MATHEMATICAL PHOTONICS

A Photonic Many-Body System, Particle by Particle

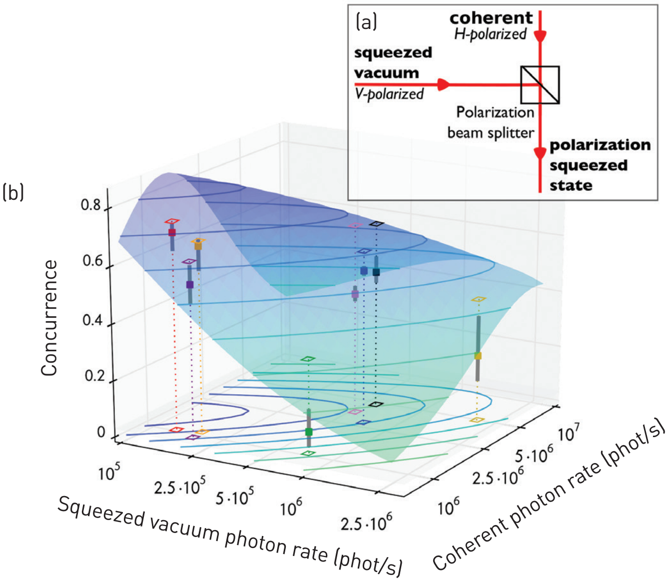
Ever since Epicurus introduced his atomic theory in ancient Greece, the nature of the microscopic world has been a central scientific question. Our modern vision now encompasses not only atoms but photons, electrons and other fundamental particles, as well as precise descriptions of their interactions. These ingredients, coupled with powerful computers, allow humans to explain a wide range of phenomena, from chemical reactions to supernovae.

Yet not everything can be explained this way. Many open questions in science, such as the origin of high-temperature superconductivity, concern strongly interacting, many-body systems. Because such interactions generate highly entangled states, these systems resist computational solutions even on the largest computers.

A bold proposal known as quantum simulation aims to overcome this roadblock using synthetic quantum systems.[1] For example, the physics of interacting electron spins can be reproduced using ultracold atoms in an optical lattice, which offers direct access to the microscopic elements making up a macroscopic quantum system and allows direct study of their uncomputable microscopic behaviors. More recently, experiments with photonic Bose-Einstein condensates[2] and strongly interacting photons[3] have made photonic quantum simulators promising.

We recently showed how to study the individual photons that make up a macroscopic, photonic many-body system.[4] We used a beam of polarization squeezed light, for which entanglement properties can be computed exactly, as the macroscopic system. We detected photon pairs from the squeezed beam with single-photon counters and used polarization state tomography, a tool from photonic quantum information, to measure their quantum states.

We observed strong entanglement, and confirmed several untested predictions such as the role of entanglement monogamy in macroscopic systems and a transition from bipartite entanglement to multipartite entanglement with increased squeezing. The work shows that photonic systems can be studied as quantum many-body systems, and opens the way to particle-by-particle analysis of photonic Bose-Einstein condensates and other optical manifestations of quantum condensed matter. OPN



(a) Schematic setup for generating the polarization squeezed state (PSS). (b) Entanglement of photons in a PSS, showing concurrence (a measure of pairwise entanglement) as a function of the number of photons in the two polarization components. The degree of squeezing increases with the number of photons in the squeezed vacuum, yet, remarkably, the photons show polarization entanglement for any amount of squeezing.

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