Active correction of low-order aberrations for exo-Earth imaging with future large space observatories

Context

The detection of Earth analogs around Sun-like stars represents one of the most exciting goals in today's astronomy. Imaging and spectrally analyzing Earth twins will give us access to their physical parameters and the chemical composition of their atmosphere, providing us clues on their demography, the formation and evolution of planetary systems, and on the possible presence of life outside our solar system. Imaging these so-called exo-Earths at the horizon 2035 constitutes a tremendous instrumental challenge because of the 10 billions flux ratio (or contrast) between these telluric companions and their sun at angular separations of a few hundredths of an arcsecond, in the visible and infrared bands.

Space observatories with a 8 to 15 m size primary mirror is one of the most promising approaches to achieve the required resolution and sensitivity for such observations. With a primary mirror made up with several small 1 m size segments, this telesope is currently considered in the US with the LUVOIR and HabEx space mission concepts. These large segmented aperture telescopes will produce diffraction features in the image of an observed bright star, making the observation of nearby planets very challenging. Many optical devices called coronagraphs have recently emerged to reach a 10^{10} contrast at a few tens of milliarcsecond for the detection of Earth-like planets with these telescopes.

The telescope and its coronagraphic instrument will however have some faint thermal or mechanical drifts, yielding to optical aberrations in the system. These wavefront errors will lead to starlight leaks in the image of an observed star, making the extraction of the planet photons very demanding. Pointing errors, focus drifts and other low-order aberrations (astigmatism, coma, trefoil, spherical aberration) will modify the shape of an observed star image and reduce the coronagraph ability for starlight suppression at small separations. Wavefront control and stability down to some picometric levels are required over integration times from a few hours to several days to study Earth twins around Sun-like stars.

For the past few years, several strategies have emerged to achieve an ultra-stable stellar signal and one of the most promising schemes deals with Zernike phase contrast methods. Based on interferometry principles, this approach uses an optical device called a Zernike sensor that uses a phase dot to encode the phase aberrations in the telescope pupil into intensity variations in a relayed pupil. In the context of future space missions with exo-Earth imaging capabilities, one option consists in taking advantage of the stellar signal that is filtered by the coronagraph with this wavefront sensor to compensate for these aberrations with some deformable mirrors.

Proposed work

The student will develop innovative wavefront sensing paths based on the Zernike sensor to measure the low-order aberrations for the exo-Earth observation with future large segmented aperture telescopes in space. S/he will first review the literature to get familiar with the state of the art of the existing methods. The Ph.D student will then develop the formalism of Zernike wavefront sensors for the stellar signal that are filtered by different types of coronagraphs. With numerical simulations, s/he will study the impact of chromatic effects, coronagraph nature, telescope primary mirror co-phasing errors on the low-order aberration measurements and s/he will develop some control algorithms to compensate for the low-order wavefront errors of the system.

The student will also investigate new hybrid concepts combining coronagraphy and Zernike wavefront sensing to make the design of future exoplanet imagers compact and simplify the complexity of these systems. Her/his works will lead to first in-lab demonstrations in Nice, on the SPEED testbed that is dedicated to the direct imaging of rocky planets with the ELT (PI : Patrice Martinez) or in Calern observatory, on CIAO, a dedicated adaptive optics platform for general astrophysics (PI : Lyu Abe). This innovating real-time calibration will then be validated in laboratory by the student in Baltimore, in collaboration with Rémi Soummer and his group on HiCAT, the high-contrast testbed for exo-Earth imaging with complex aperture telescopes at the Space Telescope Science Institute in Baltimore. This NASA-created organization manages and heads the research made with the Hubble and the James Webb Space Telescopes.

Applicant's profile

The applicant will have a Master 2 degree level (Engineering school or research master's degree) in physics, optics, astronomy or other related fields. Skills in geometric and Fourier optics, scientific programming, in-lab practice (laser handling, opto-mechanical components, detectors, optics alignment), or in data processing will be an asset for this research work.
The applicant will be enthusiast, dynamic, autonomous while having team work abilities. A strong interest in astronomy and interdisciplinary work will be a plus.

Ph.D location and funds

The Ph.D work will take place at the Laboratoire Lagrange of the Observatoire de la Côte d'Azur, in the beautiful Valrose campus, in the heart of Nice. This work will be performed in partnership with Thales Alenia Space and in collaboration with the Space Telescope Science Institute in Baltimore, USA.
Ph.D funding requests are currently under review (Region SUD PACA, UCA, Thales Alenia Space).

Supervision

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Application

Please send your application by including a curriculum and a cover letter to Mamadou N'Diaye (`mamadou.ndiaye@oca.eu`).