Bessel-Gaussian entanglement

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Entanglement: “spooky action at a distance”
Engineering quantum states for specific applications

\[ |\psi\rangle = a + b + c + \ldots \]

OAM spectrum
Azimuthally-phased beams have helical wavefronts and consequently carry OAM.

\[
\psi = \sum_{\ell=-\infty}^{\infty} a_{\ell,-\ell} |\ell,-\ell\rangle
\]

\[
u(r, \theta, z) = u_0(r, z) \exp\left[iqz - \frac{i\ell \theta}{r}\right]
\]

Spin Clockwise: 1
Spin Anticlockwise: 0

Message Received: 101110 = A

GAUSSIAN BEAM
LAGUERRE-GAUSSIAN BEAM
Higher-order Bessel-Gaussian beams carry OAM

\[ u(r, \theta, z) = J_\ell(k_r r) \exp(i\ell \theta) \]
Generating Bessel-Gaussian beams using spatial light modulators (SLMs)

\[ \exp(ikr) \exp(i\ell \phi) \]

\[ \text{sign}\{\exp(ikr)\} \exp(i\ell \phi) \]

\[ \text{sign}\{J_\ell(kr)\} \exp(i\ell \phi) \]

Blazed axicon

Binary axicon

Binary Bessel

\[ m = -1 \]

\[ m = +1 \]

\[ Z_{max} \]
Experimental setup to detect entanglement
Experimental setup to detect entanglement

BG mode

Hologram

Gaussian mode

Single-mode fibre

$\ell = 2$

$\ell = 2$

$\ell = 0$
Violation of Bell’s inequality demonstrates entanglement

\[ S = 2.78 \pm 0.05 > 2 \]
Comparison of OAM spectra – measuring coincidence count rates

OAM is conserved

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OAM spectrum is dependent on the radial component

$k_r = 0 \text{ rad/mm}$
$k_r = 20 \text{ rad/mm}$
$k_r = 35 \text{ rad/mm}$
Reconstruction of the density matrix using a full state tomography

M. McLaren et al., 2012, Opt. Express, 20, 23589
Properties of Bessel-Gauss beams – reconstruction after an obstruction
Entanglement setup with obstruction

- **Obstruction**: 400 μm
- **355 nm laser**
- **BBO**
- **IF**
- **CCD**
- **Variable aperture**
- **SLM A**
- **BS**
- **SLM B**
- **L1**
- **L2**
- **L3**
- **L4**
- **M1**
- **M2**
- **M3**
- **M4**
- **IF**
- **SMF**
- **Coincidence counter**
Reconstruction of quantum entanglement?
Reconstruction of quantum entanglement

(a) 

(b) 

(c) 

M. McLaren et al., 2013, To be submitted
Further potential for Bessel-Gaussian modes in quantum entanglement.
Thank you

- The Biggest Blizzard in History
- The Second Coming
- Zombie Outbreak
- Life in General

Things that could be happening outside that you wouldn't know about because your lab/office has no windows.