DEPARTMENT OF ASTRONOMY AND STEWARD OBSERVATORY

Exo-Earth imaging and spectroscopy with phase-mask coronagraphs and adaptive optics strategies for future large observatories (v2)

Location

Laboratoire Lagrange of the Observatoire de la Côte d'Azur, Université Côte d'Azur and CNRS, in Nice, France, with research stays at Steward Observatory, University of Arizona (UA) in Tucson, USA.

Funding

Ph.D is funded through a joint CNRS-UA program (labelled "Habitability theses cluster" within the framework of the 80PRIME program).

Duration

36 months, envisioned starting and ending dates: November 1^{st}, 2023 - October 30^{th}, 2026.

Supervisors

Mamadou N'Diaye, CNRS research staff (Habilitation) - mamadou.ndiaye@oca.eu
Ewan S. Douglas, UA Assistant Professor - douglase@arizona.edu

Collaborators

Patrice Martinez, Mathilde Beaulieu (Lagrange), Kyle Van Gorkom, Jaren Ashcraft (UA)

Context

With Earth the one known example of a life-harboring planet, in a galaxy of billions of stars, the conditions for life to arise are poorly understood. Observations with high-contrast methods give us insights on their atmospheric composition, informing us on the diversity and habitability of Earth analogs. The high-contrast field addresses the image formation and the spectral analysis of faint companions around bright sources, attempting to reach a *contrast* of several orders of magnitude (star-planet flux ratios from 10^5 to 10^{10} at angular separation smaller than one arc second) in the visible and near-infrared bands.

A systemic approach combining all the key features in high-contrast instrumentation still needs significant development to determine the ultimate contrast performance and set constraints on telescope designs for exoEarth observations: (i) wavefront sensing for low-order aberration measurements, (ii) phase-mask coronagraphy for starlight diffraction suppression at short separations, (iii) wavefront control for high-contrast dark region around an observed star image.

Producing a dark zone at a few resolution elements λ/D (with λ and D denoting the observing wavelength and the telescope aperture) close to the star allows us to access a handful of faint rocky planets. A key problem to solve is the closed-loop sensing and control of speckles, the light seeds caused by picometer changes in optical surfaces, that contaminate such a dark zone. Stabilizing this region during the observation enhance the planet signal-to-ratio and maximize the science return of the observatories.

UA has recently produced a 10^8 dark region at $4\,\lambda$/D in visible light, with a contrast generation loop based on focal plane wavefront sensing and implicit Electric Field Conjugation, and without contrast stabilization loops (Van Gorkom et al., 2022). The research project revolves around (i) exploring novel phase mask coronagraph designs and wavefront control algorithms to produce a 10^9 dark zone down to 2λ/D, (ii) enhancing the real-time removal of spurious speckles in this dark region at the sub-nanometric level with a novel control loop – essential to efficiently observing telluric planets.

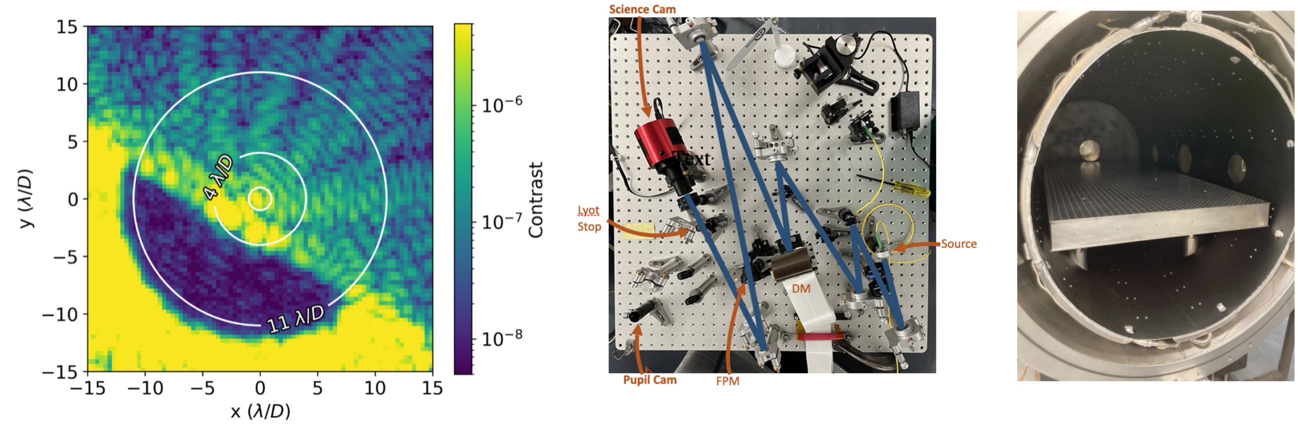

Figure 1: Left: High-contrast dark region generated in the UA Space Astrophysics Lab optical bench (middle) showing sensitivity to planets with 2×10^8 contrast at 0.06 arcsec for a 8 m telescope in the visible. Right: 1.2m diameter UA vibration-isolated thermal vacuum coronagraph test chamber in fabrication (delivery in Feb. 2022). The chamber is available to the team for testing wavefront sensing and control in a space-like environment.

Proposed work

The PhD candidate will develop wavefront sensing and control schemes based on interferometric methods such as the Self-coherent camera, the Lyot Low-order and the Zernike wavefront sensors to control the speckles in the dark region and reach stabilized contrasts at $2\lambda/\mathrm{D}$ of 10^7 in air with a segmented telescope aperture in Nice and 10^9 in vacuum with a clear telescope aperture in Tucson, in the presence of wavefront perturbations.

They will first review the state of the art of the existing methods before investigating the measurement of low-, mid- and high-order modes using the light rejected by phase-mask coronagraphs through numerical simulations. They will then explore the interaction of multiple wavefront control loops and investigate data fusion strategies using machine learning aspects for contrast stability.

Their works will lead to first in-lab experiments in Nice, on the SPEED testbed that is dedicated to rocky planet imaging with ELTs (PI: P. Martinez) and in Tucson, on the UA Space Coronagraph optical bench that explores wavefront control algorithms for exoplanet imaging missions (PI: E. Douglas).

Applicant's profile

The applicant will have a Master 2 degree level or equivalent (Engineering school or research master's degree) in physics, optics, astronomy or other related fields. Skills in geometric and Fourier optics, scientific programming (ideally in python), in-lab practice (laser handling, opto-mechanical components, detectors, optics alignment), or in data processing will be assets for this research work.

The applicant is expected to be enthusiast, dynamic, autonomous while having team work abilities. A strong interest in astronomy and interdisciplinary work will be a plus.

Application

Please send your application to the CNRS website, by including a curriculum, a cover letter and a transcript of grades/marks addressed to M. N'Diaye and E. S. Douglas.

All applications sent by June 8th, 2023 will receive full consideration. If necessary, we will afterwards accept applications on a rolling basis until the position is fulfilled.