High-dimensional Stokes-space Spatial Beam Analyser

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We demonstrate a device that performs a single-shot measurement of amplitude, phase, and coherence of an unknown beam by generalising the principles of Stokes polarimetry to the arbitrary N-dimensional spatial case. The device can distinguish multiple mutually incoherent wavefronts within a single beam, without an external reference in a near lossless fashion and in real-time.
Current methods such as homodyne, heterodyne and self-reference techniques [1] could be used to perform a similar measurement to our device, however each have their own drawbacks. For homodyne and heterodyne, a well-defined reference is needed, but is not always available. Self-reference techniques on the other hand, do not require an external reference and work by interfering the beam's spatial components with itself, either in a sequential or single-shot fashion. However sequential methods may not be appropriate for real-time applications and both sequential and single-shot methods incur beamsplitter-like losses that scale with the number of modes.

Our device uses multi-plane light conversion (MPLC) [2], which transforms a beam through a cascade of phase manipulations. The MPLC allows every spatial state in the higher-dimensional Stokes-space that describes the beam, to be interfered with every other spatial state. The device consists of order N phase planes, where N is the number of spatial modes the device must support. The device approximates a unitary transformation between an input beam composed of N=6 Laguerre-Gaussian spatial components, and an output array of $2N^2$-N=66 Gaussian spots. From the intensity of those spots the complete spatial state of the beam is acquired. Akin to measuring the polarisation state of a beam (N=2) by measuring the intensity in 3 different polarisation bases. The device could be used for a variety of applications such as: spatial state tomography in quantum optics, mode division multiplexing, or to characterise the spatial state of an arbitrary light source.

[1] H.Ji, *et al*, *Opt.Lett.*, 44, 2065–2068 (2019)

[2] N.K.Fontaine, *et al*, *Nat.Commun.*, 10, 1865 (2019)

[3] M.Agnew, *et al*, *Phys. Rev. A*, 84 (2011)