Quantum enhanced superresolution microscopy
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Far-field optical microscopy beyond the Abbe diffraction limit, making use of nonlinear excitation (e.g. STED), or temporal fluctuations in fluorescence (PALM, STORM, SOFI) is already a reality. In contrast, overcoming the diffraction limit using non-classical properties of light is very difficult to achieve due to the requirement of nonlinearity and the fragility of quantum states of light. Here, we experimentally demonstrate superresolution microscopy based on quantum properties of light naturally emitted by fluorophores used as markers in fluorescence microscopy. Our approach is based on photon antibunching, the tendency of fluorophores to emit photons one by one rather than in bursts. Although a distinctively quantum phenomenon, antibunching is readily observed in most common fluorophores even at room temperature.

This nonclassical resource can be utilized directly to enhance the imaging resolution, since the nonclassical far-field intensity correlations induced by antibunching carry high spatial frequency information on the spatial distribution of emitters [1]. Detecting photon statistics simultaneously in the entire field of view, we were able to detect non-classical correlations of the second and third order, and reconstructed images with resolution significantly beyond the diffraction limit.

Alternatively, we demonstrate the utilization of antibunching for augmenting the capabilities of other commonly used superresolution techniques, such as localization-based superresolution imaging [2] or image-scanning confocal microscopy [3]. For this end, we use a novel detector comprised of an array of single photon detectors connected to a densely packed fiber bundle, acting as a low-noise single photon sensitive camera, and enabling the measurement of photon correlations. These features allow us to enhance the spatial resolution with which multiple emitters can be imaged and localized compared with techniques that rely on an integrated photon count using CCD cameras. An example for resolution enhancement by quantum image scanning confocal microscopy is given in Fig. 1.

Finally, new modalities for harnessing quantum photon statistics for super-resolved imaging will be discussed.


Fig. 1: Images of a microtubule-labeled 3T3 cell stained with quantum dots by: confocal (left), image-scanning confocal (center) and quantum image scanning confocal (right). Scale bar is 0.5μm.