Thesis subject

Name of the laboratory: Laboratoire d'Astrophysique de Marseille

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Subject's title: **Characterization of transiting exoplanets in the habitable zone**

Subject description:

The 2020s decade will be the starting point of a new golden age for astronomy and especially exoplanets with new space missions such as the *JWST*, *PLATO*, and *ARIEL* as well as the extremely large telescopes (ELTs) in the ground. These new facilities will allow the scientific community to go one step further in the detection and characterization of exoplanets, in particular, those located in the habitable zone (where water might be in liquid phase at their surface). The characterization of these planets implies to measure their fundamental parameters (both the mass and the radius), allowing to model their internal structure (e.g. Brugger et al., 2017) as well as probe their atmosphere to determine their chemical composition and physical properties.

Among the 4700+ exoplanets known to date, relatively few systems have been detected to transit bright stars. The thousands of planets detected by the *Kepler* space telescope have faint host stars which strongly limit their ability for characterizing their mass and atmosphere. Focusing only on the planets in habitable zone transiting bright, solar-like stars, the number of systems drops to nearly zero. The main objective of the *PLATO* space mission (ESA third M-class mission, to be launched in 2026) is exactly to find such Earth analogs transiting bright stars.

The objective of the PhD thesis is to develop a new software to characterize transiting exoplanets in the habitable zone of bright stars that will be detected by the *PLATO* mission. For that, the PhD student will mainly have to develop a state-of-the-art analysis tool, taking into account dynamical interactions between exoplanets, stellar variability as well as other constraints such as asteroseismology to model the host star. It will be developed based on the experience from the PASTIS software already available at LAM (Díaz et al., 2014). This new tool will become the prototype of the software that will be implemented in the Exoplanet Analysis System (EAS) for the *PLATO* mission (Work Package #367 of the *PLATO* Data Center). This workpackage corresponds to the last processing step of the PLATO pipeline. It aims at computing the physical parameters of the detected planets, hence the final scientific product of the *PLATO* mission. The PhD student will be involved in the *PLATO* exoplanet team at LAM and of course the *PLATO* consortium.

This modelling is relatively complex and should take into account various phenomena. First, the central stars exhibits variability with timescales spanning from a few minutes up to decades. This variability, which is not perfectly understood, limits the interpretation of the data. Second, most small planets are in multi-planetary systems. If these planets are close to orbital resonances, they undergo dynamical interactions which challenge their physical modelling. Moreover, the systems might host additional, unseen planets. If those planets are not taken into account in the analysis of the data, they might bias the results or lead to incorrect conclusions. Finally, transiting planets can not be modelled without taking into account their host stars. As a consequence, the modelling of the planetary systems that will be detected by the *PLATO* missions requires state-of-the-art analysis and statistical tools.

The new tool will be used in priority to analyze available photometric and spectroscopic data on HIP41378, a bright system hosting 5 transiting exoplanets, among which 3 are in the habitable zone (Santerne et al., 2019). HIP41378 was intensively observed over the past 5 years and is currently the unique target of a 95-h monitoring program with the ESPRESSO spectrograph on the ESO VLT in Chile (2021-2023). The newly collected ESPRESSO data will have to be modelled together with new photometric data from *HST*, *CHEOPS*, *JWST*, or ground-based observatories that are foreseen during the PhD thesis. The PhD student will also be involved in the analysis of new planetary systems (eg Armstrong et al., 2020) that are currently observed by various facilities such as HARPS (ESO, Chile), SOPHIE (OHP-France), CARMENES (CalarAlto, Spain), SPIRou (CFHT, Hawaii), *TESS* (NASA), and *CHEOPS* (ESA).

Moreover, the PhD student will participate to new observing campaigns with the aim at probing the atmosphere of the planets in the habitable zone of HIP41378.

Finally, the PhD student will join the activities of the exoplanet group at LAM in a vibrant research environment.

Bibliography:

- *Armstrong, Lopez, Adibekyan, et al., 2020, Nature, 583, 39A "A remnant planetary core in the hot-Neptune desert"*
- Brugger, Mousis, Deleuil, et al. 2017, ApJ, 850, 93 "*Constraints on low mass Exoplanets Interiors from Stellar Abundances"*
- Santerne, Malavolta, Kosiarek, et al. 2019, submitted to Nature Astronomy (arXiv:1911.07355) "*An extremely low-density and temperate giant exoplanet*"

Díaz, Almenara, Santerne, et al. 2014, MNRAS, 441, 983 "*PASTIS: Bayesian extrasolar planet validation - I. General framework, models, and performance*"