Thesis subject

Name of the laboratory: **LAM**

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Subject's title: Development of advanced post-processing methods for the direct detection of exoplanets with ground-based high-contrast imagers

Subject description:

The observation of extrasolar systems with direct imaging instruments offers unique opportunities to study the formation of exoplanets. High angular resolution images provide the complete view of the outer regions of extrasolar systems and let us directly observe the formation and evolution of giant planets within their protoplanetary disk. By collecting the photons emitted by the planets, they also let us study their atmospheric composition and structure, key diagnostics to constrain their formation history. The direct observation of exoplanets is however challenged by the extreme contrast ratios between these faint objects and their host star (typically 10^{-4}—10^{-6}), and by their short apparent separation to the star (in the order of 0.5'' or less). In addition to dedicated devices that reject the stellar flux at the instrument level, aggressive image processing is necessary to further subtract the residual starlight (the PSF) from the images and detect exoplanets hidden in the data.

The development of advanced post-processing techniques is a key research field to enable the detection of the faintest exoplanets and probe new detection limits. Over the past 5 years, dedicated high-contrast imaging instruments have been installed on all the major 10m-class ground-based telescopes (among them the SPHERE instrument on the VLT), equipped with extreme adaptive optics systems, optimized coronagraphic devices, and internal wavefront sensors. These state-of-the-art instruments now routinely deliver high-quality images with the highest raw contrast limits achieved within 1'' from a target star. Processed with the traditional PSF subtraction methods and algorithms, these data are typically sensitive to Jupiter-mass planets at ~10 AU from their host stars.

The core of this PhD project is to develop new data processing techniques with the goal of further improving detection limits of the latest ground-based high-contrast imagers and possibly discover new extrasolar systems. These new techniques will leverage 1/ the high stability of these instruments, 2/ the real-time monitoring of the wavefront by the instrument sensors, and most importantly 3/ the vast mine of data accumulated by the instrument for the past 5 years. The successful candidate will have access to the complete public archives of the SPHERE instrument, which includes observations of several hundreds of stars. He·she will first adapt a post-processing technique successfully developed for the archives of the Hubble Space Telescopes to better estimate the subtracted PSF (gain of a factor of ~20 in contrast limits). He·she will then develop data selection techniques leveraging the quantity and diversity of datasets in the SPHERE archive and the data of its wavefront sensors to optimize the estimation of the subtracted PSF. Novel estimation methods based on supervised machine learning techniques can also be explored. The PhD student will finally characterize the performance of this technique and compare it to the traditional post-processing approaches. He·she will be the prime actor on any discovery and subsequent follow-up campaign associated to this work.

Our team 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 while being part of our team. 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.

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. As an equal opportunity employer, we will not discriminate because of gender, religion, color, nationality, or sexual orientation.

Although not mandatory for applying, candidates with background or experience with the following topics will be given additional attention: image and signal processing techniques, machine learning techniques, wavefront sensing and control, high angular resolution techniques.

Bibliography:

Mining the Hubble archives with a new image processing method:
Soummer et al. 2014, ApJL 786, L23: https://ui.adsabs.harvard.edu/abs/2014ApJ...786L..23S/abstract
Choquet et al. 2016, ApJL 817, L2: https://ui.adsabs.harvard.edu/abs/2016ApJ...817L...2C/abstract
Choquet et al. 2017, ApJL 834, L12: https://ui.adsabs.harvard.edu/abs/2017ApJ...834L..12C/abstract
Choquet et al. 2018, ApJ, 854, 53: https://ui.adsabs.harvard.edu/abs/2018ApJ...854...53C/abstract

Major discoveries with the VLT-SPHERE instrument with traditional processing methods:
Vigan et al 2015 MNRAS 454,129: https://ui.adsabs.harvard.edu/abs/2015MNRAS.454..129V/abstract
Chauvin et al. 2017, A&A, 605 L9: https://ui.adsabs.harvard.edu/abs/2017A%26A...605L...9C/abstract
Keppler et al 2018 A&A 617 A44 https://ui.adsabs.harvard.edu/abs/2018A%26A...617A..44K/abstract
Müller et al. 2018, A&A, 617, L2: https://ui.adsabs.harvard.edu/abs/2018A%26A...617L...2M/abstract