Comment on ”Can Two-Photon Correlation of Chaotic Light be Considered as Correlation of Intensity Fluctuations ?”

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A Comment on the Letter by G. Scarcelli, V. Berardi and Y. Shih, Phys. Rev. Lett. 96, 063602 (2006).

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In a recent letter \cite{1}, Scarcelli, Berardi and Shih discuss their recent experiments that demonstrated ghost imaging by two-photon correlation with chaotic light. The main claim of the letter is that the observed two-photon correlation cannot be explained by a classical model. Here I show how a classical reasoning similar to the classical explanation of the Hanbury-Brown and Twiss experiment \cite{2}, can fully account for the results.

In the experiment, a beam of chaotic light from a pseudo-thermal source (a laser beam that its spatial phase is randomized by a moving diffuser) is split by a beam splitter; one beam is sent through an aperture object to a large bucket detector and the other is sent to a small detector, positioned at the same distance from the beam splitter as the object. The ghost image is detected by measuring the intensity correlation between the two detectors as the position of the small detector is scanned across the beam.

Classically, chaotic thermal light can be considered as a random noisy field $E(x, t)$ with a transverse correlation length (speckle size) $l_s$ and correlation time $\tau_c$ that are short compared to the dimensions of the beam and the integration time, respectively. The beam splitter later produces two identical copies of this noisy field $E_1(z = 0, x, t) = E_2(z = 0, x, t)$, which propagate one to the object and the other to the small detector. Since the two copies are identical they remain so during propagation of any distance $z$, so the field (and intensity) distributions are the same at any two planes of equal distance from the beam splitter

$$E_1(z, x, t) = E_2(z, x, t). \tag{1}$$

It is therefore clear that regardless of the distance from the source or the beam splitter, the intensities at equivalent points in the two beams are fully correlated, while at points that differ by more than the speckle size they are uncorrelated. Assuming Poissonian statistics for the spatial intensity distribution, the correlation between equivalent points can be shown to be two times larger than the uncorrelated background, as one expects for thermal light \cite{3}.

Let us consider first a simple object that is composed of two small holes in an opaque screen at points $y_1, y_2$, each hole is small compared to the correlation length of the intensity and the distance between them is large compared to the correlation length. It is clear that as the small detector is scanned across the equivalent plane, cross correlation peaks will appear at $x = y_1$ and $x = y_2$, exactly as shown in Fig. 2 of \cite{1}. Since only one of the two holes can contribute to the correlation at every point, the signal to background ratio is only 3:2 in this measurement, and will continue to degrade as the object becomes more complex, which is a consequence of the use of a bucket detector. Yet, contrary to the authors claim, the use of a bucket detector does not wash out the correlation completely. In fact, for an object aperture of area $A$ and small detector area $a$, the signal to background ratio $S$ is

$$S = \frac{1 + (A/a)}{(A/a)} \tag{2}.$$

The area of the small detector is limited by the speckle area $l_s^2$, which imposes the diffraction limit on the imaging resolution. Consequently, a tradeoff exists between the imaging resolution (small detector area $a$), and the detection contrast $(S)$. For a given $a$, the maximal area of the object is limited by the noise in the correlation measurement.

The inclusion of a lens in one arm of the experiment images (and magnifies) the intensity distribution from a plane $z = z_1$ to another plane $z = z_2$, but does not affect the basic concept. Accordingly, the intensity cross-correlation properties discussed previously, are just copied (and stretched) from one plane to the other, which explains the results shown in figure 3 of \cite{1}.

It is true, as the authors claim that the results cannot be modelled by the Hanbury-Brown and Twiss formula, but this is only because this formula inherently assumes far-field (it was developed originally for astronomical measurements). Yet, the basic phenomenon here and in the Hanbury-Brown Twiss experiment is exactly the same, since the inherent correlation between the two beams exists in any plane from near field to far field.

\cite{1} G. Scarcelli, V. Berardi, and Y. Shih, Phys. Rev. Lett. 96, 063602 (2006).
[2] R. Hanbury-Brown and R. Q. Twiss, Nature 177, 27 (1956).

[3] J. W. Goodman, *Statistical Optics* (John Wiley and Sons, 1985), 1st ed.