Quantitative Super-Resolution Microscopy Using Nonclassical Photon Statistics

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We demonstrate the use of nonclassical photon statistics to enhance the spatial resolution of an optical microscope beyond the diffraction limit. By measuring the photon-number distribution of fluorescence emitted by nitrogen-vacancy (NV) centers in nanodiamond particles, we infer the number of NVs within individual particles and resolve spatial features smaller than the microscope's point spread function. Figure 1 shows NV fluorescence collected using a home-built confocal microscope and detected with an array of four single-photon avalanche photodiodes. The nanodiamonds are approximately 40 nm in size and host between one and ~100 NV centers, resulting in a wide range of observed brightness. Under the assumption of equal emitter brightness, the number of NVs N can be estimated from the second-order correlation function via $g^{(2)} \simeq 1 - 1/N$ (values shown adjacent to particles). In practice, NVs exhibit unequal brightness due to their dipole orientation and Purcell-induced modifications of their radiative rates. We are therefore developing analysis algorithms that improve emitter-number estimation using the full photon-statistics map, enabling quantitative fluorescence microscopy for general single-photon emitter systems.

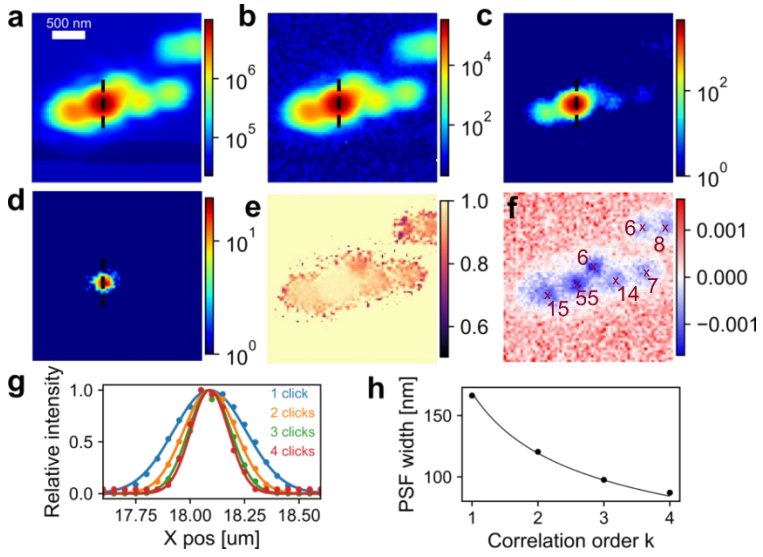

Fig. 1: ***Confocal scan of nanodiamonds****. **a–d** show images constructed from 1-, 2-, 3-, and 4-click events, respectively. **e** shows the $g^{(2)}$ map, while **f** displays the Mandel Q parameter. Panels **g** and **h** show the point spread function (PSF), extracted along the black dashed line in **a-d**, narrowing as √k [black continuous line] with increasing correlation order k, consistent with Refs [1-2].*

References

[1] D Monticone et al. "Beating the Abbe Diffraction Limit in Confocal Microscopy via Nonclassical Photon Statistics," Phys. Rev. Lett. 113, 143602 (2014).

[2] R Tenne et al. "Super-resolution enhancement by quantum image scanning microscopy," Nat. Photon. 13, 116-122 (2019).