CENTRE DE RECHERCHE ASTROPHYSIQUE DE LYON

Centre de Recherche Astrophysique de Lyon
UMR 5574

Master 2 Research internship offer
Academic year 2024 – 2025

Internship supervisors: Olivier Flasseur, Ferréol Soulez, Eric Thiébaut
@ : olivier.flasseur@univ-lyon1.fr ferreol.soulez@univ-lyon1.fr
eric.thiebaut@univ-lyon1.fr

Address/Workplace: CRAL **-** site Charles André : 9 avenue C. André, St Genis Laval

Hosting research team: AIRI

Internship title: Direct detection and characterization of exoplanets: learning, metadata, and priors

Summary of proposed work:

Context: The direct observation of the close environment of stars can reveal the presence of exoplanets and circumstellar disks, providing crucial information for a better understanding of planetary system formation, evolution, and diversity. Given the very small angular separation with respect to the host star and the huge contrast between the (bright) star and the (faint) exoplanets and disks, imaging the immediate vicinity of a star is extremely challenging. In addition to the use of extreme adaptive optics and a coronagraph, dedicated post-processing methods combining images recorded with the pupil tracking mode of the telescope are needed to efficiently suppress the nuisance component (speckles and noise) corrupting the signals of interest.

In recent works, we have introduced innovative post-processing methods that combine statistical modeling of the nuisance component with deep learning [1,2,3]. These models achieve state-of-the-art performance, surpassing traditional inverse-problem approaches in detecting point-like sources such as exoplanets. However, there is still room for improvement, particularly near the star where the component of interest is the most affected by starlight contamination.

In this context, data science developments are decisive to improve the detection sensitivity of exoplanets and the accuracy of their photometric characterization (i.e., spectrum estimation).

Possible research directions: This project will build on recent advances in modeling the nuisance component that corrupts high-contrast total intensity observations. The focus will be on improving exoplanet detection and characterization. Possible research directions include:

1/ Generating prior information on exoplanet spectra: Develop prior information on typical exoplanet spectra using physics-based simulations that account for atmospheric chemistry and cloud presence. Key questions center on designing effective architectures and learning strategies to create these priors, as well as determining methods for their use — whether by integrating them as regularization terms in inverse-problem approaches or employing them as generative models — to improve exoplanet detection and characterization.

2/ Integrating metadata into nuisance modeling: Improve nuisance models by incorporating diverse metadata that accompany scientific data. This metadata includes time series that monitor observational conditions at the observatory, images from differential tip-tilt sensor providing instantaneous (but noisy) views of the instrument's point spread function, and telemetry from the adaptive optics system. These sources provide insight into the quality of individual temporal exposures and are expected to improve the robustness of deep nuisance models. Open questions focus on selecting the most informative metrics and determining effective methods for integrating such heterogeneous data into the models.

Data: The project will focus on developing / improving new processing algorithms using spectroscopic total intensity observations (i.e., spatio-temporal-spectral data recorded with an Integral Field Spectrograph) from the SPHERE instrument, currently operating on the Very Large Telescope. Once a proof of concept is established, simulations for HARMONI, one of the first-light instruments of the upcoming Extremely Large Telescope, may be considered. In this case, the algorithm will be adapted to account for HARMONI's specific features, particularly its higher spectral resolution. In both cases, we have access to an initial library of synthetic exoplanet spectra at the spectral resolution specific to the instruments under consideration.

Bibliography:

[1] Flasseur+, "deep PACO: Combining statistical models with deep learning for exoplanet detection and characterization in direct imaging at high contrast", Monthly Notices of the Royal Astronomical Society, 527(1), 1534-1562, 2023, https://arxiv.org/pdf/2303.02461

[2] Flasseur+, "Combining multi-spectral data with statistical and deep-learning models for improved exoplanet detection in direct imaging at high contrast", EUSIPCO, 2023, https://arxiv.org/pdf/2306.12266

[3] Bodrito+, "MODEL&CO: Exoplanet detection in angular differential imaging by learning across multiple observations.", *Monthly Notices of the Royal Astronomical Society* 534.2, 1569-1596, 2024, https://arxiv.org/pdf/2409.17178

Nature of the financial support for the internship: Labex LIO or team funding

Potential for a follow-up as a PhD thesis: Yes