Thesis subject

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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 the realization of major projects such as the *JWST*, *PLATO*, and *ARIEL* space missions 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 its chemical composition and physical properties.

Among the 4000+ 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 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.

Planetary systems are however relatively complex. First, the central stars exhibit variability with timescales spanning from a few minutes up to decades. This variability, which is not perfectly understood, limits the interpretation of the data collected with the next-generation instruments. Second, most small planets are in multi-planetary system. If these planets are close to the resonance, they undergo dynamical interactions which challenge their modelling. Finally, 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. As a consequence, state-of-the-art analysis and statistical tool are needed to fully interpret the data collected by new-generation instruments.

HIP41378 is an example of this complexity. It is a fascinating system composed of five exoplanets transiting a bright star, among which, three are in the habitable zone (Santerne et al., 2019). They are among the best planets for atmospheric characterization. The system is dynamically active with all planets close to the mean-motion resonance. Their transits thus exhibit large timing variations, at the level of a few hours. The system also hosts additional non-transiting planets. One has already been detected and there are very likely more planets to be detected in this unique system. This system is a foretaste of what *PLATO* will massively discover.

The objective of the PhD thesis will be to precisely characterize transiting exoplanets in the habitable zone of bright stars. 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 (PASTIS 2.0) will become a 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). The PhD student is therefore expected to be involved in the *PLATO* consortium.

The new tool PASTIS 2.0 will be used to analyze the system HIP41378 which was intensively observed over the past 5 years and will still be monitored over 2 years by the ESPRESSO spectrograph on the ESO VLT in Chile. 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.

Moreover, the PhD student might participate to new observing campaigns with the aim at probing the atmosphere of the planets in the habitable zone of HIP41378 as well as searching for exo-rings or exo-moons.

Finally, the PhD student will join the activities of the exoplanet group at LAM in a vibrant research environment. She/he might also join the exoplanet programs to which the team is involved with the SOPHIE, HARPS, and SPIRou spectrographs, as well as the programmes on the recently launched *CHEOPS* observatory.

Bibliography:

- 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*"