Thesis subject

Name of the laboratory: Laboratoire d'Astrophysique de Marseille

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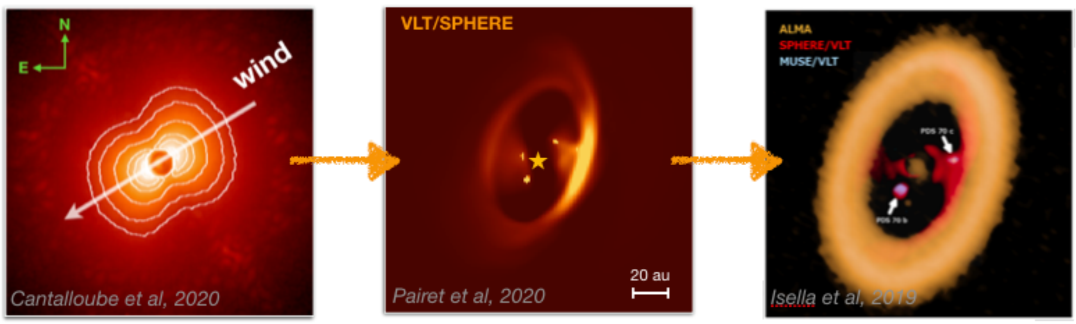
Subject's title: Alleviating the wind-driven halo with post-processing techniques for the detection of planetary systems by high-contrast imaging.

Subject description:
One key question of modern astrophysics is to understand the formation and evolution of planetary systems. High-contrast imaging (HCI) is a prime observational technique that can address such questions by making it possible to witness the interactions between forming planet(s) and the circumstellar material. This technique is very challenging since it consists in detecting signals from giant planets and/or circumstellar disks that are more than 5 order of magnitude fainter than the host-star at an angular separation as small as 100 milli-arcseconds (mas). As a consequence, instruments dedicated to HCI are installed on the largest 8-m class telescopes to reach the best sensitivity and spatial resolution and they are working in the near-infrared where the contrast between the host star and the young planet is more favorable. High-contrast instruments are equipped with two essential elements: (1) an adaptive optics system that recovers the spatial resolution given by the theoretical diffraction limit of the telescope despite the Earth atmospheric turbulence degrading it and (2) a coronagraph that blocks most of the light from the host star while preserving faint close-in signals. From high-contrast images, advanced image post-processing techniques are needed to further carve out the residual starlight after the coronagraph and unveil circumstellar signals that are 10^6 times fainter than the host star. This technique notably revealed the first protoplanet in the 5Myr old PDS70 system [*Keppler et al., 2018*], which is responsible for shaping the wide gap observed in its protoplanetary disk (Fig. 1). However, high-contrast imaging is extremely sensitive to optical wavefront errors, in particular at small angular separation (below 100mas) where we expect most planets to lie [*e.g., Vigan et al., 2020*]. To enhance the demography of giant gaseous planets close to the snow line (3 to 10 au), in link with other indirect exoplanet detection techniques, one main pathway is **to develop or adapt image post-processing techniques to cope with the current limitations of high-contrast instruments**.

This PhD position aims at characterizing young planetary systems in-depth thanks to the development and application of advanced image processing techniques designed to bypass the current limitations of high-contrast imaging. The PhD candidate will be in charge of (i) developing new image analysis and processing tools in the context of high-contrast imaging, (ii) leading her/his/their own proposals to gather more data on the most promising systems, and (iii) analyzing and interpreting these data using the most recent image processing tools.

The PhD candidate will first tackle the limitation of the so-called "wind-driven halo", a signature of the adaptive optics servolag that appears when the atmospheric turbulence evolves faster than the correction bandwidth of the adaptive optics (Fig. 1). We estimated that this signature affects 30 to 40% of all the images taken by the VLT/SPHERE instrument and remains after application of traditional image processing techniques [*Cantalloube et al., 2020a*]. The PhD candidate will be developing a toolbox to analyze and remove this contribution from the images before the application of classical image processing techniques, and therefore gain up to one order of magnitude in contrast below 500mas. This step involves comparing the analysis of the images with the telemetry data from the adaptive optics and the turbulence profiler and weather station at the observatory.

As a second step, the PhD candidate will revisit young systems showing hints of circumstellar features with this new tool and the latest post-processing techniques dedicated to disk imaging and point source extraction [*Pairet et al., 2021; Dahlvist et al., 2020, Cantalloube et al., 2020b*]. The PhD candidate will write observing proposals to acquire complementary data in order to better unveil and analyze the origin of the substructures in young protoplanetary disks with VLT/SPHERE, VLT/MUSE, VLT-I/GRAVITY and potentially ALMA data.



Left: Image from the VLT/SPHERE instrument exhibiting an intense wind-driven halo. **Middle**: Image of the PDS70 system, processed with the latest image processing technique dedicated to disk imaging, MAYONNAISE. **Right**: Superposition of 3 observational techniques of the same system PDS70 (ALMA, VLT/SPHERE and VLT/MUSE).

By joining the LAM, the PhD candidate will benefit from its vibrant research environment at the Research & Development Group and will have the opportunity to join various research projects for the community, such as the 'exoplanet imaging data challenge' [Cantalloube et al., 2020b], the PAPYRUS student instrumental project [https://anr-wolf.com/index.php/wolf-the-project/ressources-2/on-sky-bench-papyrus/], and instrumental projects such as VLT/SPHERE [Beuzit et al., 2019], ELT/METIS [Brandl et al., 2016] or ELT/HARMONI [Thatte et al., 2016].