A three-particle, three-dimensonal GHZ state using twisted photons

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Initially proposed as a two-particle problem, the concept of entanglement was extended to three particles by Greenberger, Horne, and Zeilinger in 1989 [1]. Commonly referred to as GHZ states, these entangled multipartite systems have allowed for a non-statistical, "all or nothing" violation of local realism. To date, experimental realizations of GHZ states have been limited to two dimensions due to the use of polarization-entangled photons. For example, a polarization-entangled GHZ state has the form:

$$\Psi_{\mathrm{GHZ}} = \frac{1}{\sqrt{2}}[|HHH\rangle + |VVV\rangle] \qquad (1)$$

Recent experiments have shown multipartite entanglement of 8 photonic qubits [2] and 14 qubits in ion-traps [3]. These two experiments represent the current state of the art for the generation of multipartite entanglement. Alternatively, the orbital angular momentum (OAM) of photons offers a discrete, infinite-dimensional Hilbert space. Entanglement of photonic OAM has been shown up to a (100x100) dimensions [4]. Many recent techniques have also been developed to manipulate the OAM of light in a manner similar to that of polarization [5]. This high-dimensional degree of freedom offers the potential to realize GHZ states of the form:

$$\Psi_{\mathrm{GHZ}} = \frac{1}{\sqrt{3}}[|AAA\rangle + |BBB\rangle + |CCC\rangle] \qquad (2)$$

In addition, one can use the dimensionality offered by OAM to explore further types of exotic entangled states, for example, one that is entangled in different dimensions for different particles [6]:

$$\Psi_{\mathrm{GHZ}} = \frac{1}{\sqrt{3}}[|AAA\rangle + |BBB\rangle + |CCA\rangle] \qquad (3)$$

We describe an experiment that aims to realize such states using the OAM photonic degree of freedom. Here, I will present recent progress our group has made towards achieving this goal.

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