PhD proposal

Name of host organization: **Laboratoire d'Astrophysique de Marseille / Institut Fresnel**
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Title: **Metasurfaces with effective index tailoring for astronomical instrumentation in space**

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Summary of the subject:

Formation and evolution of galaxies, stellar physics, near Earth objects and exoplanets detection and characterization, these challenges could be overcome with a new generation of astronomical instruments on ground and in space. Among them, two candidates are foreseen: spectro-imagers offer unique capabilities for exploiting simultaneously photometry and spectroscopy; coronographs and wavefront sensors are the key sub-systems for revealing exoplanets orbiting around stars. We are developing at LAM new concepts of instruments using breakthrough technologies, including micro-mirrors arrays, non-planar blazed gratings and metasurfaces.
To optimize the spectrograph efficiency, a design of nanostructured blazed gratings is under development during a thesis within the collaboration between LAM, Institut Fresnel and FEMTO-ST. It uses topology optimization based on the resolution of the Maxwell's equations with the Finite Element Method (2D and 3D). Unprecedented efficiencies on very large wavelength bands, insensitivity with the polarization, low straylight nanostructured blazed gratings are foreseen. For exoplanet imaging a combination of extreme-AO / space telescope combined with extreme-coronography is required. We propose to develop metasurface-based coronographs with effective index tailoring for future space telescopes, and pathfinders on-ground and space demonstrators.

The goal of this thesis is to study the design, the realization and the characterization of metasurfaces with effective index tailoring for astronomical instrumentation in space. One key demonstrator will be especially developed: a scalar vortex coronograph for high contrast imaging. Three main axes will be searched:

1- ***Modeling***
Starting from the existing numerical tools developed by LAM-Institut Fresnel, including topology optimization based on finite element modelling of Maxwell's equations, a 3D design of a scalar vortex coronograph will be studied, exceeding the performance of the currently studied vector vortex coronograph suffering from polarization issues. By the resolution of direct and inverse problems for broadband/multi-wavelength, high efficiency and high contrast objectives, and using homogenisation of the effective index, innovative yet manufacturable designs of the nanostructured coronograph will be modelled, taking into account the final instrumental requirements.

2- Prototype realization and characterization
The most promising design of the scalar vortex coronograph will be realized at FEMTO-ST (Besançon) and characterized in LAM and Institut Fresnel facilities. Phase measurement in near-field and far-field (collaboration with ONERA, Paris) at nanometer scale, as well as straylight measurement will permit unprecedented characterization of such devices. Performances will be compared with the models and tolerancing of component key parameters with respect to the realization technologies will be determined.

3- Instrumental benefit evaluation
Optimization of the nanostructure design will also take into account a large number of high-contrast imaging system parameters, for end-to-end performance evaluation.

We are looking for an excellent candidate with a solid background and interest in physics/optics and with a strong taste for numerical developments.

Additional information:

Keywords: Metasurfaces, Finite Element Modelling, Topology optimization, Diffraction grating, Coronograph
Required skills: We are looking for highly motivated candidates with a background in general physics, optics and electromagnetism modelling. This project involves numerical developments and experiments.
Funding: CNRS / CNES
Begin/End dates: September 2025 – August 2028