



Master in Photonics – “PHOTONICS BCN” Master ERASMUS Mundus “EuroPhotonics”

MASTER THESIS PROPOSAL

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Laboratory: Quantum Engineering of Light

Institution: ICFO

City, Country: Barcelona, Spain

Title of the master thesis: Analysis of the fundamental sensitivity limits of nonlinear interferometers for imaging and sensing with quantum estimation theory tools

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Summary of the subject (maximum 1 page):

Nonlinear interferometers are interferometers that contain optical parametric amplifiers (nonlinear crystals) inside [see Figure 1]. They have received a lot of attention recently for applications in imaging, sensing, spectroscopy, microscopy and optical coherence tomography. From a practical point of view, an advantage of these systems is that one can choose a wavelength for the idler beam (i_1 and i_2), which interacts with the sample and is never detected, and another wavelength for the signal beam (s_1 and s_2), which is detected with a high efficiency. This is why the general term “measurements with undetected photons” is used for such systems.

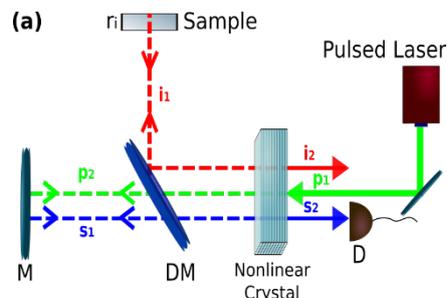


Figure 1. Sketch of a SU (1,1) nonlinear interferometer (from G. J. Machado, G. Frascella, J. P. Torres, and M. V. Chekhova, *Optical coherence tomography with a nonlinear interferometer in the high parametric gain regime*, Applied Physics Letters **117**, 094002 (2020)).



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Most of these systems work in the low parametric gain regime of parametric amplification, where low photon fluxes are generated. In this regime it is necessary to use single-photon detectors or CCD cameras with very high sensitivity, and long integration times to obtain high-quality images, which put strong requirements on the stability of the optical systems. However, the advantages for sensing and imaging of nonlinear interferometers still exist in the high-parametric gain regime detectors, which provide lower integration times for obtaining high-quality images and avoid using single-photon detectors or CCD cameras with very high sensitivities. Standard spectrometers can be used instead.

In this project we aim at obtaining the fundamental sensitivity limits that these systems can achieve for imaging and sensing. For this we will need to use quantum estimation theory tools and calculate the quantum Fisher information and the Cramer-Rao sensitivity bound. What are the sensitivity limits for the low and high parametric gain regimes? How can we saturate the limits, i. e., make a measurement that achieves the highest sensitivity allowed? We will consider simple but important cases in sensing to illustrate our results.