Multi-spatial-mode squeezed light for direct quantum imaging

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The development of quantum sensors is an integral part of the nowadays quantum technologies, in an effort to transform quantum physics to industrial applications. In particular, squeezed light can be used to improve the performance of optical sensors in cases where their sensitivity is limited by the fundamental shot noise of light. Multi-spatial-mode (MSM) squeezing extends this benefit to imaging and spectroscopy techniques, by exploiting the reduction of quantum noise on multiple spatial modes simultaneously [1]. For instance reduction of the quantum fluctuations on the relevant quadrature, amplitude for absorption imaging or phase for phase-contrast imaging, leads to smoother images. Squeezed light illumination can even deliver increased spatial resolution in certain super-resolution schemes, and is likely to play a role in those applications where the signal to noise ratio cannot be improved by simply increasing the amount of light shone on the object. This can be the case for fragile biological samples, where an optical heating threshold exists.

Four-wave mixing (FWM) in hot atomic vapors has been shown to be an efficient way to produce MSM squeezed light [2,3]. So far, most experiments have focused on the continuous detection of light, sacrificing resolution and operating at analyzing frequencies high enough to avoid technical noise [2,3]. Here we report on the direct observation of spatial intensity-difference squeezing between twin beams with a CCD camera. The twin beams are generated by FWM in hot rubidium vapor and their intensity fluctuations are spatially correlated. We show that from shot-to-shot, the fluctuations of the photon numbers in any matching areas of the twin beams are identical, with an uncertainty less than the shot noise, i.e. less than the square root of the mean photon number in these areas. To show this, we have developed a spectroscopy technique producing the spatial noise power spectrum of the intensity difference, as well as a wavelet analysis, which reduces the impact of overall technical noise on the twin beams. Together, these techniques inform us on the spatial structure of the squeezing and ultimately help us to determine the size and shape of objects that could be better detected with this form of quantum illumination.

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