Large reduction of quantum fluctuations of light from a single emitter by an optical nanostructure

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Optical nanostructures are promising candidates to explore the limits of light-matter interactions at the quantum regime [1]. As a fingerprint of the granularity of quantum light in such interactions, antibunching has been assessed in the fluorescence of single emitters coupled to nanostructures. In contrast, electromagnetic field fluctuations below shot noise [2], which mirror the nonclassical wave nature of light, are challenging to measure [3] at the single emitter level and have not been measured in these hybrid systems. Such reduced quantum fluctuations are unique characteristics of squeezed states of light [4] which are relevant for overcoming classical application limits in, for instance, precision measurements, spectroscopy, and optical communications. Despite recent experimental [3] and theoretical [5] advances on the microscopic scale, sources of squeezed light commonly depend yet on optical nonlinearities of macroscopic systems, typically crystals or atomic vapors [4]. Here, we present our recent proposal [6] for creating squeezed light at the nanoscale from a single quantum emitter mediated by a nanostructure.

Our model is illustrated with a two-level system placed close to a gold nanosphere, which are illuminated by a plane wave that is linearly polarized (see Fig. 1, left). We are interested in studying the degree of squeezing detectable in the light scattered by the hybrid system in the near and far field regions.

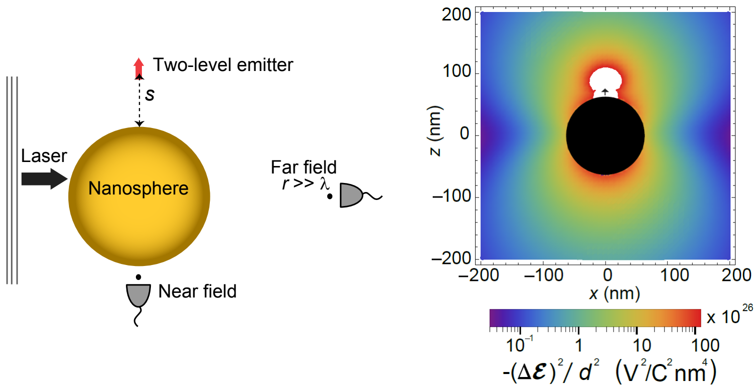

Fig. 1 (Left) Sketch of the hybrid system consisting of a two-level system separated from a gold nanosphere with detection points in the far and near fields. (Right) Near field manipulation of squeezing over the nanosphere cross section.

Introducing the electric field operator in the variance $(\Delta\hat{\mathscr{E}})^2 = \langle : (\hat{E} - \langle \hat{E} \rangle)^2 : \rangle$ for the electric field quadrature, $\hat{E}(\mathbf{r},t) = \hat{E}^{(+)}(\mathbf{r},t) + H.c.$, and using normal ordering (:) to compare directly the variance to the shot noise, we obtain the electric field fluctuations that characterize squeezed states of light, i.e., when $(\Delta\hat{\mathscr{E}})^2 < 0$. Importantly, we identify the quantum fluctuations in the optical coherence $\hat{\sigma}$ as the main contribution to generate electromagnetic squeezing. These are affected by the enhancement of the driving field and the spontaneous decay rate due to the presence of the nanostructure, which allow to strongly relax the conditions for overcoming shot noise in terms of bandwidth and excitation power. Moreover, the overall amplitude of the field fluctuations is also modified, permitting its quantum fluctuations to be significantly reduced with respect to shot noise, specially in the near field as shown in Fig. 1 (right). These results open a pathway towards the experimental measurement of such squeezed states of light in state-of-the art setups and their manipulation on the nanoscale, with prospects for advancing applications at the single-photon level.

References

[1] M. S. Tame, K. R. McEnery, Ş. K. Özdemir, J. Lee, S. A. Maier, and M. S. Kim, "Quantum plasmonics," Nat. Phys. **9**, 329 (2013).
[2] D. F. Walls, and P. Zoller, "Reduced quantum fluctuations in resonance fluorescence," Phys. Rev. Lett. **47**, 709 (1981).
[3] A. Ourjoumtsev, A. Kubanek, M. Koch, C. Sames, P. W. Pinkse, G. Rempe, and K. Murr, "Observation of squeezed light from one atom excited with two photons," Nature, **474**, 623 (2011).
[4] W. Vogel, and D.-G. Welsch, *Quantum optics*, (Wiley Verlag, Weinheim, 2006)
[5] P. Grünwald and W. Vogel, "Optimal Squeezing in Resonance Fluorescence via Atomic-State Purification," Phys. Rev. Lett., **109**, 013601 (2012).
[6] D. Martín-Cano, H. R. Haakh, K. Murr, and M. Agio, "Large suppression of quantum fluctuations of light from a single emitter by an optical nanostructure," Phys. Rev. Lett., **113**, 263605 (2014).

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