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

MASTER THESIS PROPOSAL

Dates: April 2025 – July or September 2025

Laboratory: BiOPT – Wavefront Engineering Group, Departament de Física Aplicada

Institution: Universitat de Barcelona (UB)

City, Country: Barcelona, Spain

Title of the master thesis: Robustness of vector beams for super-resolution microscopy.

Name of the master thesis supervisor and co-supervisor: David Maluenda & Estela Martín

Email address: dmaluenda@ub.edu

Phone number: +34 619 029 310

Mail address: Departament de Física Aplicada, Planta 5, Facultat de Física, Universitat de Barcelona, Martí i Franquès 1, Barcelona 08028, Spain

Keywords: Super-resolution microscopy, depletion (STED and RESOLFT) microscopy, fluorescence microscopy, vortex beams, donut beams, spatial light modulators, liquid crystal displays.

Summary of the subject:

Advanced optical microscopy techniques are extensively utilized in life sciences. Fluorescence microscopy, in particular, serves as a crucial tool for investigating biological processes at cellular and molecular levels. However, its spatial resolution is inherently constrained by the diffraction limit, which restricts the observation of structures smaller than approximately 200 nm. To address this limitation, non-optical methods like electron microscopy or atomic force microscopy have been explored since the mid-20th century. Despite their advancements, these methods lack the flexibility of visible light microscopy, which is highly compatible with molecular biology labeling techniques.

The advent of super-resolution microscopy in the early 21st century has surpassed the diffraction limit through purely optical methods. Techniques such as STED, RESOLFT, and SIM achieve nanometer-scale resolution but encounter challenges when studying fast biological processes. These techniques combine Gaussian beams with doughnut shaped beams. While Gaussian beams are robust against aberrations, some of the commonly-used doughnut beams are very sensitive to them. This drawback becomes especially relevant for astigmatism, since it depends on the field of view and deteriorates the quality of the beams depending on the specific imaging region of the sample. In this project, we will generate vector beams with a Liquid Crystal Display to produce highly focused doughnut beams suitable for super-resolution microscopy, and we will characterize them under different types and degree of aberrations.

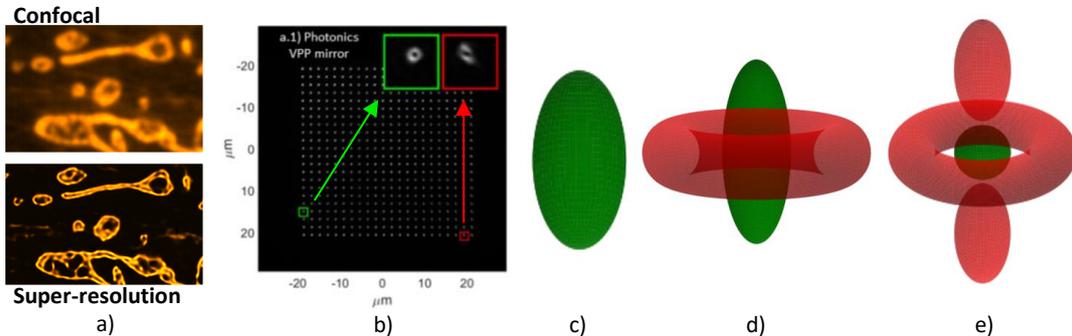


Figure 1. a) Comparison between confocal and super-resolution microscopy imaging. b) Quality of doughnut shaped beams at different regions on the sample plane. c-e) 3D PSF of a Gaussian beam (green) and two different doughnut shaped beams (red).

Objectives:

The objectives of this master’s degree project are: (i) to generate vector beams using a Liquid Crystal Spatial Light Modulator (LC-SLM); (ii) to characterize their three-dimensional Point Spread Function (3D PSF) under the influence of computer-generated aberrations; and (iii) to obtain improved super-resolution microscopy images. The student will work on the experimental setup to create highly focused doughnut beams, ensuring their quality and reproducibility. Then, the student will add on the LC-SLM different types and degrees of aberrations, such as astigmatism and higher-order aberrations, and analyse how these aberrations affect the 3D PSF of the vector beams by means of fluorescent molecules and nanobeads. Among different kinds of vector beams, azimuthally polarized light will be used as a benchmark to assess their sensitivity to aberrations and the quality of final super-resolution images.

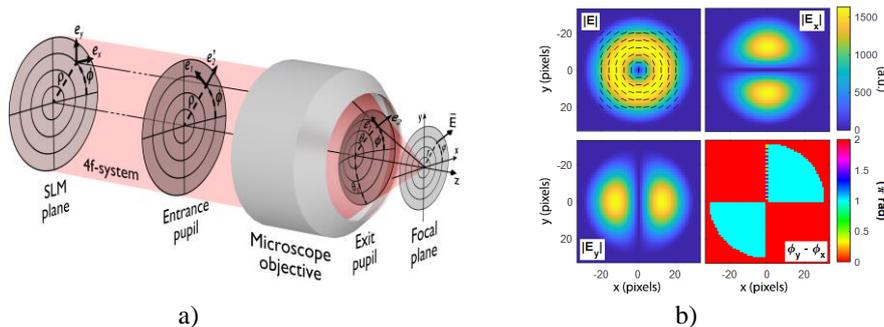


Figure 2. a) Diagram of the primary planes involved in the generation of vector beams, where \mathbf{e}_1 and \mathbf{e}_2 are the azimuthal and radial unit vectors, respectively. b) Component fields of an azimuthally polarized beam at the entrance pupil of the microscope objective, where the small lines at the $|E|$ subfigure indicate the local polarization direction.

Additional information:

* Required skills: Disposition for experimental work in a microscopy lab, interested in biophotonics, proficient in a computer language with preference for Matlab, Python and LabVIEW.

* Miscellaneous: Early incorporation is possible.