Thesis subject

Name of the laboratory: LAM

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Subject's title: High-precision radial-velocity for exoplanet characterisation : exploitation of the SOPHIE archive and the SOPHIE-red wavelength extension

Subject description:

Among the 5506 planets detected (and many more candidate), few complete planetary system are well characterized. Radial velocities provide an in-depth view of the planetary systems around nearby and bright stars, as they allow the detection of planets with mutual inclination that are not always in transit. To study the formation and dynamic history of a planet system, it is essential to have a complete view of their architecture.

SOPHIE is a high-precision radial-velocity (RV) spectrograph in the visible mounted on the 1.93m telescope at OHP (France) since 2006. After several instrumental improvements, SOPHIE is since 2011 able to detect Super-Earth and Neptune planets with an accuracy of less than 1 m/s. The number of RV facilities across the world that have already proven to reach a precision at the level of 1 m/s is still very low. Among them, SOPHIE is the only northern instrument dedicated to exoplanet search with more than 260 nights per year allocated. Among the exoplanets programs with SOPHIE, we are conducting a large program to search for low-mass objects around 1-solar-type stars, 2-already know systems, 3- M dwarfs. Among the exoplanetary system recently discovered (e.g. Courcol et al 2015, Hobson et al. 2018,2019, Heidari et al. 2022, Cortes-Zuleta 2023), very specific systems have been unveiled : Gl411b, a Venus-like planet and the second closest system to the Earth (Diaz et al. 2019), HD158259 a multiplanetary system in resonance (Hara et al. 2020), HD88986b a long-period Neptune-mass planet that is likely transiting (Heidari et al. 2024).

The camera of the SOPHIE spectrograph will be replaced in October 2024. The new detector have better performances and will allow to image a larger wavelength domain. The extension of several orders of diffraction towards the near-infrared

permits us to have more radial-velocity content, hence a better accuracy especially for K and M dwarfs. The K stars, less studied by the community until now, are very interesting because the effect of the stellar activity is seen to be lower than for G stars, their habitable zone is farther from the star than for M stars, and the probability of transit is higher than for G stars. Planets in the habitable zone of nearby K dwarfs are also of particular interest for the future major space missions like HWO (NASA) and LIFE (ESA) which will aim at searching for biomarkers on those planets, albeit they still need to be discovered.

The PhD student will join the SOPHIE-Red team both at LAM and OHP with collaborators in Paris, Grenoble, Toulouse, Geneva, Porto and Birmingham. In order to fully exploit the extension in wavelength of SOPHIE-red, they will have to study several instrumental and observational effects that need to be taken into account, such as the stability of the wavelength calibration, correction of the telluric lines, or characterizing the RV offset between SOPHIE and SOPHIE-red. For that, they will rely on several codes already developed or used by the advisors for other instruments (SPIRou, NIRPS) that could be adapted and tested (e.g. NAIRA, LBL). The PhD student will also be in charge to develop and contribute to a new program to search for and characterize planets around K dwarfs with SOPHIE-red.

The long baseline of SOPHIE, together with the former instrument ELODIE (since 1995) is the longest radial-velocity time series in the world. It could be combined with the Gaia astrometric data for exoplanetary system (DR4), expected to be released in 2026, to derive the true masses of exoplanets (not just their line-of-sight projected, minimum mass). In the second part of the PhD, the student will combine SOPHIE+ELODIE RVs with GAIA astrometry and hence explore exoplanets in the outer part of their system.

In case of delays with instrumental upgrade or data release, the SOPHIE archive has more than 13 years of intensive monitoring of bright and nearby stars. Recent improvement in the data analysis (Grouffal et al., subm.) allows to find smaller planets in the existing data. The PhD student will thus be in charge of analysing these data allowing to perform a unique and large statistical analysis. We also already identified several planetary systems that still need to be characterized and published among our PI archival data.

The PhD advisors are responsible or co-investigator of several SOPHIE programs. They are in strong collaboration with an European group of ~20 researchers (3 institutes in France, one in Geneva, Switzerland, one in Porto, Portugal, and one in Birmingham, UK). I.B. is the PI of the SOPHIE high-precision programs. A.S. is the PI of the BEBOP program to search for circumbinary planets. The exoplanet group at LAM is also strongly involved in several other projects: SPIRou, SPHERE, CHEOPS, TESS, PLATO and ANDES.

Bibliography:

Bouchy et al. 2009, A&A, 505, 853
Cortes-Zuleta, Boisse et al. 2023, A&A, 673, 14
Courcol et al. 2015, A&A, 581, 38
Diaz et al. 2019, A&A, 625, 17
Grouffal, Santerne et al., submitted
Hara et al. 2020, A&A, 636, 6
Heidari, Boisse et al. 2022, A&A, 658, 176
Heidari, Boisse et al. 2023, A&A accepted, arXiv:2311.13513
Hobson et al. 2018, A&A, 618, 103
Hobson et al. 2019, A&A, 625, 18