Quantum enhanced wavefront detection

Experimental detection of partially coherent beams

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Wavefront tomo-short overview

Wavefront sensors provide tomographic measurement of coherence function

What is quantum in the problem of classical signal?

-> quantum state tomography of coherence matrix

State representation:

- Pure state – coherent modes of field
- Mixed states – coherence matrix – statistical mixture of waves

Measurement description:

- POVM – microlens far-field transformation

Discrete classical beams

Important is the presence of base in which the state of light is represented by small number of parameters:

- Space truncation
- Informationaly complete wavefront tomography

Examples of discrete signals

- Modes of fiber
- Modes of resonator
- Vortex beams

$$\langle r,\varphi | n \rangle \cong Exp(-in\varphi)$$

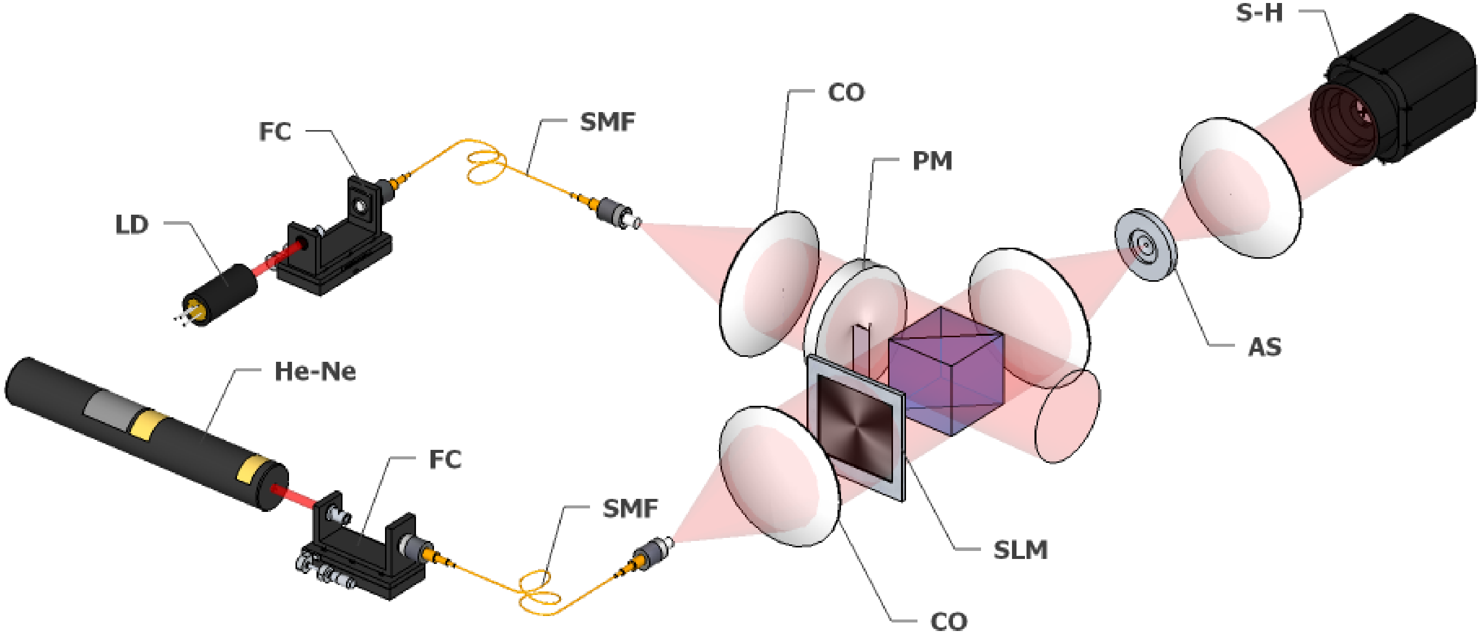
Purpose of experiment

- Realize mixed state of vortex beam
- Perform state tomography with a standard SH detector
- Invert the data with the Maximum-Likelihood approach and compare the result with the target state
- Check the reconstruction by beam propagation

$$\rho_{true} = \left| V_{-3} - \frac{i}{2} V_{-6} \right\rangle \left\langle V_{-3} - \frac{i}{2} V_{-6} \right| + \frac{1}{2} \left| V_3 \right\rangle \left\langle V_3 \right|$$

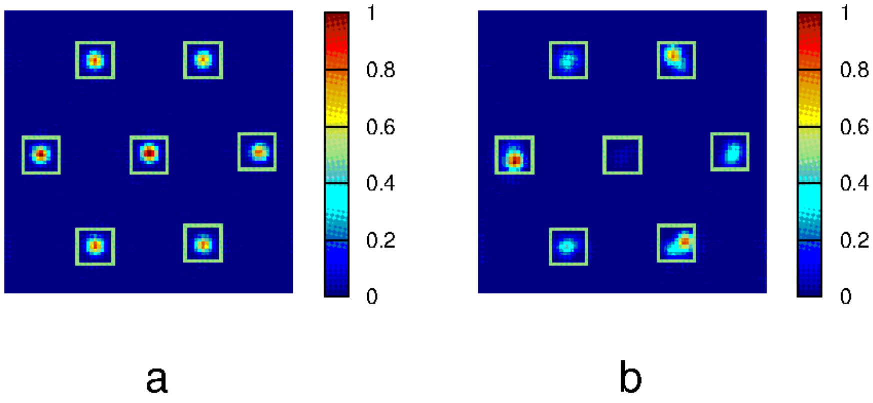
State preparation

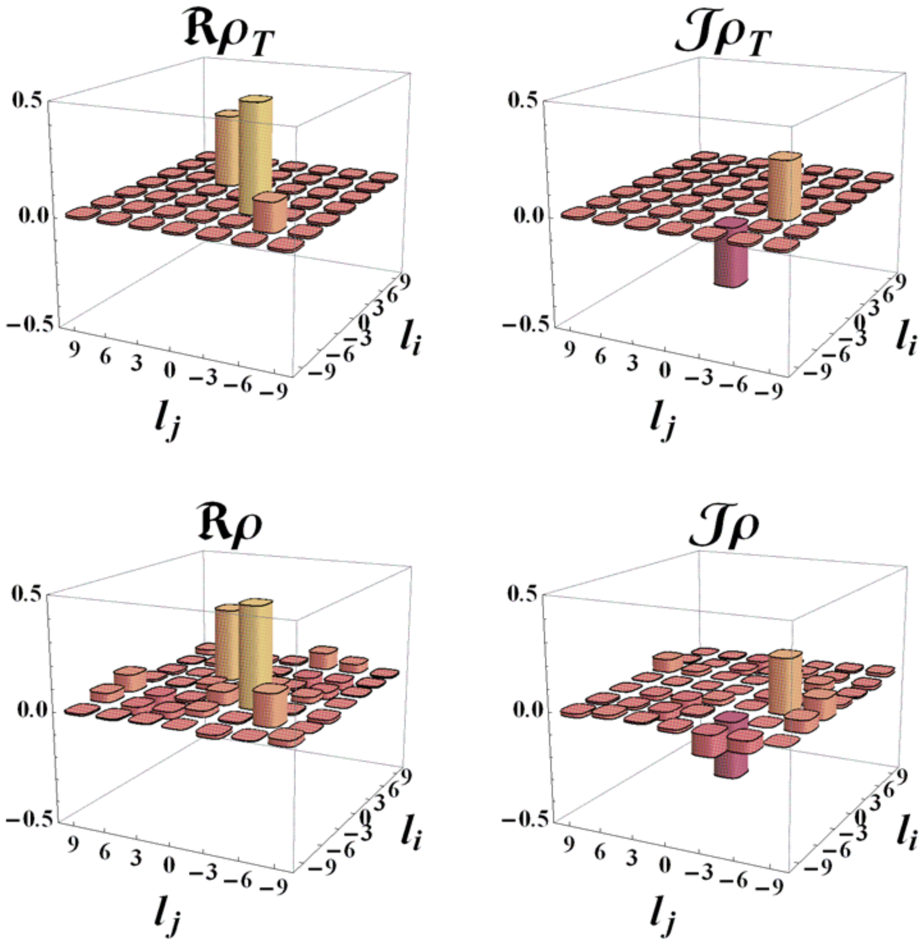
$$\rho_{true} = \left| V_{-3} - \frac{i}{2} V_{-6} \right\rangle \left\langle V_{-3} - \frac{i}{2} V_{-6} \right| + \frac{1}{2} \left| V_3 \right\rangle \left\langle V_3 \right|$$



State reconstruction

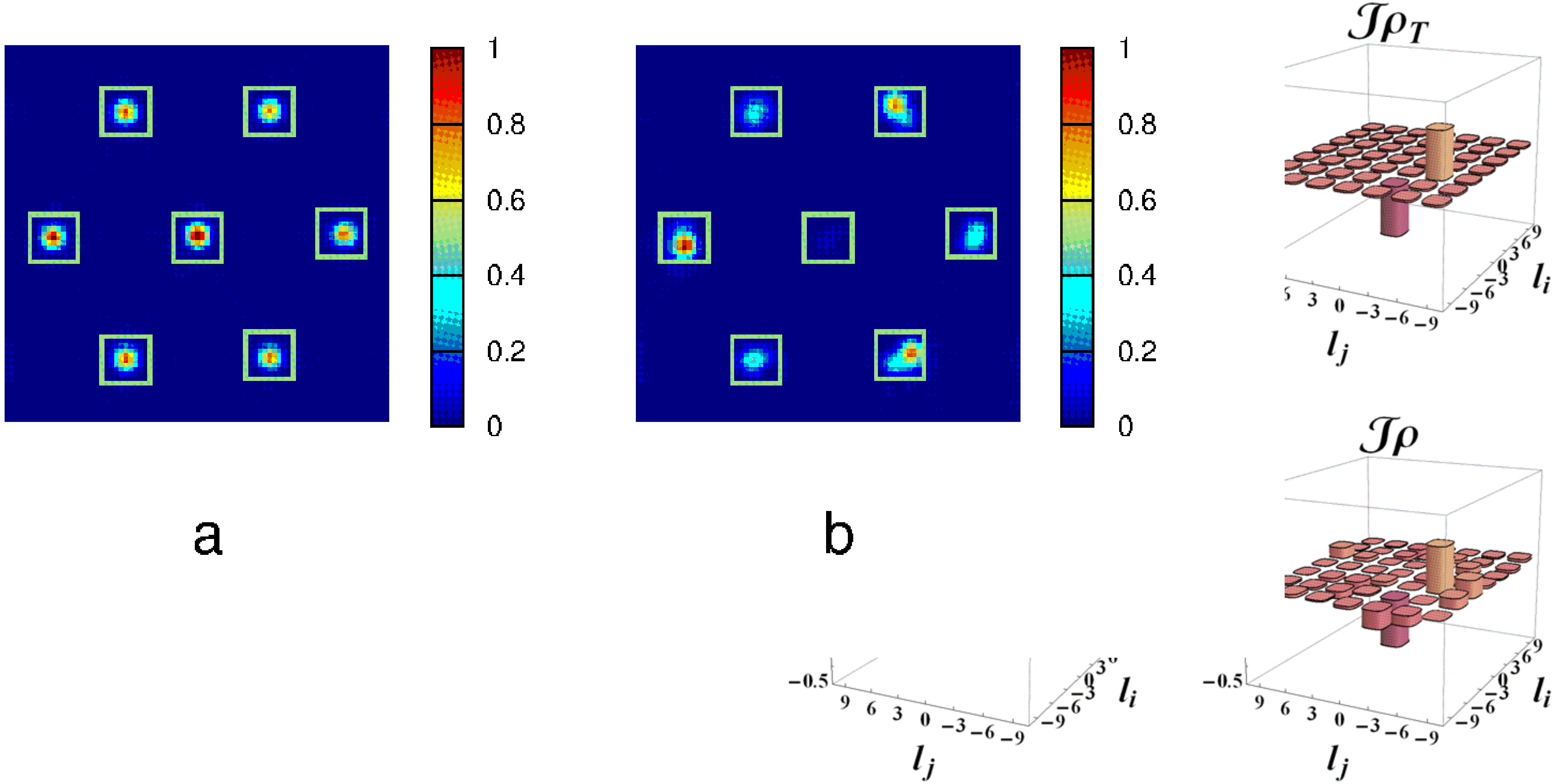
$$\rho_{true} = \left| V_{-3} - \frac{i}{2} V_{-6} \right\rangle \left\langle V_{-3} - \frac{i}{2} V_{-6} \right| + \frac{1}{2} \left| V_3 \right\rangle \left\langle V_3 \right|$$





State reconstruction

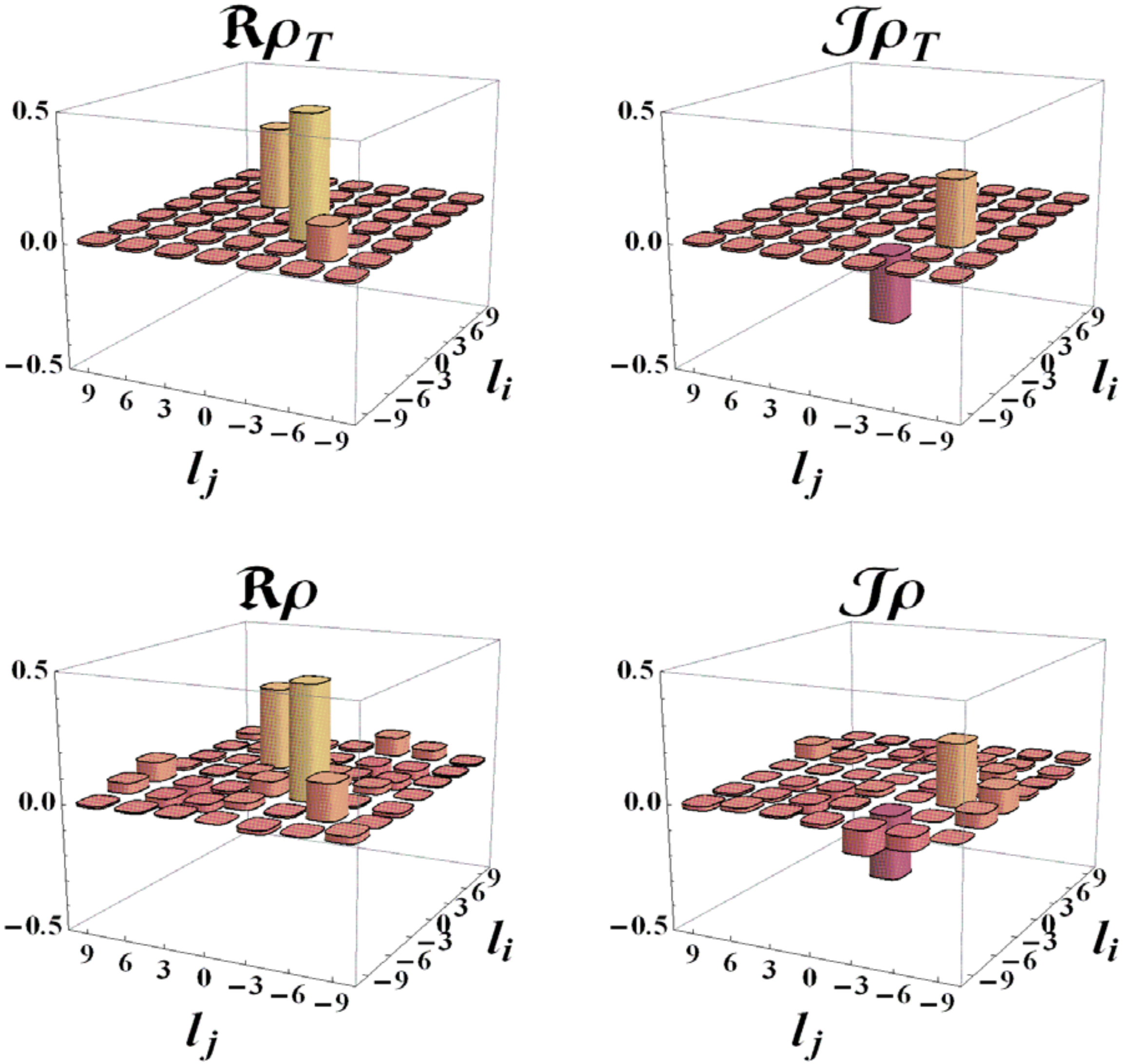
$$\rho_{true} = \left| V_{-3} - \frac{i}{2} V_{-6} \right\rangle \left\langle V_{-3} - \frac{i}{2} V_{-6} \right| + \frac{1}{2} \left| V_3 \right\rangle \left\langle V_3 \right|$$



State reconstruction

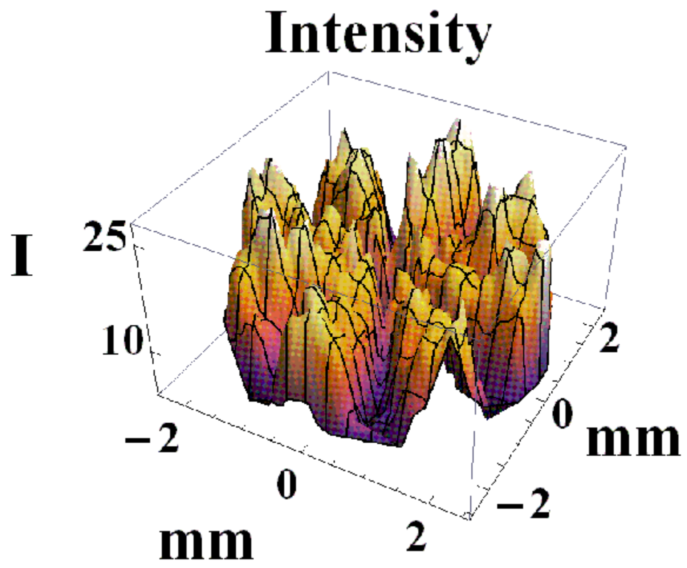
$$\rho_{true} = \left| V_{-3} - \frac{i}{2} V_{-6} \right\rangle \left\langle V_{-3} - \frac{i}{2} V_{-6} \right| + \frac{1}{2} \left| V_3 \right\rangle \left\langle V_3 \right|$$

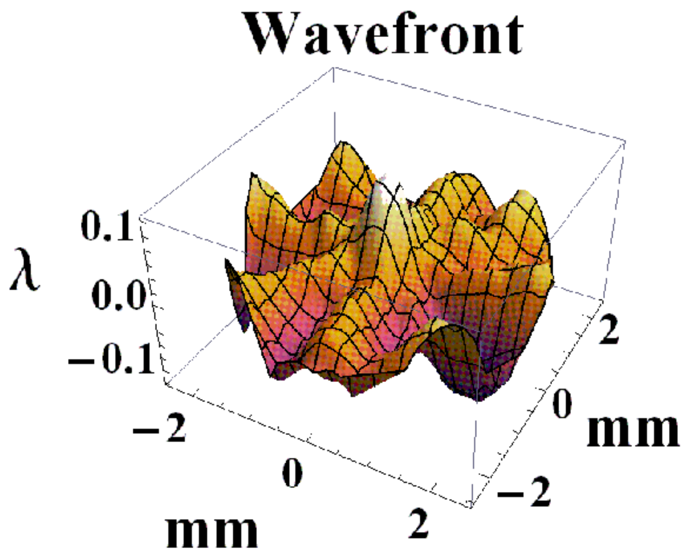
Fidelity = 0.98



Standard SH vortex reconstruction

Assumption of wavefront without dislocations prevents this features from the reconstruction





Propagation of optical vortices

propagation of light

$$I(x) = \int_{-\infty}^{\infty} h(x, x')h^*(x, x'')G(x', x'')dx'dx''$$

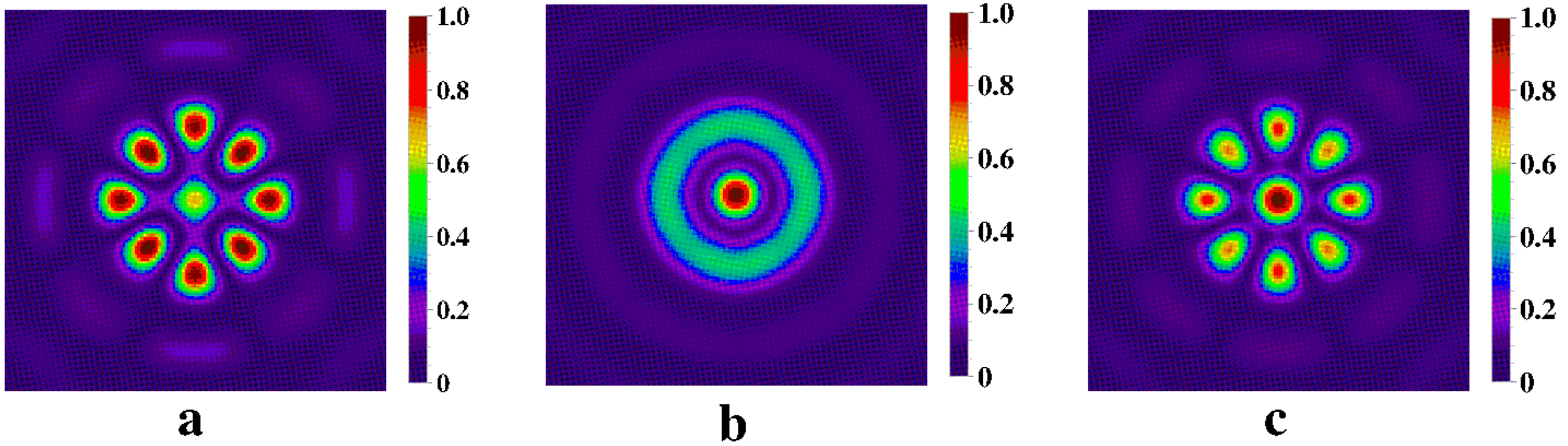
mutual intensity $G(x', x'') = \langle x' | \rho | x'' \rangle$

- knowledge of second-order coherence properties is required for digital propagation/focusing etc.

Coherence and vortex far-field

Influence of spatial coherence on the far field intensity distribution

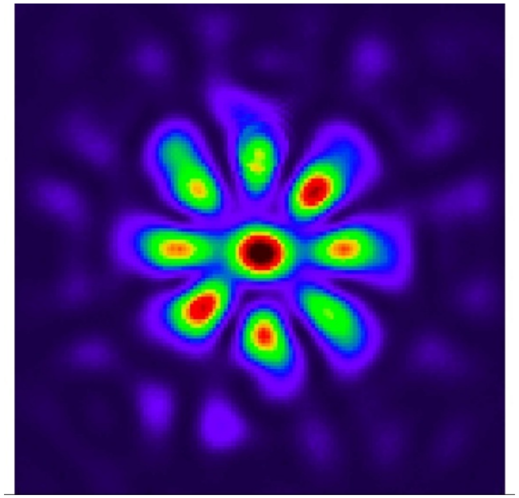
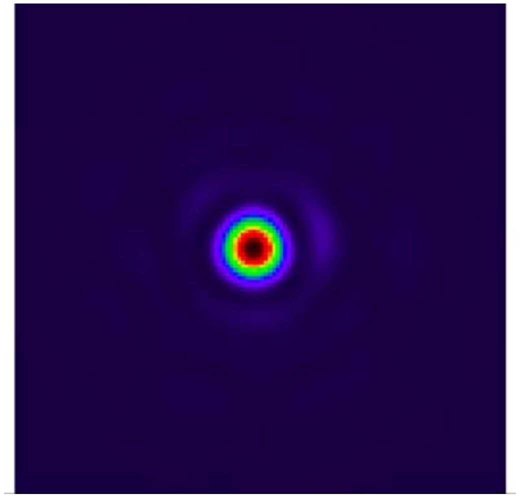
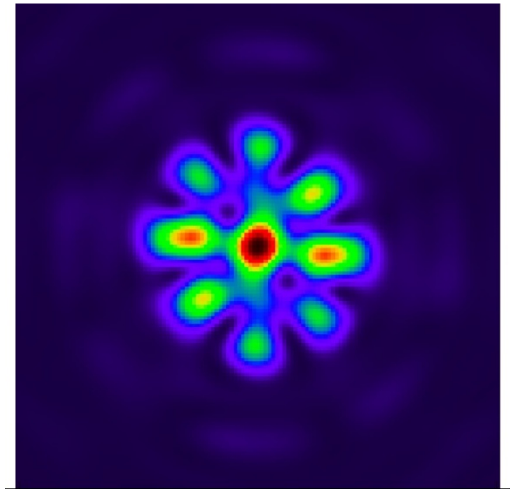
$$\rho_{true} = \left| V_4 - V_{-4} \right\rangle \left\langle V_4 - V_{-4} \right| + k \left| V_0 \right\rangle \left\langle V_0 \right|$$



a) Fully coherent superposition b) incoherent mixture c) partially coherent mixture

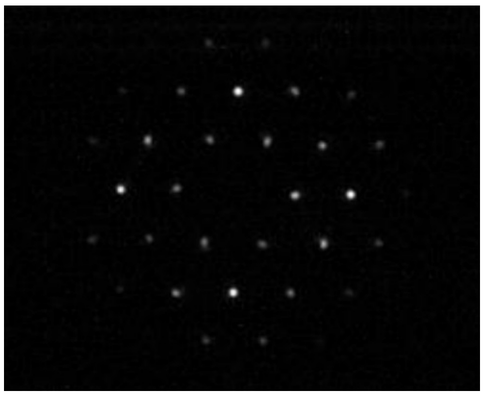
Propagation ...

Numerical propagation and direct measurement comparison

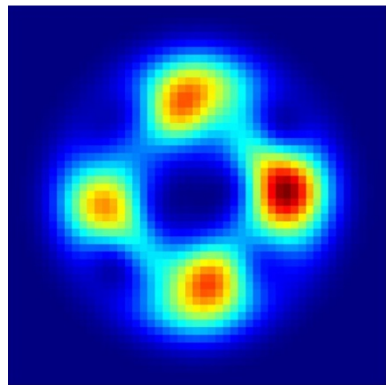
CCD	*Conventional*	*Tomo*
		
Normalized correlation coefficient	0.47	0.89

Propagation of LG coherent beam

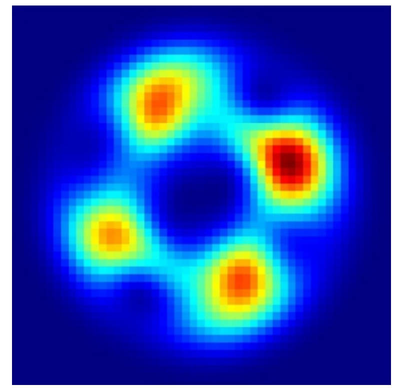
- target state $|LG_0^4\rangle + |LG_0^8\rangle$

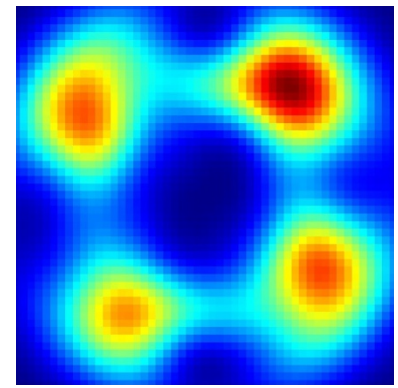


SH data



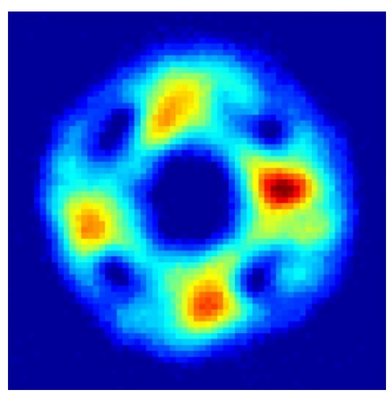
tomography



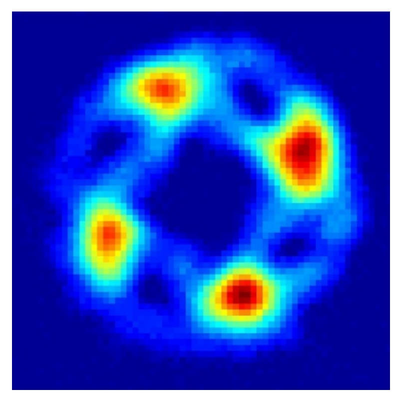


digital propagation

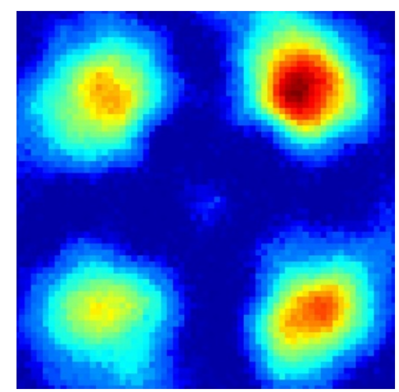
CCD



0 cm



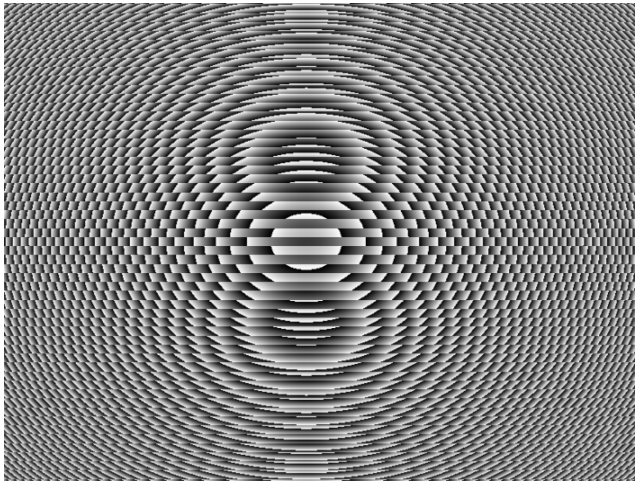
17 cm

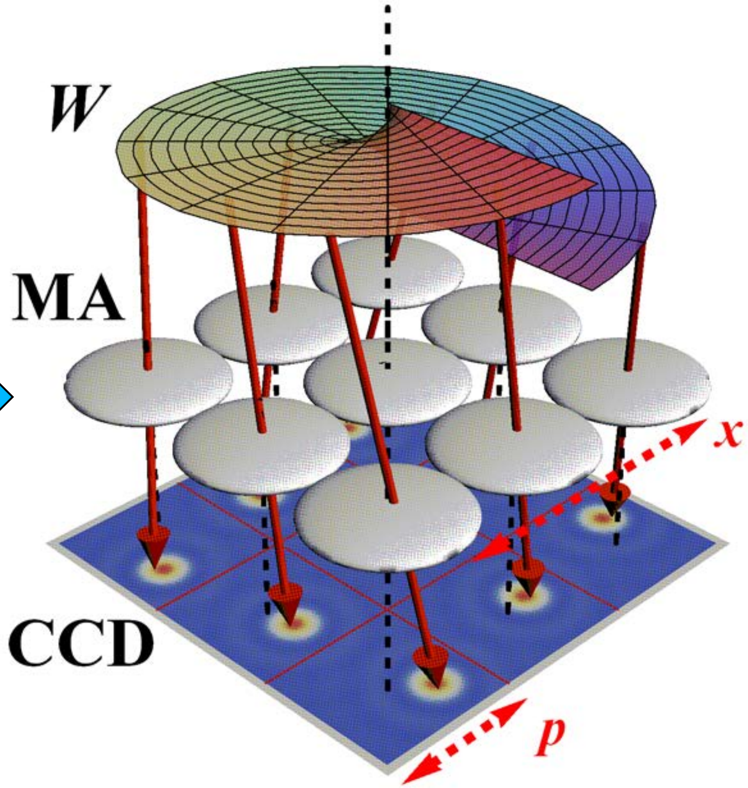


62 cm

Future work

Solving the problem of non-overlapping microlens apertures by holographic element instead of array?





Conclusions

- Non-trivial coherence measurement with a SH wavefront sensor was experimentaly demonstrated
- Method was validated by the propagation method
- Helical wavefronts of vortex beam were successfuly detected

- possible extensions
  - Realization of the microlens array transform by holographic element