Active control of mid-order aberrations based on Zernike wavefront sensors for exoearth imaging with future large space observatories

Context

The observation of Earth analogs around Sun-like stars represents one of the most exciting goals in today's astronomy. Imaging and spectrally analyzing terrestrial exoplanets will give us access to their physical parameters and the chemical composition of their atmosphere, providing us clues on the demography, the formation and evolution of planetary systems, and on the presence of biomarkers outside our solar system. However, imaging Earth twins around solar-type stars requires to overcome a 10 billion (10^{10}) star-to-planet flux ratio (i.e. contrast) at less than 100 milli-arcsecond (mas) in visible light.

Space observatories with a large segmented aperture telescope allow for achieving the resolution and sensitivity for such observations. Their combination with a coronagraphic instrument, an optical system for starlight suppression and wavefront control, represent a promising approach to produce high-contrast images for exoearth observations. However, the thermal or mechanical evolution of such a facility yield to optical wavefront error drifts that degrade contrast during the observing time, limiting our ability to retrieve planetary signals. Wavefront error stability at the sub-nanometric level is required to maintain the 10^{10} contrast during the observations for exoplanet imaging and spectroscopy.

Since 2019, our teams at Thales Alenia Space (TAS) and Observatoire de la Côte d'Azur (OCA) have been working together on two complementary approaches to achieve an ultra-stable stellar signal: (i) a very stable structure of the whole telescope and (ii) the use of active optics inside the coronagraphic instrument. In a joint thesis (2019-2022) on the second aspect, we have been exploring wavefront control strategies using Zernike phase-contrast methods to control pointing errors, focus drifts, and other first Zernike modes. In collaboration with the Space Telescope Science Institute (STScI) in Baltimore, we proposed and validated in laboratory a low-order wavefront control loop using a Zernike wavefront sensor through a coronagraph for wavefront and contrast stability (Pourcelot et al. 2022).

The control of mid-order aberrations, including fine cophasing errors of segmented aperture telescopes, represents another critical aspect for contrast stability during observations. Due to the signal filtering operated by the coronagraph, the previous low-order scheme cannot address these errors. In this PhD thesis, we propose to investigate a dedicated mid-order wavefront control loop based on an alternative Zernike sensor to ensure the temporal control and stability of these errors down to a sub-nanometric level.

Proposed work

The PhD candidate will develop innovative closed-loop correction based on Zernike sensors to control the mid-order aberrations for exoplanet observations with future large space telescopes. S/he will first review the state of the art of the existing methods before investigating the measurement of residual piston/tip/tilt errors, and higher-order modes through numerical simulations and based on TAS telescope models. S/he will then explore the interaction of multiple wavefront control loops and investigate data fusion strategies using machine learning aspects for contrast stability.

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) and on the KERNEL bench that explores novel interferometric concepts for the VLT (PI: Frantz Martinache).

This innovating real-time calibration will then be validated in laboratory by the PhD candidate in Baltimore, in collaboration with Rémi Soummer and his group on HiCAT, the high-contrast testbed for exoplanet imaging with complex aperture telescopes at STScI 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). All applications sent by end of May will receive full consideration. If necessary afterwards, we will accept applications on a rolling basis.