Phase-Sensitive Quantum Imaging Using Thermal Light Fields

Robert W. Boyd

Can we perform high-quality imaging using only a very small number of photons per pixel?

And can we do it if the light has thermal statistics?

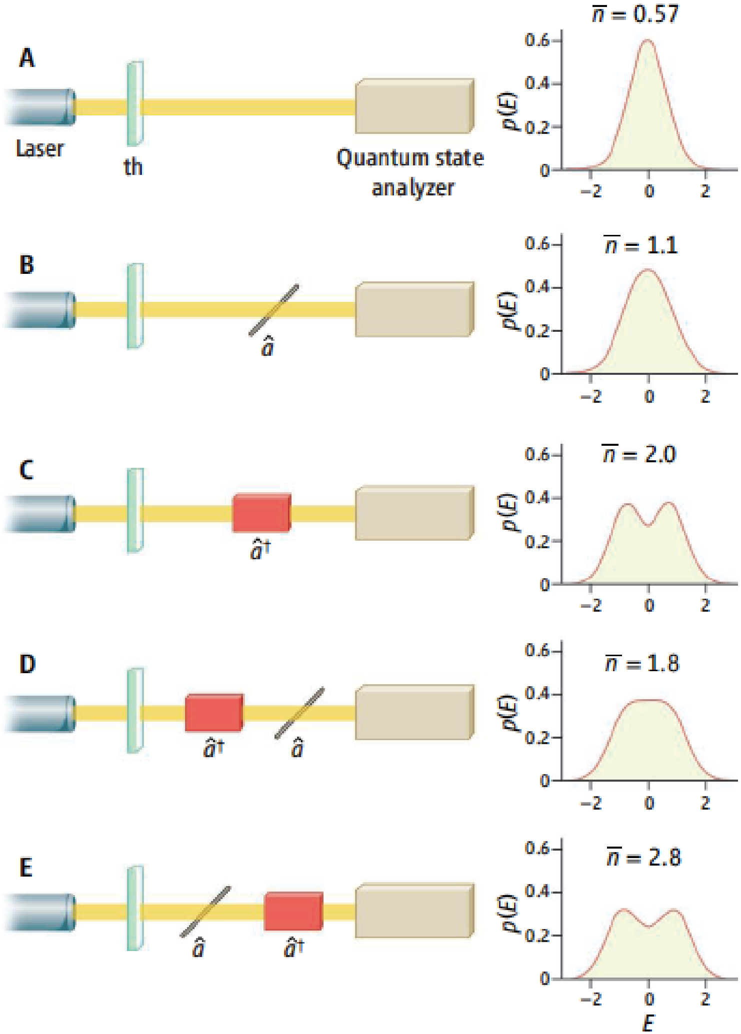
Note that image information is carried primarily by the phase, not the amplitude of the optical field

Presented at CERC Group Meeting, April 20, 2016

PHYSICS

Quantum Weirdness in the Lab

Robert W. Boyd, Kam Wai Clifford Chan, Malcolm N. O'Sullivan

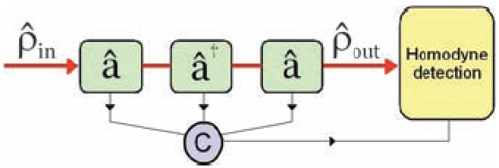


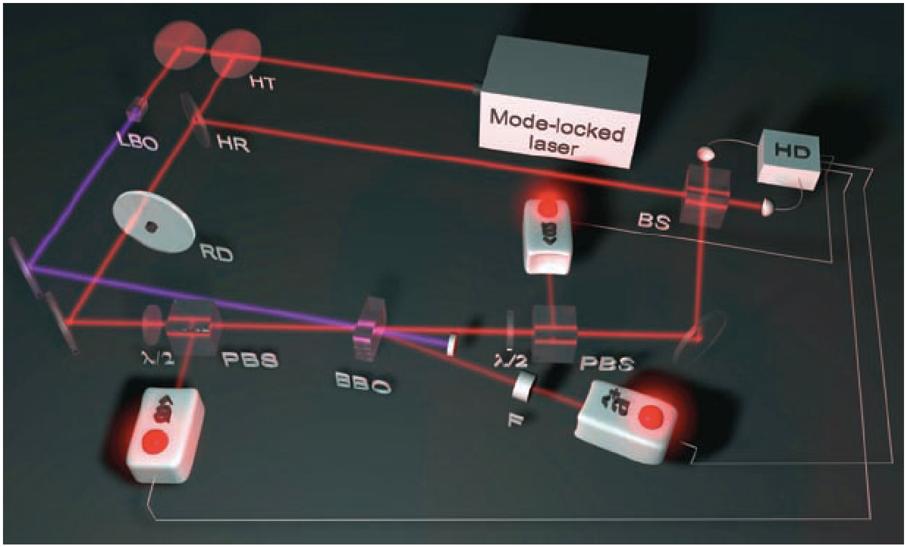
In an intriguing and illustrative report on page 1890 of this issue, Parigi *et al.* (*3*) present the results of a laboratory demonstration of what happens in the quantum mechanical operations of photon creation and annihilation, which lacks commutativity. These authors add a single photon to a light beam, which corresponds to the action of the standard quantum mechanical creation operator $\hat{a}^\dagger$. They can also subtract a single photon from the light beam, which corresponds to the annihilation operator $\hat{a}$.

Probing Quantum Commutation Rules by Addition and Subtraction of Single Photons to/from a Light Field

Valentina Parigi,[1] Alessandro Zavatta,[2] Myungshik Kim,[3] Marco Bellini[1,4]*

The possibility of arbitrarily “adding” and “subtracting” single photons to and from a light field may give access to a complete engineering of quantum states and to fundamental quantum phenomena. We experimentally implemented simple alternated sequences of photon creation and annihilation on a thermal field and used quantum tomography to verify the peculiar character of the resulting light states. In particular, as the final states depend on the order in which the two actions are performed, we directly observed the noncommutativity of the creation and annihilation operators, one of the cardinal concepts of quantum mechanics, at the basis of the quantum behavior of light. These results represent a step toward the full quantum control of a field and may provide new resources for quantum information protocols.





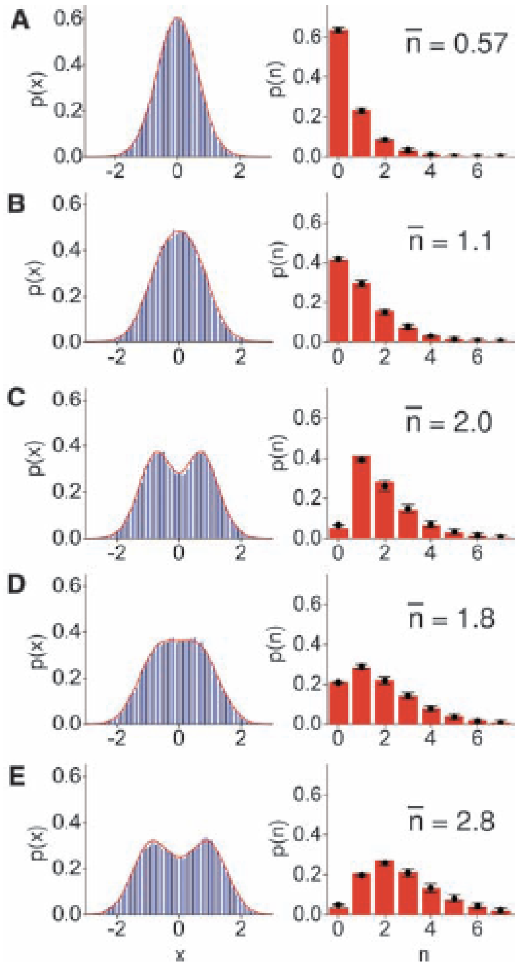


Fig. 3. Experimental quadrature distribution histograms and theoretical curves (superposed solid lines) for (**A**) the original thermal state; (**B**) the photon-subtracted state; (**C**) the photon-added state; (**D**) the photon-added-then-subtracted state; (**E**) the photon-subtracted-then-added state. The second column

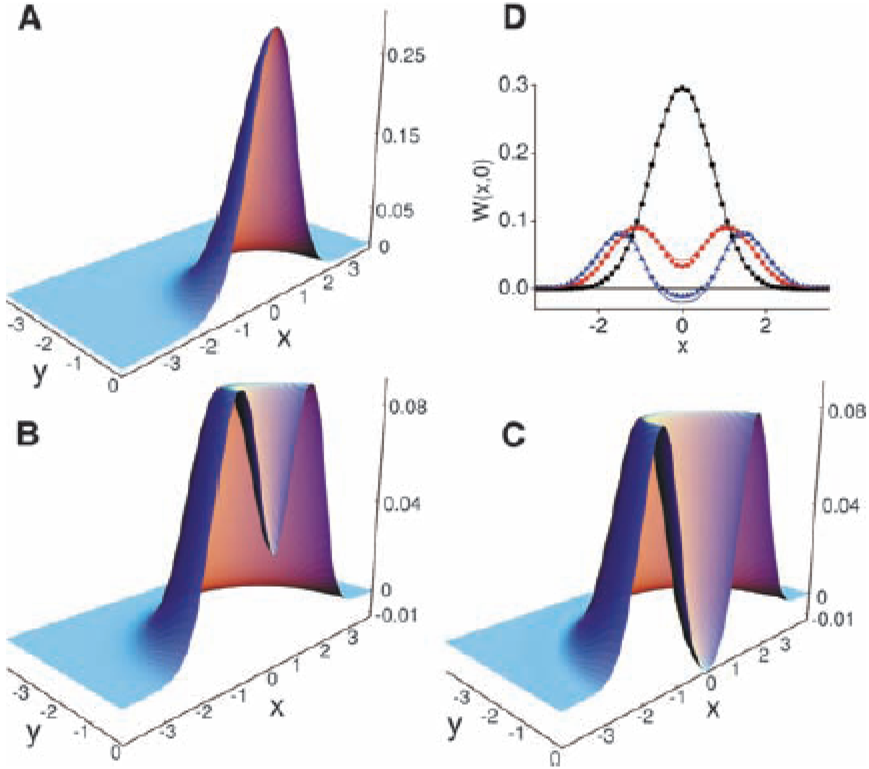


Fig. 4. Experimental WFs (corrected for detection inefficiency) for (**A**) the original thermal state; (**B**) the photon-added-then-subtracted state; (**C**) the photon-subtracted-then-added state. (**D**) presents sections of the above Wigner functions (black squares correspond to the thermal field; red circles and blue triangles correspond to the photon-added-then-subtracted and the photon-subtracted-then-added states, respectively), together with the corresponding theoretical predictions (solid curves) (*2*).

Enhanced Interferometry Using Photon-Subtracted Thermal States

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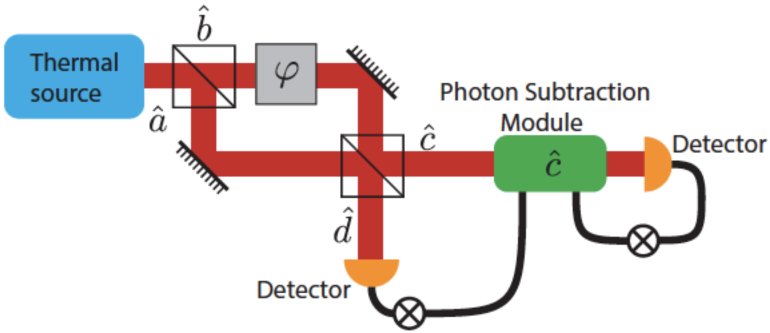
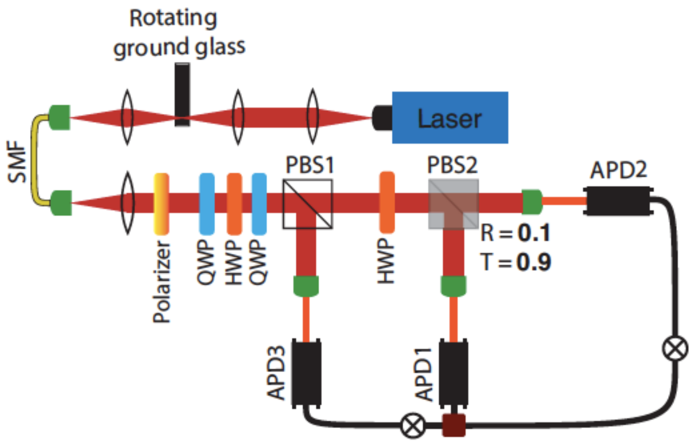
We propose and implement a quantum procedure for enhancing the sensitivity of the phase shift experienced by a weak beam of light possessing thermal statistics in passing through a phase object. We implement photon subtraction from the light field exiting an interferometer possessing the phase object in one of its arms. As a consequence of photon subtraction, the remaining light field acquired strong non-classical statistics, and this allows us to determine the signal with improved signal-to-noise ratio. This method can be used to enhance the sensitivity in a variety of practical applications, including that of forming the image of an object illuminated only by weak thermal light.

the concept

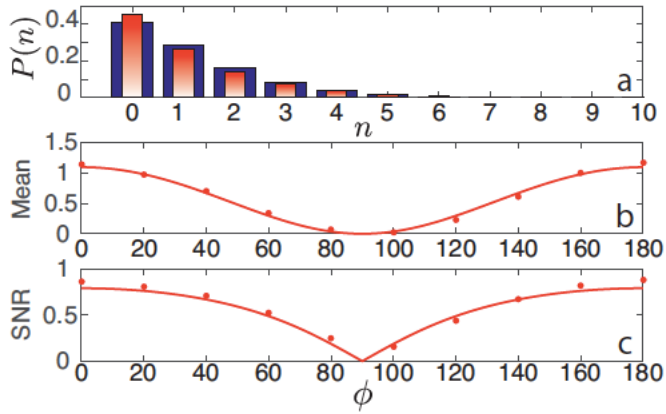


the implementation

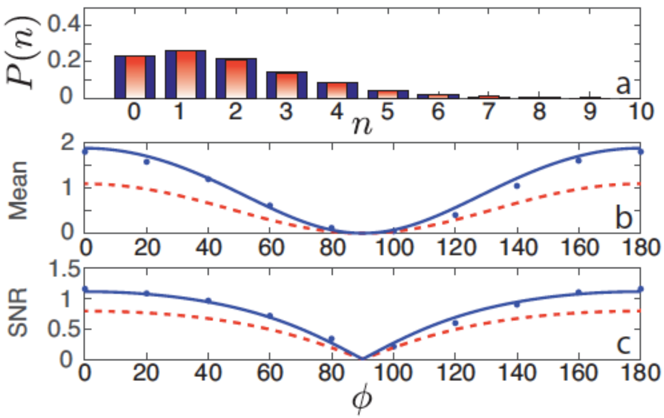


Results

without photon subtraction



with one-photon subtraction



with two-photon subtraction