French Polytech network form for PhD Research Grants from the China Scholarship Council

This document describes one of the PhD subjects proposed by the French Polytech network. The network is composed of 15 engineering schools/universities. The document also provides information about the supervisor. Please contact the PhD supervisor by email for further information regarding your application.

Supervisor information	
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University name	Université Côte d'Azur (UCA)
Country	France

PhD information	
Title	Optimal wavefront shaping architecture for exoplanet direct imaging at short angular separations with segmented telescopes

Main topics regards to CSC list (3 topics at maximum)	Engineering science
Required skills in science and engineering	Optics, Astrophysics, Numerical Modeling. Knowledge of IDL, Matlab or eq.

Subject description (two pages maximum including biblio)

Understanding the formation, evolution and diversity of extrasolar planets is one of the challenges of modern astrophysics. In two decades, many discoveries have already revealed the complex nature of more than 4000 objects. The spectral characterization of these planets' atmosphere is crucial for determining the conditions for the appearance of life elsewhere than on Earth. Direct imaging is a suitable technique for the spectral study of the atmospheres of exoplanets similar to those of the Solar System. However, even if the latest results obtained with the most advanced instruments, from space or the ground, have allowed a spectacular breakthrough in the physics of exoplanets, they are still limited by the very high contrast and the angular proximity between exoplanets and their parent stars. Coronagraphs attenuate starlight without affecting the signal from their nearby environment to reveal it. However, atmospheric turbulence (for groud-based observatory exclusively), internal turbulence, polishing defects on optics, alignment errors and thermal expansions of telescopes that can vary over time further limit their performance. Active aberration correction techniques composed of deformable mirrors and wavefront sensors will then equip future high-dynamic range instruments such as NASA WFIRST, HaBEX or LUVOIR space projects or scientific instruments installed at the focus of extremely large telescopes (European ELT-PCS instrument). Both coronagraphy and active aberration correction (wavefront control & shaping) represent intensive research fields from which we expect to improve the detection yield.

In 2013 we started specific R&D for high-contrast imaging on large telescopes (ELT type) or spatial missions (post-JWST). This R&D, developed within the SPEED project [Segmented Pupil Experiment for Exoplanet Detection, https://lagrange.oca.eu/fr/accueil-speed, Martinez et al. 2015], aims to study observation methods in very high-dynamic range with a segmented telescope oriented towards short angular separations. The SPEED facility is a 750k€ project (hardware) installed in a clean-room environment (ISO7) and was funded (hardware and/or PhD thesis) by the French gouvernment, the European Union as part of the FEDER program, the PACA région, the Observatory of Côte d'Azur, the Lagrange Laboratory, the University of Côte d'Azur, the French spatial agency (CNES) and Airbus Defense and Space. Access to short angular separations opens the way to a scientific niche of prime importance: exoplanets orbiting around late-type (M) stars. The very high density of M-type stars in the environment close to our Sun (~ 80%) makes them excellent candidates for detecting exoplanets in the habitable zone. The Phase Induced Amplitude Apodization Complex Mask Coronagraph (PIAACMC, Guyon et al.

2014, Martinez et al. 2020) is a coronagraph that approaches the theoretical limits of detection and accommodates complex pupil architecture (on-axis telescope, central obstruction, primary mirror segmentation, etc.). Obtaining high contrast in the field of observation is related to (1) the measurement of the wavefront, ideally on the scientific image downstream of the coronagraph, (2) to the control and shaping of the wavefront by using one or more deformable mirrors.
For aspect (1), we have proposed an alternative design to the well-known Self-Coherent Camera (SCC, Baudoz et al. 2005). The SCC allows efficient measurement of the complex field on the coronagraphic image by taking advantage of the inconsistency between stellar and planetary lights to spatially modulate the speckles. In 2019 we proposed an alternative design of the SCC : the Fast-Modulated SCC (FM-SCC, Martinez et al. 2019), that we expect to be well adaptated to the PIAACMC.
For aspect (2), a deformable multi-mirror architecture (active optics) combined to the PIAACMC is implemented on SPEED. The student will work on the SPEED facility that offers ad-hoc environment complex enough and mimicking the next generation of observatories pupil fragmentation.

The prime objective of the thesis concentrate on quasi-static speckle control compensating for the bench optical aberrations and gradually advancing towards the most advanced techniques to create a very high contrast dark hole at the science detector. The thesis work will consist of obtaining the expected dark-hole image within the SPEED bench and reaching 10-7 contrast at close to diffraction limit (1 lambda/D). The work includes numerical modeling, implementation and laboratory testing activities. The thesis work will repeatedly rely on the end-to-end simulator of the SPEED bench (Beaulieu et al. 2017, 2020) developed to analyze the experimental results and estimate the ultimate accessible contrast. The perspectives of the thesis are multiple:
— in the short term, the aim is to demonstrate the effectiveness of the PIAACMC + FM-SCC coupling (complex field measurement on coronagraphic image) + active optics (dark hole) on the SPEED bench;
— in the medium term, it is a question of acquiring experience on critical aspects necessary to obtain the ultimate performance of current and future ground-based instruments (ELT-PCS). In particular, future segmented telescopes seeking exoplanet research relies to the exquisite quality and stability of the wavefront. Wavefront errors have stringent requirements to achieve and to maintain over the required hours of observation to deliver a contrast floor that enable the detection and characterization of exo-Earths. Among the driving objectives of the thesis, the stability of the dark-hole image to phasing residuals and their temporal evolution, speckle temporal characteristics, missing segments, etc., is expected ;
— in the long term, it involves participating in the prospective analysis to define instrumental building blocks for future coronagraphic space instrumentation.

In this context, the SPEED facility will allow significant advances in ground and space instrumentation, where a strong synergy and complementarity exist in the requirements, concepts, and architectural solutions for direct imaging of exoplanets. The thesis will take place within the Lagrange Laboratory localized on the Valrose University (University of Côte d’Azur) in Nice center.

Guyon et al. 2014 : APJ « High performance Lyot and PIAA coronagraphy for arbitrarily shaped telescope apertures »

Martinez et al. 2015 : ESO Messenger n°159 « The segmented pupil experiment for exoplanet detection : SPEEDing up R&D towards high-contrast imaging »
Martinez et al. 2019 : A&A Letter « Fast-modulation imaging with the self-coherent camera »
Martinez et al. 2020 : A&A Vol 635, A126 « Design and manufacturing of a multi-zone phase-shifting coronagraph mask for extremely large telescopes »
Beaulieu et al. 2017 : MNRAS Vol. 469 « High-contrast imaging at small separations : impact of the optical configuration of two deformable mirrors on dark holes »
Beaulieu et al. 2020 : MNRAS Vol. 498 « High-contrast imaging at small angular separations : II. Impact on the dark hole of a realistic optical setup with two deformable mirrors »