

## Quantum Physics

# Two-photon speckle as a probe of multi-dimensional entanglement

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We calculate the statistical distribution  $P_2(I_2)$  of the speckle pattern produced by a photon pair current  $I_2$  transmitted through a random medium, and compare with the single-photon speckle distribution  $P_1(I_1)$ . We show that the purity  $\text{Tr } \rho^2$  of a two-photon density matrix  $\rho$  can be directly extracted from the first two moments of  $P_1$  and  $P_2$ . A one-to-one relationship is derived between  $P_1$  and  $P_2$  if the photon pair is in an  $M$ -dimensional entangled pure state. For  $M \gg 1$  the single-photon speckle disappears, while the two-photon speckle acquires an exponential distribution. The exponential distribution transforms into a Gaussian if the quantum entanglement is degraded to a classical correlation of  $M \gg 1$  two-photon states. Two-photon speckle can therefore discriminate between multi-dimensional quantum and classical correlations.

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