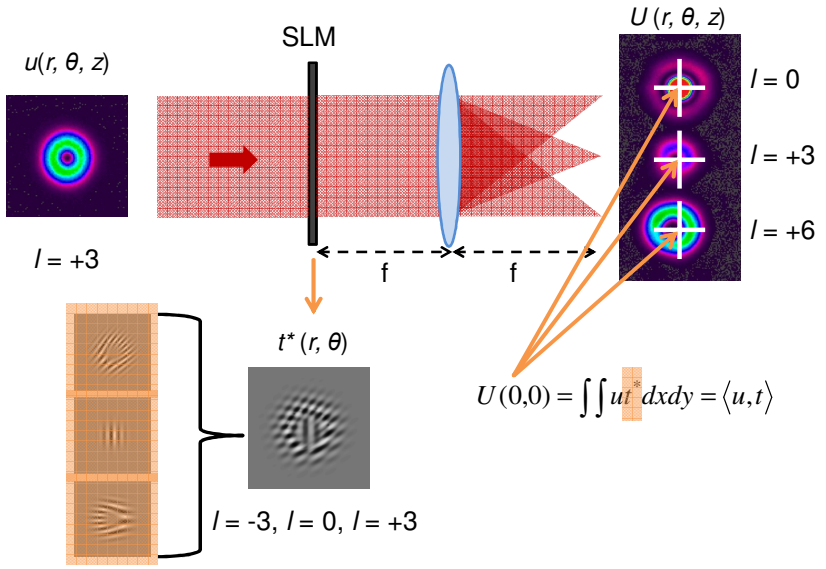
Appropriate match filters can also be created to find the modal phases



The spatial carrier frequency of each mode shifts it to a desired location in the Fourier plane



Multiplexing allows many measurements at once



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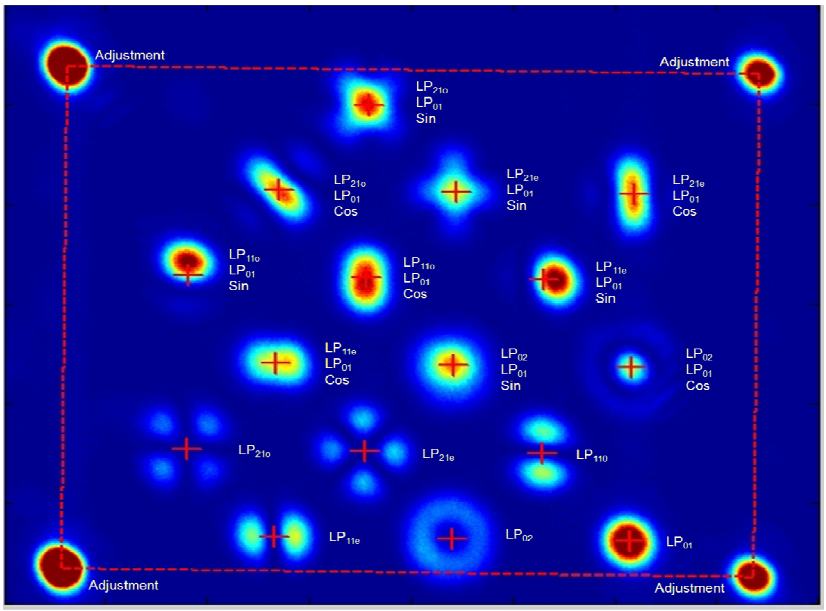
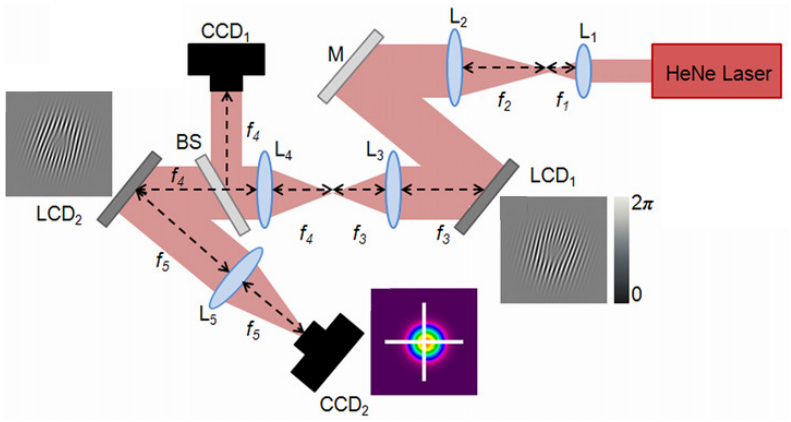
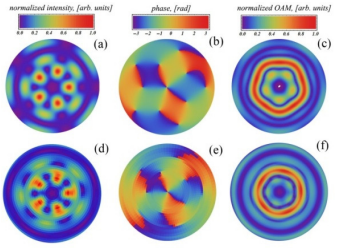


The measurement requires only a SLM and a lens

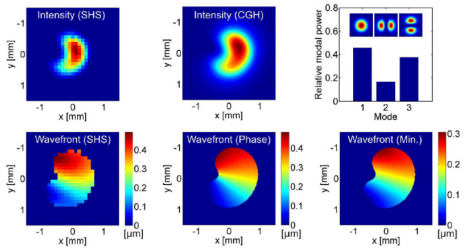


Adv. Opt. & Photon. 8(2), 200-227 (2016).

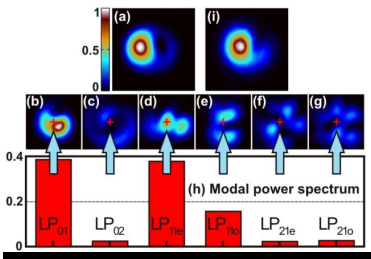
We can accurately reconstruct all the physical properties of the unknown field



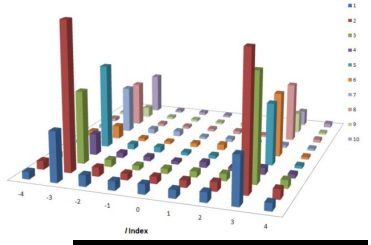
NJP 15, 073025 (2013)



App. Opt. 52, 5312 (2013); Opt. Lett. 38, 3429 (2013)



Opt. Lett. 40, 435 (2015); Opt. Lett. 39, 704 (2014)

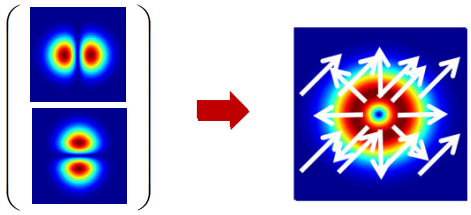


Opt. Exp. 22, 17553 (2014)
Opt. Exp. 21,165 (2013)

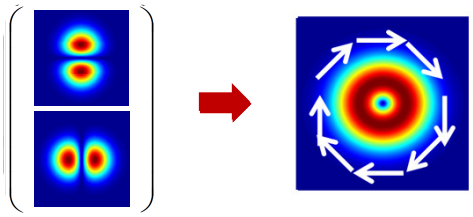
Spatially inhomogeneous polarization states are referred to as cylindrical vector beams which include radial and azimuthal polarization

VECTOR

$$\begin{pmatrix} U_1 \\ U_2 \end{pmatrix}$$



$$\begin{pmatrix} U_2 \\ U_1 \end{pmatrix}$$



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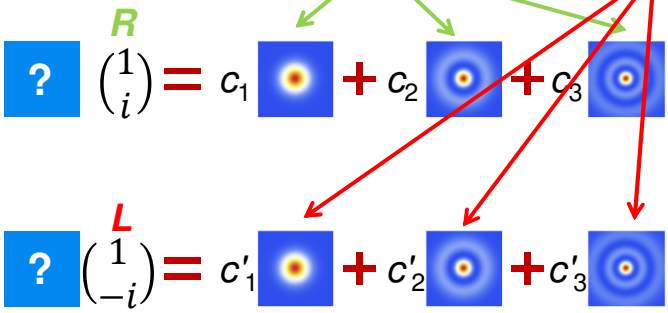
Perform this integral

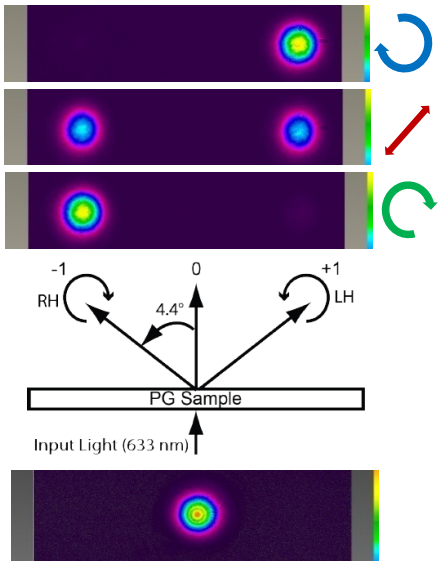
Create these modes

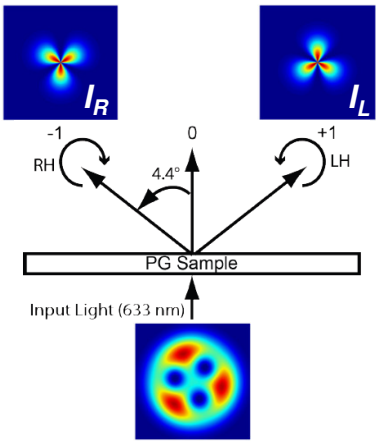
Modal decomposition expands an unknown field into an orthonormal basis to find the unknown coefficients

$$U(r,\phi).\hat{e} = \sum_{n=0}^{\infty} c_n \Psi_n \begin{pmatrix} 1 \\ i \end{pmatrix} + \sum_{n=0}^{\infty} c'_n \Psi'_n \begin{pmatrix} 1 \\ -i \end{pmatrix}$$

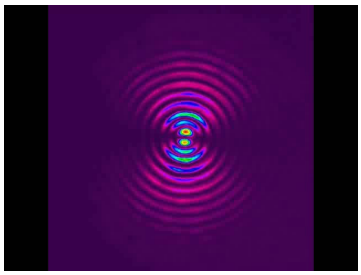


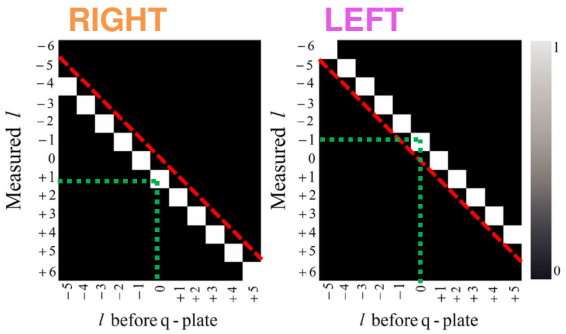
We can separate orthogonal polarization using a polarisation grating

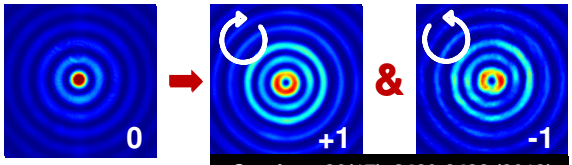




We can both create and measure vector fields

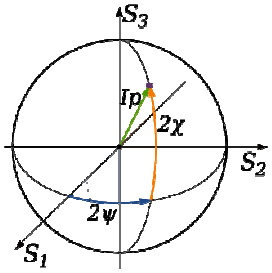






Opt. Lett. 38(17), 3429-3432 (2013)

The phase difference between the horizontal and vertical components of a field can be extracted via Stokes polarimetry



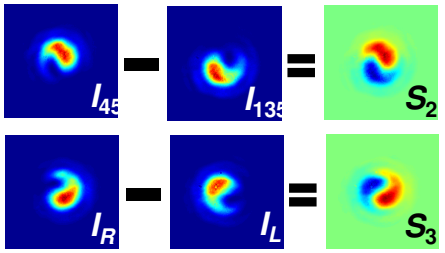
$$S_0(r,\phi) = |U_{\leftrightarrow}(r,\phi)|^2 + |U_{\updownarrow}(r,\phi)|^2 \quad = I_{0^\circ} + I_{90^\circ}$$

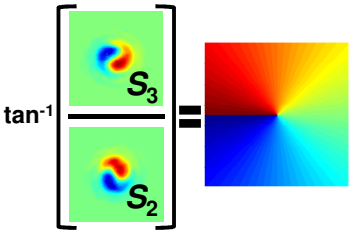
$$S_1(r,\phi) = |U_{\leftrightarrow}(r,\phi)|^2 - |U_{\updownarrow}(r,\phi)|^2 \quad = I_{0^\circ} - I_{90^\circ}$$

$$S_2(r,\phi) = 2|U_{\leftrightarrow}(r,\phi)||U_{\updownarrow}(r,\phi)|\cos(\delta(r,\phi)) \quad = I_{45^\circ} - I_{135^\circ}$$

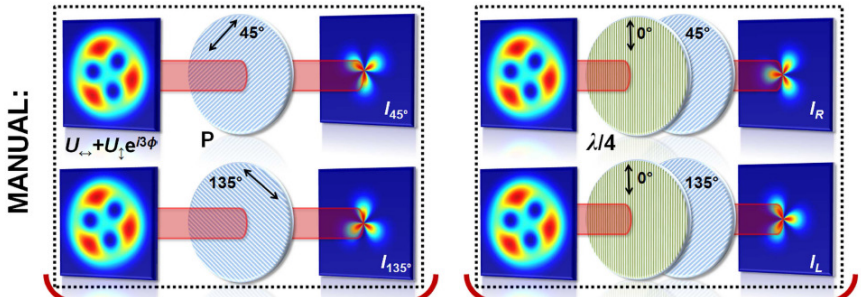
$$S_3(r,\phi) = 2|U_{\leftrightarrow}(r,\phi)||U_{\updownarrow}(r,\phi)|\sin(\delta(r,\phi)) \quad = I_R - I_L$$

$$\delta(r,\phi) = \frac{1}{2}\arctan\left(\frac{S_3(r,\phi)}{S_2(r,\phi)}\right)$$

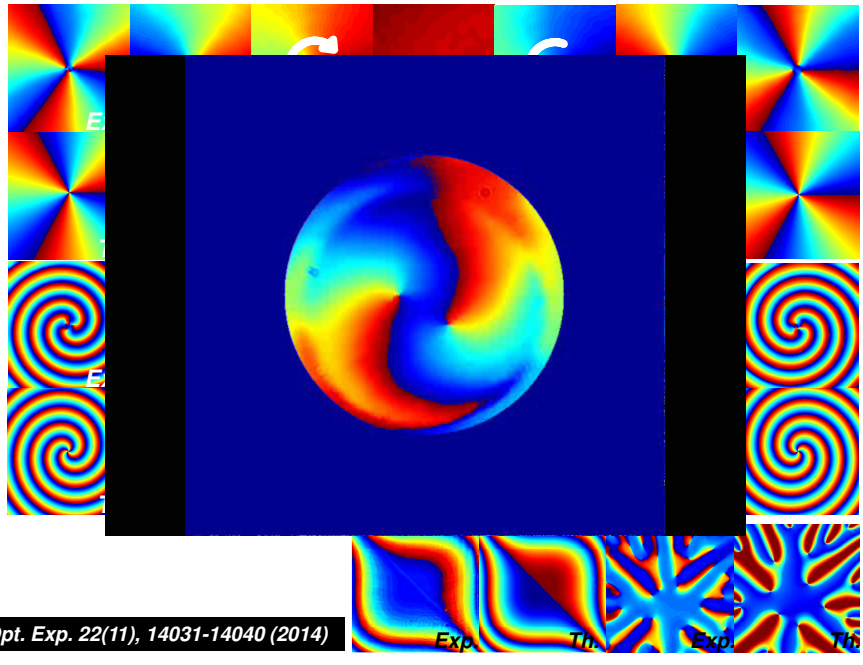




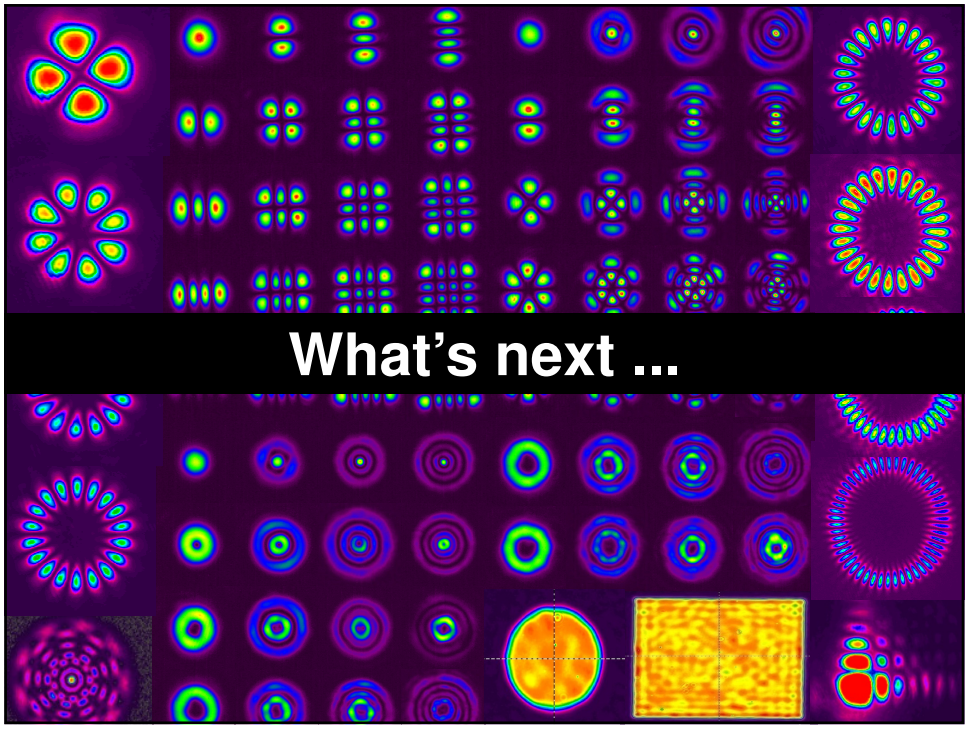
Combining these techniques, we can develop an all-digital approach for extracting phase



The modes that can be measured are endless…



Opt. Exp. 22(11), 14031-14040 (2014)

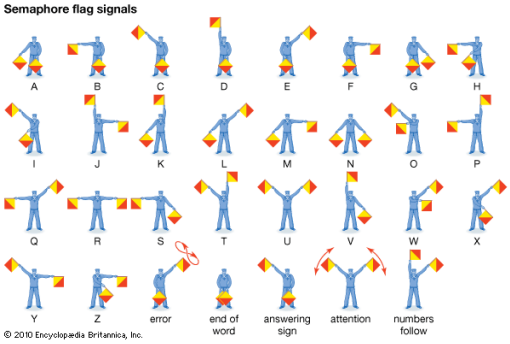


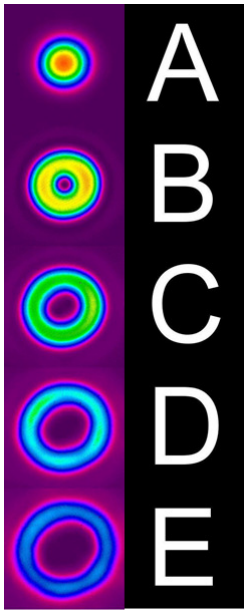
We are using the patterns of light to increase bandwidth in communication systems

Flashlight On: 1
Flashlight Off: 0

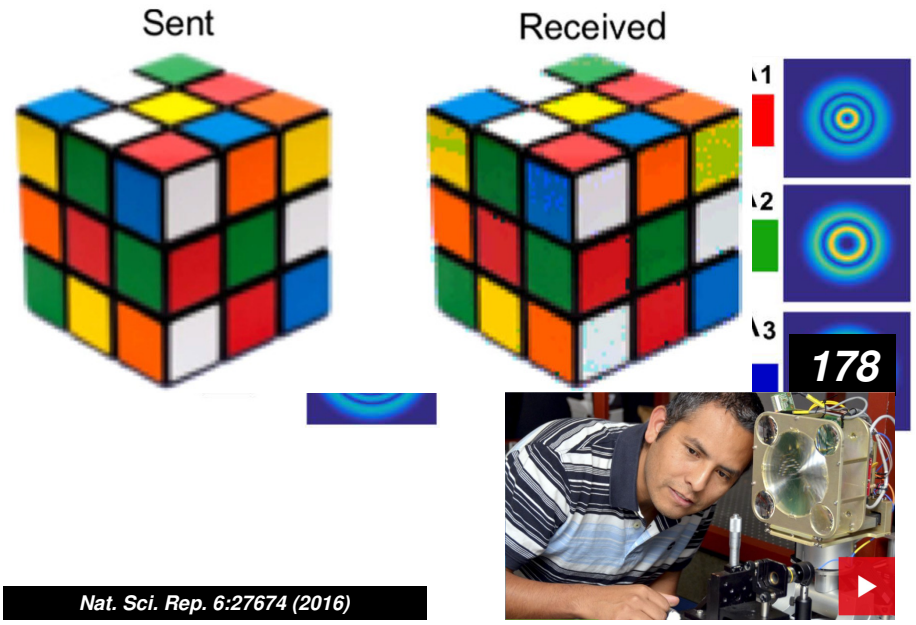
Message Received:
…101110…

Semaphore flag signals





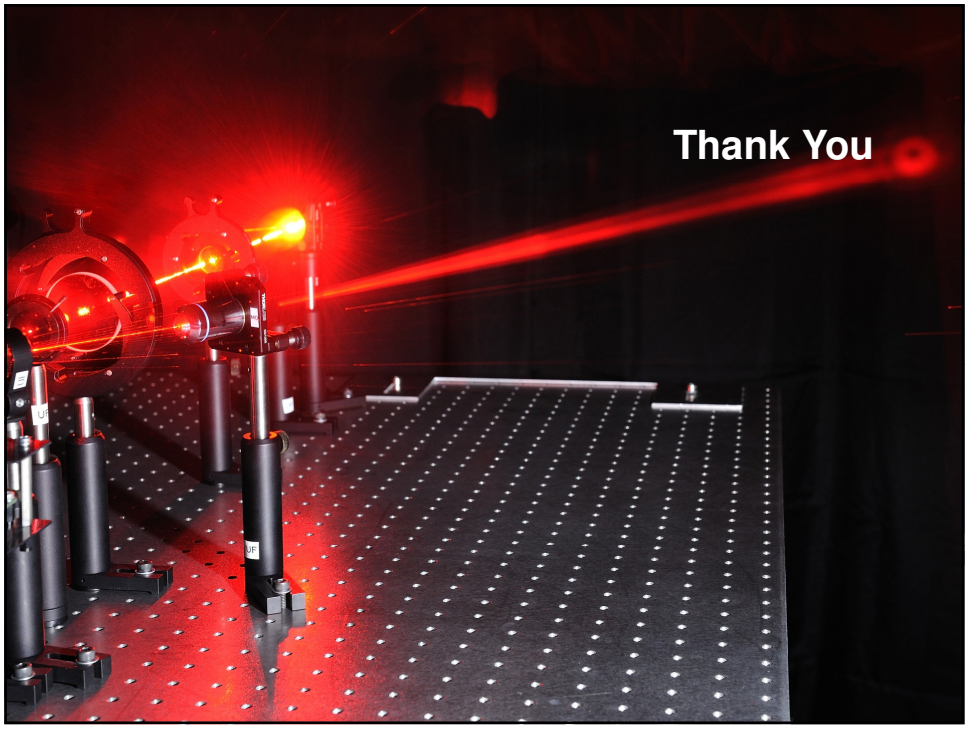
We have already demonstrated a 100X increase in the number of information channels



Nat. Sci. Rep. 6:27674 (2016)

If you want to hear more about structured light... I suggest you chat to these people...

our future through science


Thank You