PhD Thesis subject

Development of image processing methods for the detection of exoplanets in reflected light with the NASA Roman Space Telescope

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Starting date: October 1st 2022
Expected graduation date: September 30st 2025 (3 years)
University: Aix-Marseille Université, Doctoral School 352, Physics and Sciences of the matter
Work place: Laboratoire d'Astrophysique de Marseille, France
Funding: ERC consolidator grant
Application deadline: April 30st 2022

Subject description:

Determining the frequency of life in the Universe is one of the main challenges of the next decades. This requires detecting and characterizing at least a dozen of temperate rocky exoplanets ("exoEarths") to determine the presence of biomarkers in their atmospheres. This can only be done with a large telescope in space equipped with state-of-the-art spectro-imagers, capable of separating the dim signal of a planet 10^{10} times fainter than their star and lost in its bright glare in the images. This is the prime science goal of the 6m-diameter mission concept recently selected by the US National Academies as the 2040's flagship mission.

This represents an enormous technological challenge. To demonstrate such capabilities, the next NASA mission, the 2.4m-diameter Roman Space Telescope to be launched in 2027, will include for the first time in space a state-of-the-art coronagraphic imager equipped with active wavefront control (Kasdin et al. 2020). This technology will allow the imaging of Jovian planets, at 10^{-8} contrast levels from their host star, on Solar System scales (2-20 au).

In this thesis project, we propose to develop and optimize image processing methods to further improve on the exoplanet detection limits of the Roman Space Telescope. These processing methods consist in modeling the starlight distribution in the image (i.e. the coronagraphic Point Spread Function) from calibration images (e.g. observations of a nearby reference star) with advanced algorithms (least square method, principal component analysis, non-negative matrix factorization…), then subtracting this starlight model from the science data to reveal the underlying faint exoplanetary signal. Through realistic image simulations of the telescope and of its coronagraphic imager, the PhD student will first apply state-of-the-art image processing techniques and characterize their performance for the Roman mission. For this first analysis, the student will use existing simulated data (https://www.exoplanetdatachallenge.com/, Girard et al. 2020) then progressively develop their own simulated images using Roman Coronagraphic instrument data simulation tools (Krist 2014, Riggs et al. 2018).

Building up on this study, the student will then explore new methods that will make use of the specific active hardware of Roman to improve on these baseline methods. The student will simulate calibration data introducing a diversity of wavefront patterns in the instrument, representative of the quasi-static errors that are known to limit the performance of the instrument (Krist et al. 2018, Riggs et al. 2019). They will then use these complementary data to refine the starlight model subtracted to the science data. The student will develop and optimize this method for the Roman Space Telescope coronagraphic instrument, estimate its performances and compare them to classical methods.

Depending on the advancement of the project, the student will then either re-evaluate the yield of the Roman mission in terms of exoplanets detection based on the estimated performance or extend the simulations to the 6m-diameter LUVOIR mission concept.

Research environment:
This research will be done in the context of the ESCAPE ERC consolidator project of Dr. Elodie Choquet (2022-2027), aiming at developing advanced image processing methods for the detection of exoplanets with the Roman Space Telescope. The student will evolve in a team of 7 people to be built in the next few years working ESCAPE. Support will be provided for computing resources, collaborations, and conferences as part of the project.

The High-Contrast Imaging team at LAM is highly experienced in developing image processing techniques for high-contrast imaging instruments, as well as in the characterization of extrasolar systems with both the Hubble Space Telescope and with the state-of-the-art SPHERE instrument on the VLT. The successful candidate will have the opportunity to take part to observing programs with major facilities (VLT, HST, JWST) to study extrasolar systems with us. Our team has strong international collaborations on these projects (Caltech, JPL, STScI, University of Exeter, MPIA, and others), which the successful candidate will benefit from along his·her PhD program.

Candidate selection criteria:
We recognize the key role of diversity and inclusivity to enhance the dynamic and collegial atmosphere of our scientific community. Applications from women, minorities, and disabled individuals are thus strongly encouraged. We will not discriminate applications because of gender, religion, color, nationality, or sexual orientation.

Applicants must have a MSc degree in Physics or an equivalent degree. Candidates with background or experience with the following topics will be given additional attention: Optical science, Optical instrumentation, Image and signal processing techniques, Machine learning techniques, Wavefront sensing and control, High angular resolution techniques.

Application process:
Applicants must send a CV (2 pages maximum), a cover letter, all BSc and MSc transcripts (or equivalent) all in pdf format by email to Elodie Choquet (elodie.choquet@lam.fr) and Arthur Vigan (Arthur.vigan@lam.fr) by **April 30**. They must also arrange for two letters of recommendation to be sent by the same deadline.

Bibliography:

Kasdin et al. 2020, SPIE 11443, https://ui.adsabs.harvard.edu/abs/2020SPIE11443E..1UK/abstract
Girard et al. 2020, SPIE 11443, https://ui.adsabs.harvard.edu/abs/2020SPIE11443E..37G/abstract
Krist 2014, SPIE 9143, https://ui.adsabs.harvard.edu/abs/2014SPIE.9143E..0VK/abstract
Riggs et al. 2018, SPIE 10698, https://ui.adsabs.harvard.edu/abs/2018SPIE10698E..2VR/abstract
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Riggs et al. 2019, SPIE 11117, https://ui.adsabs.harvard.edu/abs/2019SPIE11117E..0FR/abstract