Quantum enhanced absorption measurement and wide field microscopy

***Ivano Ruo-Berchera*[1], *Nigam Samantaray*[1], *Alice Meda*[1], *Elena Losero*[1], *Alessio Avella*[1], *Marco Genovese*[1,2]**

1. Istituto Nazionale di Ricerca Metrologica (INRIM), 91Strada delle Cacce, IT-10135 Turin, Italy

2. INFN Sezione di Torino, via P. Giuria 1, 10125, Torino, Italy

Several proof of principle experiments have demonstrated the advantages of quantum metrology and sensing schemes over classical counterparts, although the present challenge is to overcome the gap between the proof of principles and the real applications. For example, probing and imaging delicate systems using small number of photons with true and significant sensitivity improvement (without post selection or a-posteriori loss compensation) is extraordinarily important. Here, we present the latest achievements in quantum enhanced imaging exploiting photon number correlations in twin beams. First we investigate experimentally different estimators of the absorption, and compare the results with the best known strategy (i.e. using Fock states probe) [1], also discussing some practical issues concerning the "hidden" assumptions on the stability of the source and detector response. Then, we describe the realization of a sub-shot-noise (SSN) wide field microscope [2], based on spatially multi-mode non-classical photon number correlations [3]. The microscope produces real-time images of 8000 pixels at full resolution, for $(500\mu m)^2$ field-of-view, with noise reduced at 80% of the shot noise level in each pixel. This is suitable for absorption imaging of complex structures, like biological samples. By simple post-elaboration, specifically applying a "quantum enhanced median filter", the noise is further reduced (less than 30% of the shot noise level) by setting a trade-off with the resolution. It realizes the best sensitivity per incident photon ever achieved in absorption microscopy.

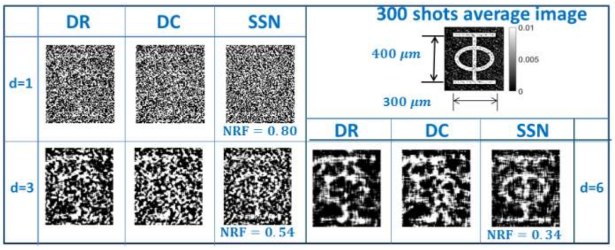

Fig. 1. Experimental imaging of a sample (in this case a ultra-thin metallic deposition on a glass slide with absorption coefficient of 1%). Single shots of direct imaging at the shot noise level (DR), differential classical imaging (DC) and sub-shot-noise imaging (SSN) are compared. The higher spatial resolution is 5 μm (d=1, top left series) while images at lower resolution (L = d*5μm, specifically for d=3 and d=6) are obtained by the application of a median filter to the shots at full resolution. From d = 3 the object start to appear in the SSN image, while it remains almost undefined in the classical images. The number of photon per pixel (which size corresponds to 5 μm in the object plane) is n_{ph}=1000. The top-right panel represents the object reconstructed by 300 shots average.

Fig. 1 shows the wide field imaging of a test sample. The performances achieved in [2] are far beyond the ones reported in previous proofs of principle of lens-less SSN wide field imaging [4], improving the spatial resolution by a factor 10-100 and reaching for the first time a true and significant improvement of the sensitivity with respect to any classical absorption microscopy at the same illumination level without any post-selection.

We believe that this technique has the potentiality for a wide-spread use in absorption microscopy of delicate systems or to investigate the properties of photosensitive structure at few-photons level.

References

[1] G. Adesso, F. Dell'Anno, S. De Siena, F. Illuminati, and L. A. M. Souza," Optimal estimation of losses at the ultimate quantum limit with non-Gaussian states", Phys. Rev. A **79**, 040305 (2009); A. Monras and M. G. A. Paris, "Optimal Quantum Estimation of Loss in Bosonic Channels"Phys. Rev. Lett. **98**, 160401(2007).

[2] N. Samantaray , I. Ruo-Berchera, A. Meda, M. Genovese 2016, "Realisation of the first sub shot noise wide field microscope," Light Sciene & Applications, doi: 10.1038/lsa.2017.5 (to appear); arXiv:1612.06169 [quant-ph].

[3] E. Brambilla, L. Caspani, O. Jedrkiewicz, L. A. Lugiato, and A. Gatti, "High-sensitivity imaging with multimode twin beams", Phys. Rev. A **77**, 053807 (2008).

[4] G. Brida, M. Genovese & I. Ruo Berchera, "Experimental realization of sub-shot-noise quantum imaging," Nature Photonics **4**, 227 (2010); G. Brida, M. Genovese, A. Meda, & I. Ruo Berchera, "Experimental quantum imaging exploiting multimode spatial correlation of twin beams," Phys. Rev. A **83**, 033811 (2011).