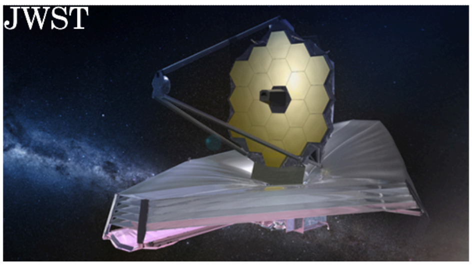
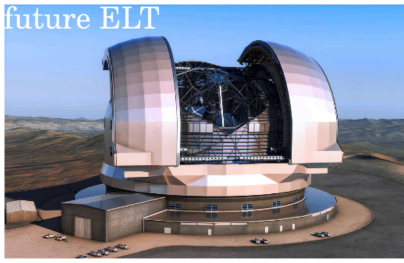




Post-doctoral position – Modeling high-contrast intensity observations for the study of circumstellar disks: from data-driven calibration to the integration of physical priors

Keywords: deep learning, data-driven approaches, inverse problems, hybrid approaches, calibration, high-contrast imaging, nuisance modeling, reconstruction of circumstellar disks.

Context: The 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, reconstructing images of 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 [1].

In recent works, we have introduced innovative post-processing methods that combine statistical modeling of the nuisance component with deep learning [2,3,4]. These models achieve state-of-the-art performance, surpassing traditional inverse-problem approaches in detecting point-like sources such as exoplanets. Simultaneously, new algorithms have been proposed to reconstruct the spatio-spectral flux distribution of circumstellar environments — composed of gas and dust forming disk structures where exoplanets form through material accretion. These reconstruction methods jointly estimate the objects of interest and the nuisance statistics using an inverse problem approach [5,6]. Although these methods demonstrate impressive reconstruction quality, there is still room for improvement, particularly near the star where disk components are most affected by starlight contamination. In addition, for both tasks (detection and reconstruction), current algorithms ignore the temporal and spatial variability of the off-axis point-spread function (PSF), affecting exoplanet detection sensitivity, astro-photometric accuracy, and the spatial resolution of the disk reconstructions.

In this context, data science developments are decisive to improve the fidelity of circumstellar disk reconstruction, especially for fine and faint structures at short angular separations. These advances will also support future instruments by allowing the design of algorithms addressing scientific challenges outlined in the Extremely Large Telescope (ELT) roadmap, using realistic simulations of astrophysical scenes.

Research objectives: This postdoctoral project will build on recent advancements by our research team in modeling the nuisance component that corrupts high-contrast total intensity observations. The focus will be on reconstructing circumstellar disks and modeling the signal degradation caused by the measurement process. The key research objectives include:

- **Integrating deep models of the nuisance component** into algorithms dedicated to circumstellar disk reconstruction in total intensity, potentially inspired from deep models we have developed for exoplanet detection.
- **Incorporating prior information** about typical flux distributions in circumstellar environments observed in total intensity. This will involve using dedicated simulators and combining this information with advanced nuisance models in the reconstruction algorithms.
- **Addressing the spatio-temporal variability** of the off-axis PSF. Two open research directions could be explored:
    - Exploiting metadata, such as adaptive optics telemetry, to track instrumental response variations due to changing observing conditions.
    - Investigating data-driven approaches to model this variability directly from the science data.

Whenever possible, raw sensor data will be considered rather than pre-processed data to better quantify signal degradation from both the measurement and processing stages, and to model and propagate uncertainties end-to-end. This process will involve calibrating and assembling raw data using inverse-problem methods developed in the DDISK ANR project (PI: Maud Langlois). While complementary, the priorities of these research objectives can be adjusted based on the applicant's expertise.

Data and Instruments: The project will focus on developing new processing algorithms using total intensity observations (imaging and spectroscopy, i.e., spatio-temporal-spectral data) 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 ELT, may be considered. The algorithms will then be adapted to account for HARMONI's specific features, particularly its higher spectral resolution.

Collaboration and Location: The postdoc will be part of a multidisciplinary collaboration. She/he will collaborate with Jean Ponce (ENS-PSL, Paris), Julien Mairal (INRIA, Grenoble) and Olivier Flasseur (CRAL, Lyon). Additional collaborations would involve experts in observational astrophysics, including Maud Langlois (CRAL, Lyon) and Anne-Marie Lagrange (LESIA, Paris). The postdoc will also collaborate with a third-year PhD student at INRIA. The postdoc will be based primarily at INRIA, with regular visits at CRAL.

Duration: The initial appointment is for one year, with a possible one-year extension (with other sources of fundings).

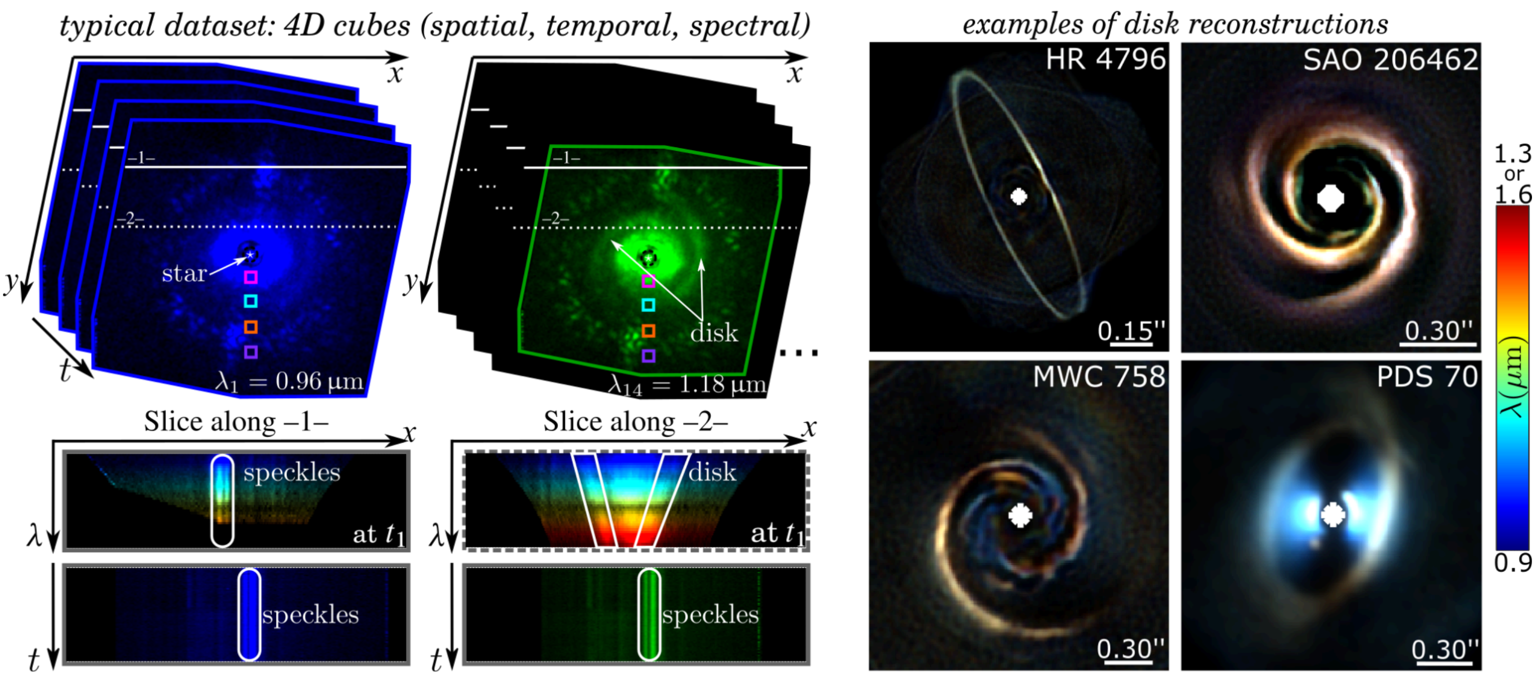
Desired Skills and Expertise: The candidate should hold a PhD in signal and image processing, applied mathematics, machine learning, computer vision and related fields. A strong interest in physics, pluri-disciplinary research and scientific applications is a plus.

Deliverables: The developed algorithms will be disseminated in peer-reviewed journals and relevant conferences in the fields of astronomy and computer science. The associated code will be made public in the time-line of the position.

Contacts and Application Process: Applicants should send the following documents to Jean Ponce (jean.ponce@ens.fr), Julien Mairal (julien.mairal@inria.fr), and Olivier Flasseur (olivier.flasseur@univ-lyon1.fr): a CV outlining qualifications and previous experiences, a cover letter detailing research interests, a list of publications, and a list of up to three referees ready to write a recommendation. Requests for additional information on the position can be sent directly by email, and a video-conference could be arranged. Applications will continue to be reviewed until the position is filled.

This position falls within a sector subject to the protection of scientific and technical potential (PPST) and therefore, in accordance with regulations, the applicant's arrival must be authorized by the competent authority of the Ministry of Higher Education and Research (MESR).

Starting Date: As soon as possible.



Left: A typical 4D dataset of observations from the Integral Field Spectrograph on the VLT/SPHERE instrument, where the signal from the circumstellar disk is corrupted by a strong and multi-correlated nuisance component (speckles and noise). Right: Examples of circumstellar disks recovered by inverse-problem-based reconstruction algorithms [5,6], separating them from the nuisance components.

References:

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