Super-resolution by accessing spatiotemporal correlations

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Abstract

We consider using a spatiotemporally correlated field produced by a superradiant quantum antenna and measurements of delayed intensity correlation functions for super-resolving imaging. For estimating a distance between a pair of objects, measuring the delayed second-order correlation function allows avoiding "the Rayleigh catastrophe". For estimating positions of a larger number of objects, measurement of the delayed function is able to provide a considerable accuracy gain over the measurement with the zero-delayed function. We show that super-resolution with the delayed function measurement can be also achieved for estimating parameters of the antenna.

A possibility to drastically improve resolution of an object by illuminating it with correlated photons started a novel subfield of research named "quantum imaging". Measuring simultaneous correlations of intensity fluctuations, one can exploit photon correlations of the imaging source and significantly improve resolution in comparison with the intensity detection. However, in this case also information loss unavoidable for direct intensity detection eventually leads to the phenomenon known as "the Rayleigh catastrophe". When the details of the imaged object become much smaller than the certain value defined by the wavelength of the imaging field and parameters of the imaging set-up (for example, the "Abbe limit"), the information about any individual detail tends to zero making practically unfeasible inferring object parameters from the measured function.

Our statement is that the information sufficient for super-resolution might be retained simply by measuring intensity correlations for different times implementing an imaging source with temporal and spatial correlations. Such a measurement allows capturing time-correlations present in the imaging field and use them for avoiding "the Rayleigh catastrophe". We illustrate our statement with the simplest archetypical example of the source creating pairs of both spatially and temporally correlated photons: just two initially excited two-level systems interacting through a common reservoir of field modes and thus spontaneously decaying by photons emission into the modes of the reservoir. The emitted field of such a basic superradiant quantum antenna in the far-field zone serves as a source for imaging.

We consider four cases: a detection of a position change of our antenna, near-field imaging of several point objects, far-field imaging of several point objects, and, finally, inference of emitters separation. We show that for considered cases of imaging of just two objects, and also for inference of the emitters separation or antenna rotation angle, measuring the delayed second-order intensity correlation functions leads to the non-zero Fisher information when the parameters in question tend to zero. But this effect disappears when only the zero-delay correlation function is measured. We show that for all the considered measurements apart form the inference of emitters separation, the super-resolution can be rather robust with respect to uncertainty of the detection moment. Finite time-resolution of realistic detectors is not spoiling super-resolution. For imaging of more than two objects "the Rayleigh catastrophe" is back, however, the resolution is much improved in comparison with the measurement of zero-delayed correlation functions.