Wavefront-sensor tomography for measuring spatial coherence

J. Řeháček, Z. Hradil, B. Stoklasa, L. Moťka

Palacky University, Olomouc, CZ

L.L. Sánchez-Soto

Complutense University, Madrid

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Program Centra kompetence

Spatial coherence

mutual intensity $G(x',x)$

- second-order coherence properties of partially coherent beams

- beam propagation and 3D imaging

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

Coherence measurement

wavefront sensors

- relatively cheap technology
- one-shot measurement
- robust compared to interferometers

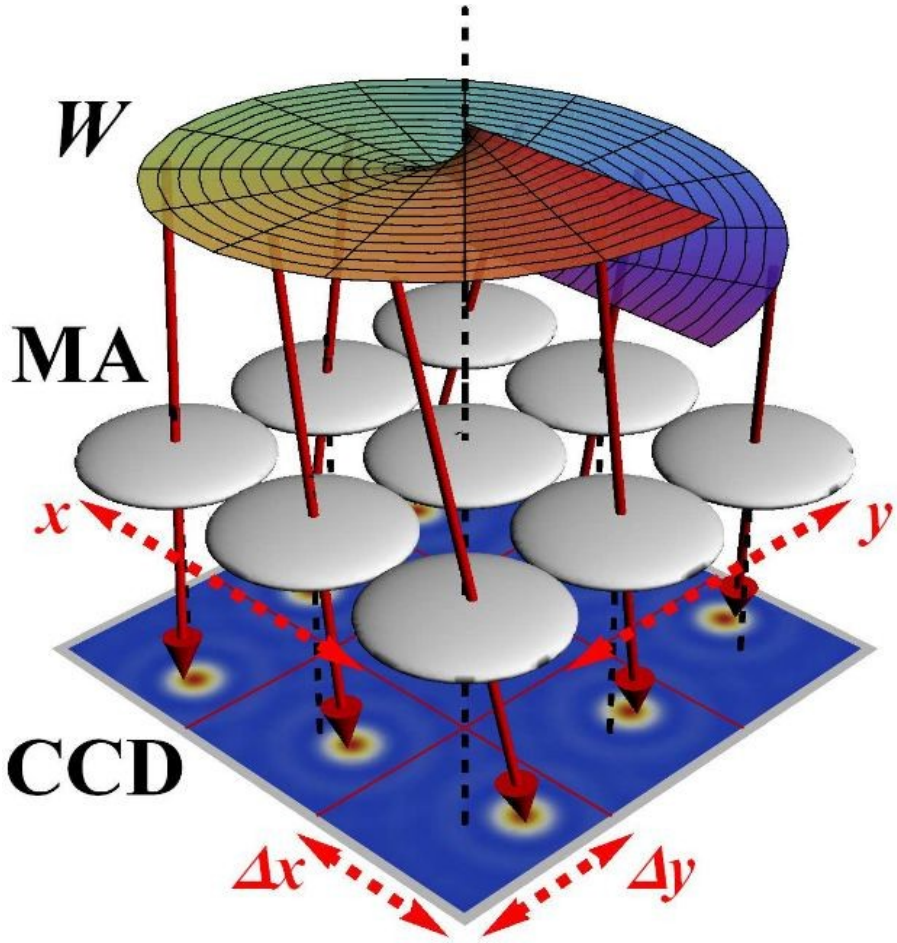
Shack-Hartmann detection

standard operation

- local wavefront tilts
  ⟹ wavefront reconstruction

alternative interpretation

- projections on position/momentum shifted pupil functions
- can be made informationally complete on a suitable search space



Z.Hradil, J.R., L.L.Sanchez-Soto, Phys. Rev. Lett. ***105****, 010401 (2010)*

L. Waller, G. Situ and J.W. Fleischer, Nature Photonics ***6****, 474 (2012)*

S-H tomography

intensity at the CCD plane

$$I_{ij} = \mathrm{Tr}\left(\rho \Pi^{ij}\right)$$

measurement matrix: $\Pi^{ij} \geq 0$

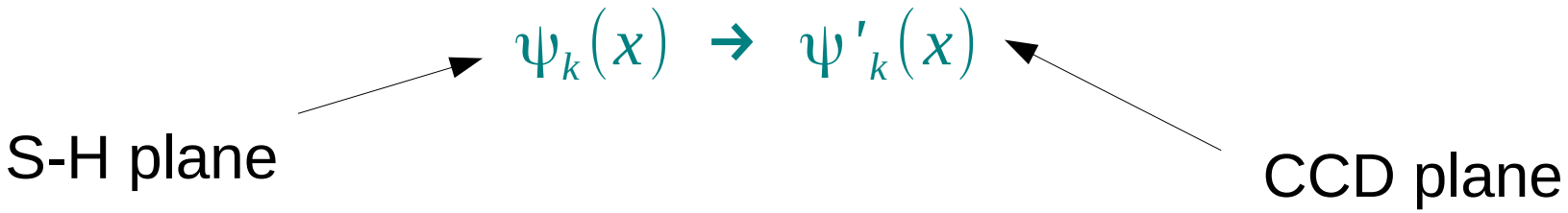
coherence matrix: $G(x', x) = \langle x' | \rho | x \rangle, \;\; \rho \geq 0$

search space

- finite subspace $\{\psi_k(x)\}, \;\; k = 1 \ldots d$
- e.g. LG, HG, plane waves ...

S-H tomography ...

measurement matrix



$$\Pi_{kl}^{ij} = \psi'^{*}_{k}(x_{ij})\,\psi'_{l}(x_{ij})$$

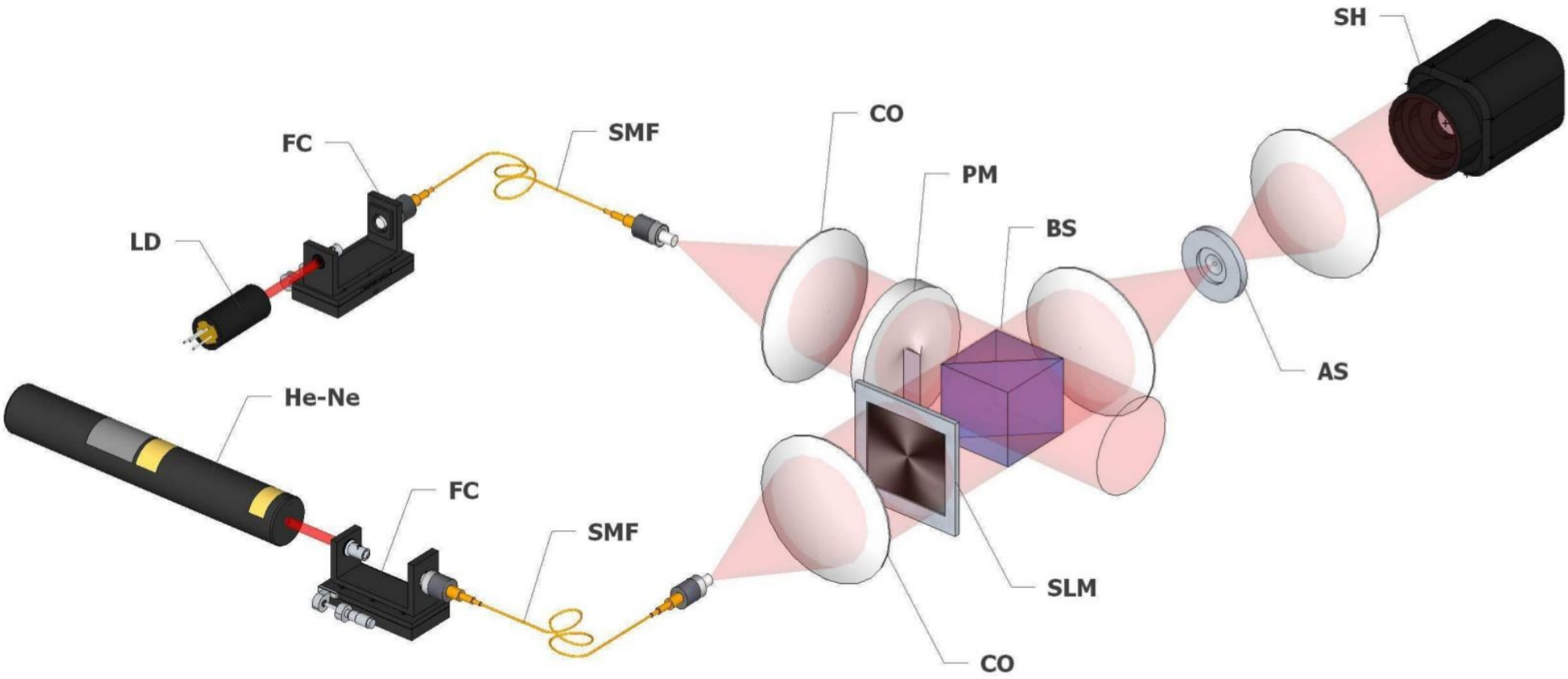
reconstruction

- formally equivalent to quantum-state reconstruction
- ML approach works fine

Y.S.Teo, H.Zhu, B.-G.Englert, J.R., Z.Hradil, Phys. Rev. Lett. ***107****, 020404 (2011)*

Experiment

Digital holography setup

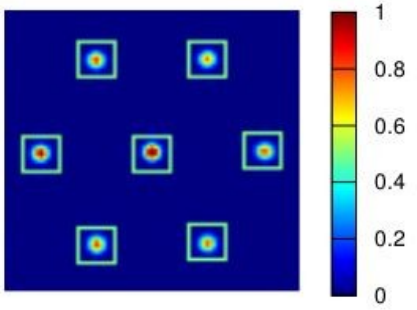


B. Stoklasa, L. Motka, J.R., Z. Hradil, L.L.Sanchez-Soto, Nature Communications DOI: 10.1038/ncomms4275.

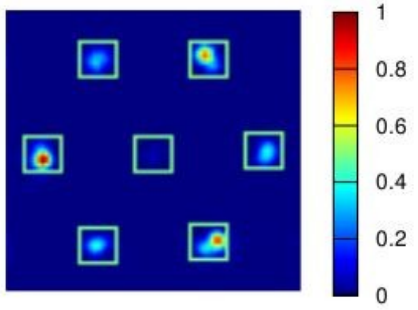
Experiment ...

vortex basis $V_l(r,\varphi) = \langle r,\varphi|V_l\rangle \propto e^{il\varphi}$

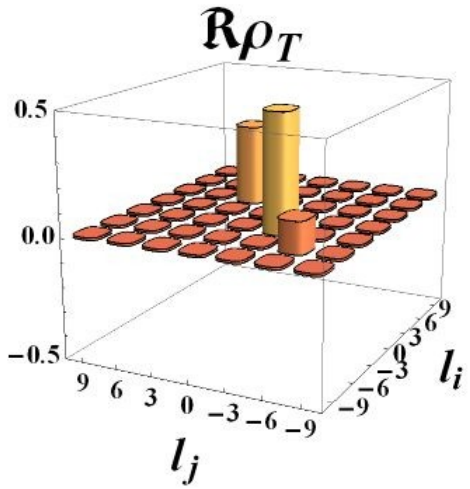
$$\rho_{\text{true}} = |V_{-3} - \frac{i}{2}V_{-6}\rangle\langle V_{-3} - \frac{i}{2}V_{-6}| + \frac{1}{2}|V_3\rangle\langle V_3|$$

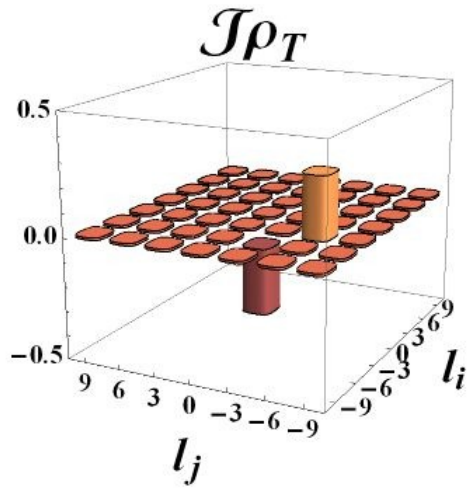


reference

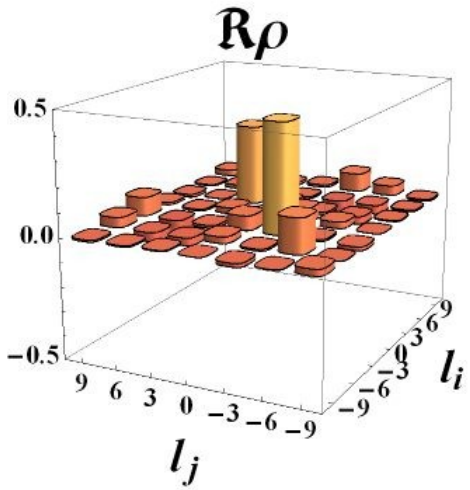


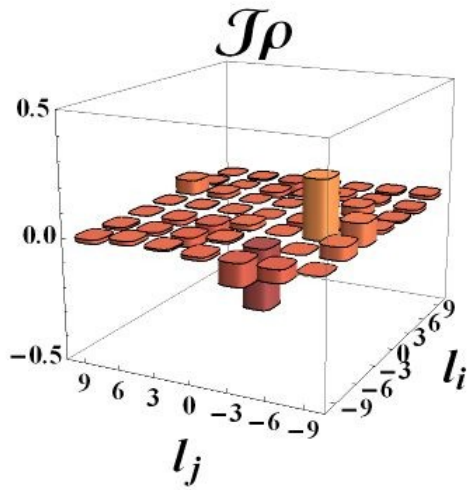
raw data





reconstruction





Beam propagation

digital propagation of partially coherent vortex beams

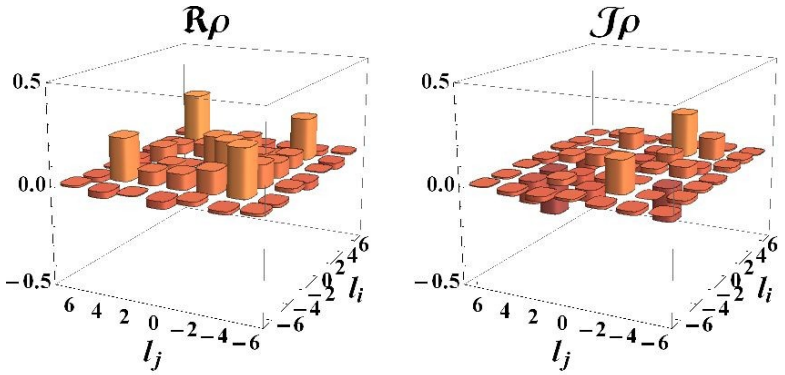
- target state

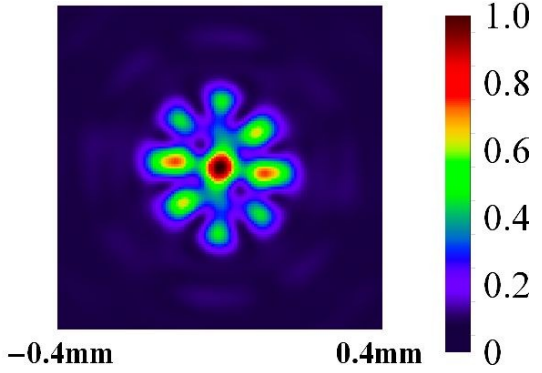
$$\rho_{\text{true}} = |V_4 + V_{-4}\rangle\langle V_4 + V_{-4}| + \lambda |V_0\rangle\langle V_0|$$

- protocol
  - beam preparation
  - S-H tomography
  - digital propagation
  - calculated intensity is compared to the actual CCD scans in the far field

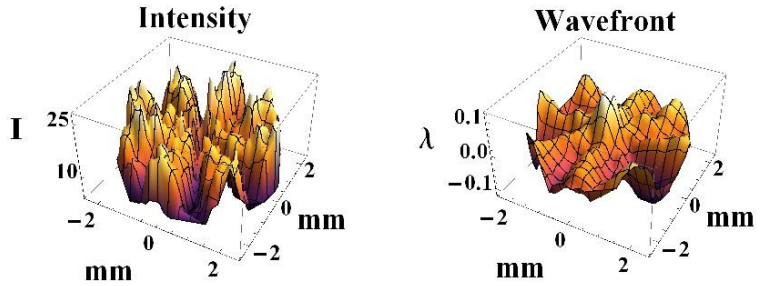
Propagation ...

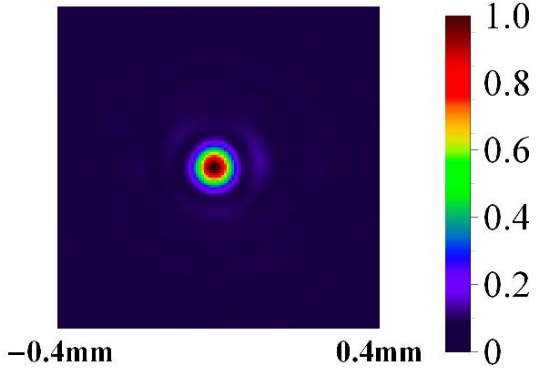
SH tomography



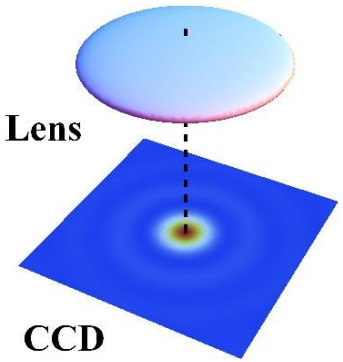


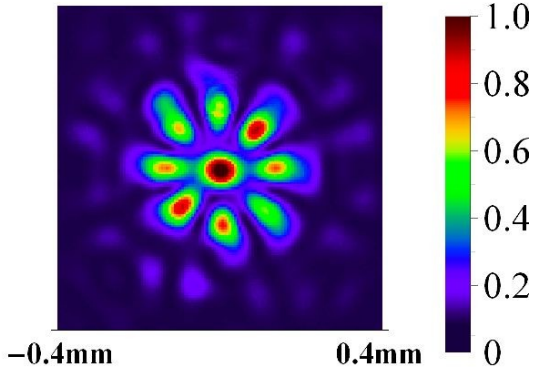
HASO





direct measurement





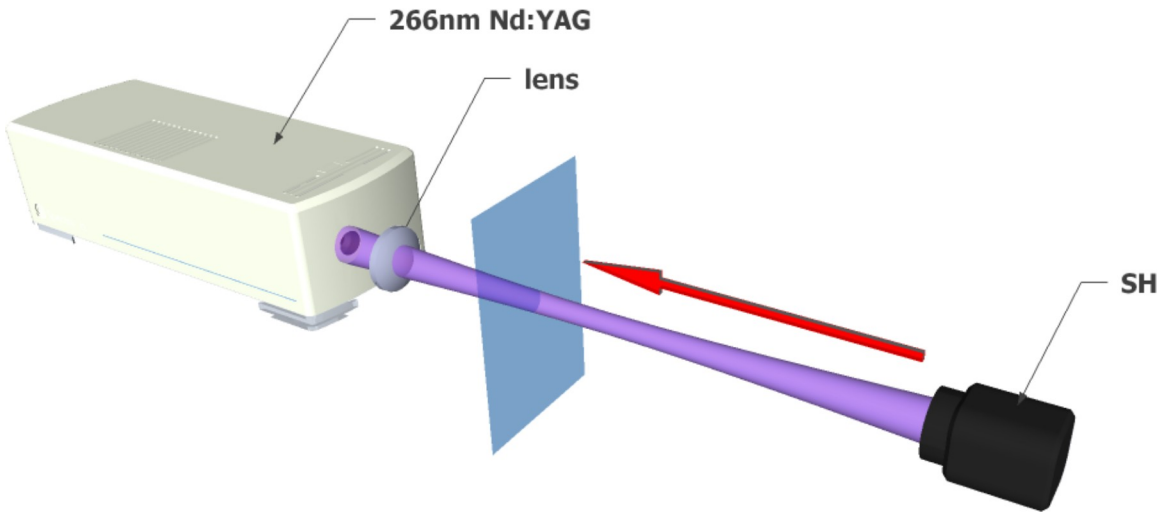
Characterization of UV laser sources

multimode light of a UV laser source

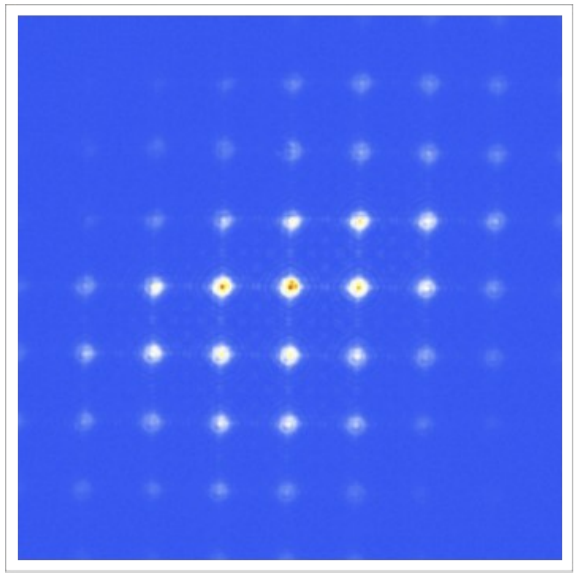
- CrystalLaser, Nd:YAG 266nm, pulse 10ns, 1kHz repetition rate
- Meopta S-H sensor, 150μm pitch, 4.6μm CCD pixel size, 7mm microlens to CCD distance
- reconstruction
  - search space: 9 lowest-order HG modes (81 parameters)
  - data: 11x11 pixels for each of 7x7 microlenses (5929 measurements)

Characterization ...

setup

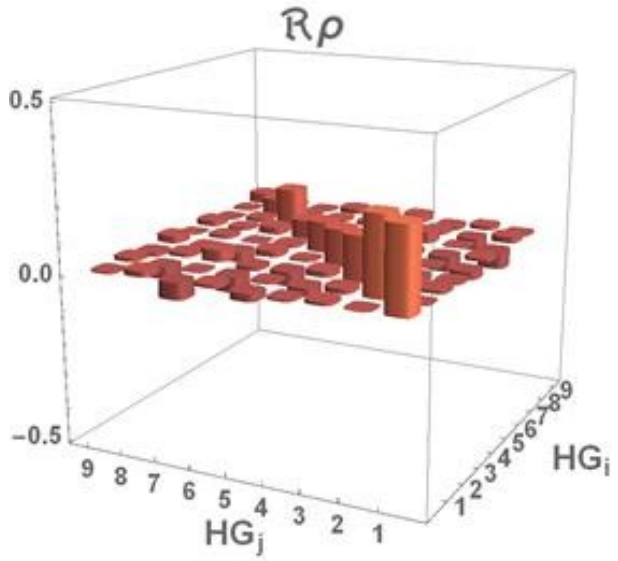


typical S-H data

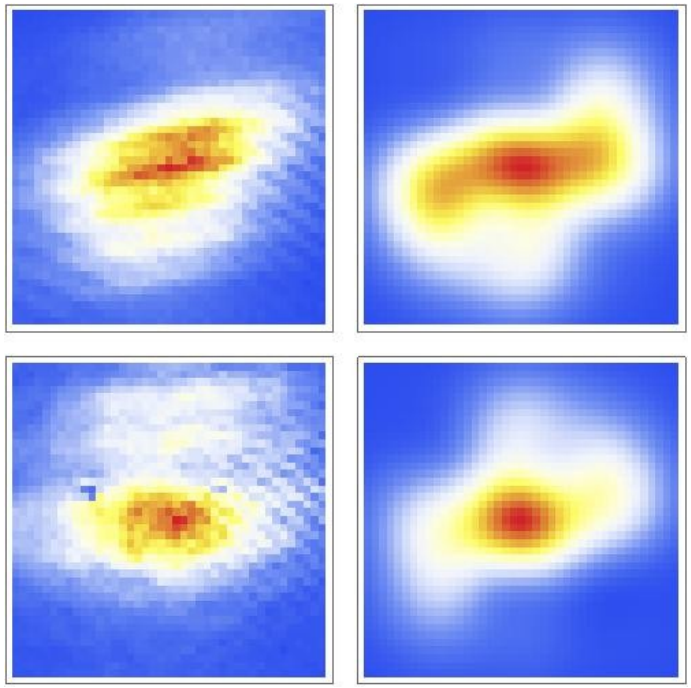


Results

reconstruction



propagation



measured, S-H plane

measured, propagated

inferred, S-H plane

inferred, propagated

Conclusions

- Quantum-state estimation techniques can be adopted for S-H data processing

- Applications:
  - complete characterization of partially coherent beams
  - 3D imaging
  - UV lasers