A low-mass sub-Neptune planet transiting the bright active star HD 73344

Sophia Sulis, LAM, AMU, Marseille, France (sophia.sulis@lam.fr)

I.J.M. Crossfield, A. Santerne, M. Saillenfest, S. Sousa, D. Mary, A. Aguichine, M. Deleuil, E. Delgado Mena, S. Mathur, A. Polanski, V. Adibekyan, I. Boisse, J.C. Costes, M. Cretignier, N. Heidari, C. Lebarbé,T. Forveille, N. Hara, N. Meunier, N. Santos, S. Balcarcel-Salazar, P. Cortés-Zuleta, S. Dalal, V. Gorjian, S. Halverson, A.W. Howard, M.R. Kosiarek, T.A. Lopez, D.V. Martin, O. Mousis, B. Rajkumar, P.A. Strøm, S. Udry, O. Venot, E. Willett

Abstract (1)

Planets with radii between 2 - 4 $R_\oplus$, closely orbiting solar-type stars, offer a unique window into the transition from rocky to giant planets. They are prime targets for atmospheric characterization using JWST or ARIEL. However, only a limited number of such planets, with accurately measured masses, are known to orbit bright stars.

In this study, **we confirmed the detection of a candidate planet** orbiting at $P_\mathrm{b} = 15.6$ days around the **very bright star HD 73344** (Vmag ~ 6.9) using photometric observations from K2, TESS and Spitzer. In addition, we analyzed the large amount of radial velocity (RV) observations we made during an intensive multi-year campaign with the SOPHIE/OHP and HIRES/Keck spectrographs.

Despite the transiting planet orbits a bright star at a short period, challenges posed by **stellar activity hindered precise mass measurements**. We proposed a **new observing strategy**, targeting the star at high cadence, and show that this can provide **better constraints on stellar variability and improve mass characterization**. The latter will be essential if we want to characterize the atmosphere of planets around F-type stars using transmission spectroscopy.

HD 73344: a very active star (2)

- Both spectroscopic and photometric data (Figs. 1 to 3) show that the star is particularly active ($\log \mathrm{R'_{HK}} = -4.6$, $S_\mathrm{ph} > 900$ ppm).

- The rotation period ($P_\mathrm{rot} \sim 9$ days) is close to the orbital period of the transiting planet (Fig.2).

- The coherence of the activity signal extends to 3 - 4 P_rot (Fig. 3), in particular in the *Area of the Gaussian fit to the CCF* indicator, known as a good marker of stellar plages (Costes et al. 2021).

- Short timescale stellar variability (oscillation and granulation dominated) has large amplitude (RMS ~ 4 - 7 m/s, depending on exposure time, Fig. 2)

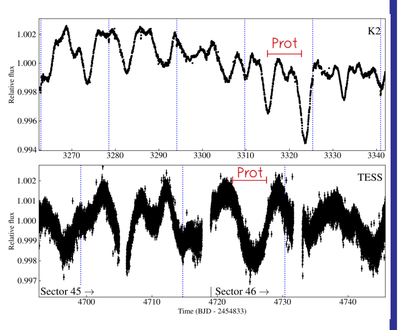

Fig.1 – Light curves of HD 73344. Transits are shown with the dotted vertical lines.

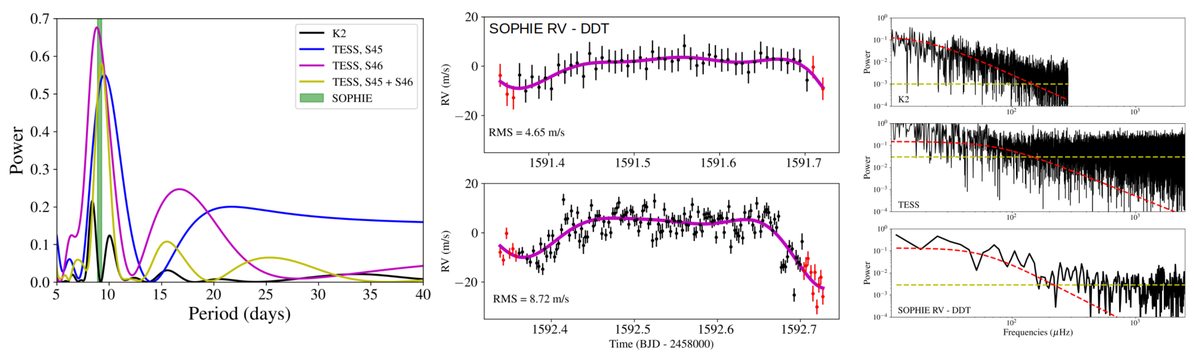

Fig.2 – *Left:* Generalized Lomb-Scargle periodograms (GLSP) of the photometric data. The green vertical line indicates the stellar rotation period $P_\mathrm{rot} = 9.1 \pm 0.2$ days found with RV data and chromospheric indicators. *Middle:* RV of HD 73344 obtained over two consecutive nights (data with airmass > 1.7 are shown in red). *Right:* GLSP of the K2, TESS and SOPHIE short cadence dataset. Stellar granulation is clearly visible (Harvey fits are in red).

HD 73344 b in context (4)

- Transmission Spectroscopy Metric (Kempton et al. 2018): TSM=260^{+640}_{-30}
$\rightarrow$ promissing target for transmission spectroscopy ?

- Warning: Large uncertainties on the planet mass $\rightarrow$ no thorough analysis of its internal structure $\rightarrow$ a crucial need for an accurate mass estimate to unveil the planet's true nature (Fig. 6, left)

- Stability analysis: The 2-planets system is in a very stable region throughout the 3σ zone (Fig. 6, right)

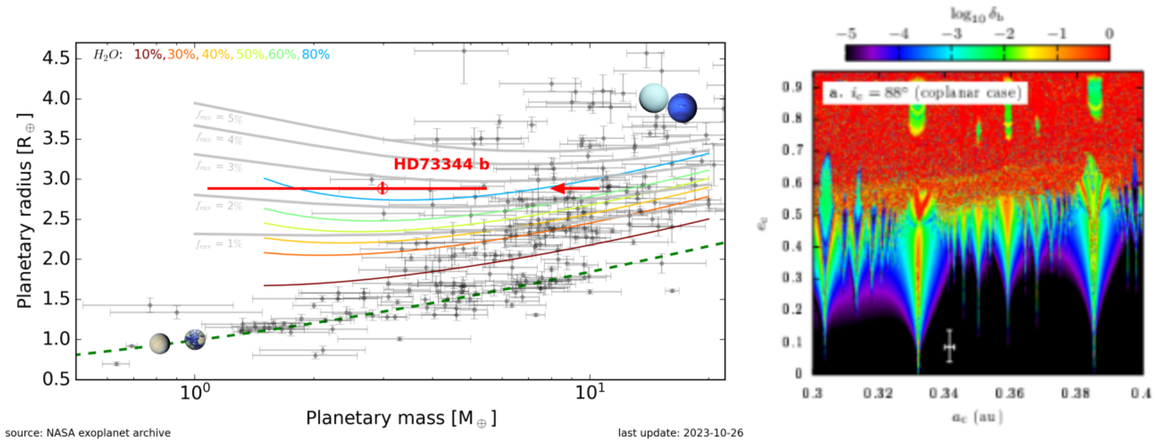

Fig.6 – *Left:* HD 73344 represented in the mass-radius diagram. Confirmed exoplanets with mass and radius precision better than 3σ and 10σ are shown with black dots. *Right:* Stability of the HD 73344 system as a function of the semi-major axis and eccentricity of planet c.

Characterization of the planetary system (3)

- We used the high-cadence SOPHIE dataset (Fig. 2) to constrain short timescale stellar variability (Gaussian process model). Stellar activity evolving at P_rot is modeled by a quasi-periodic GP model. Planets are modeled by Keplerian functions. We used the software `PASTIS` (Díaz et al. 2014) for the joint analysis of photometric and RV observations.

- The planetary signal is clearly evident in the periodograms when using 3pts/night ("unbinned" data) unlike in the case of binned observations (1pt/night), as the high-frequency noise has been effectively modeled (Fig. 4). We note, however, that without the use of priors on P_b (coming from photometry), the planet RV signal at P_b would not be detected at all.

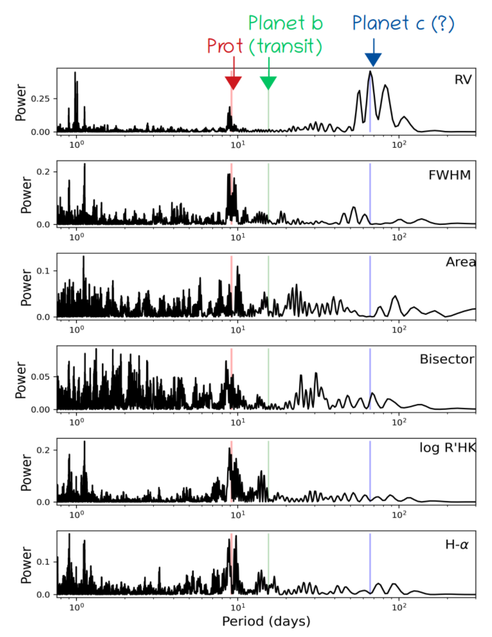

Fig.3 – GLSP of RV and activity indicators, computed on binned SOPHIE observations.

- Tests based on SOPHIE RV data reveal that not binning the data 1/ provides a more accurate estimation of stellar activity, 2/ yields planetary parameters consistent with the binned case, indicating that binning does not enhance precision in planetary parameter determination (Fig. 4).

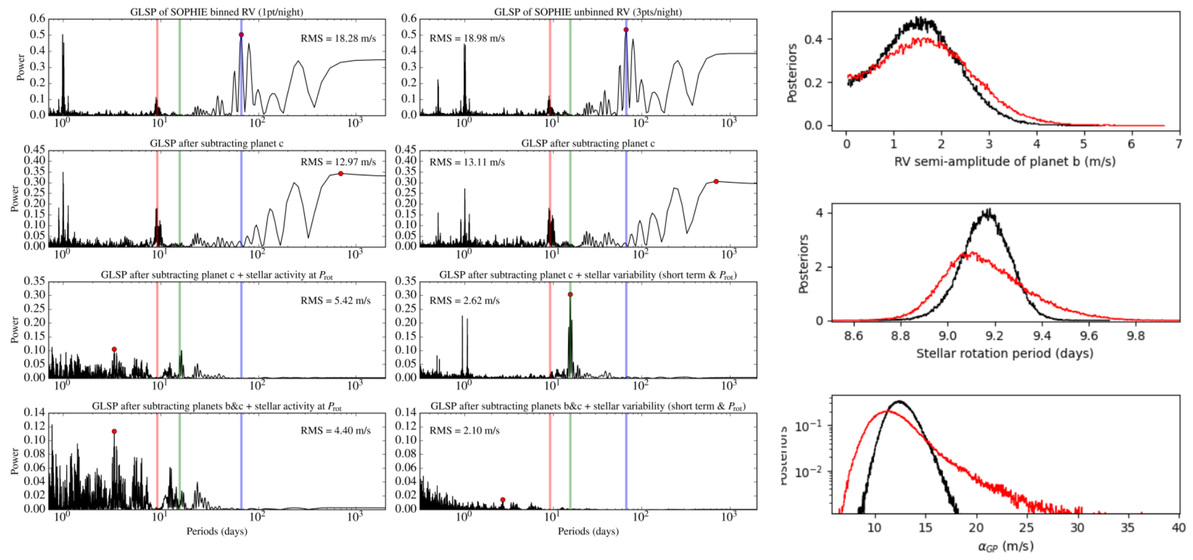

Fig.4 – *Left/Middle:* GLSP of the SOPHIE binned (1pt/night) and unbinned (3pts/night) data. *Right:* Comparison of posteriors of some parameters resulting from the analysis on the binned (red) versus unbinned (black) RV dataset.

- Final joint analysis of K2, TESS, SOPHIE, HIRES observations indicate a 2-planet system (Fig. 5):

- A transiting planet: $P_\mathrm{b} \sim 15.6$ days, $R_\mathrm{b} = 2.88^{+0.08}_{-0.07}$ $R_\oplus$, $M_\mathrm{b} = 2.98^{+2.5}_{-1.9}$ $M_\oplus$
- A non-transiting candidate planet: $P_\mathrm{c} = 66.4^{+0.1}_{-0.2}$, $M_\mathrm{c} \sin i_\mathrm{c}$=$116.3 \pm^{+12.8}_{-13.0}$ $M_\oplus$

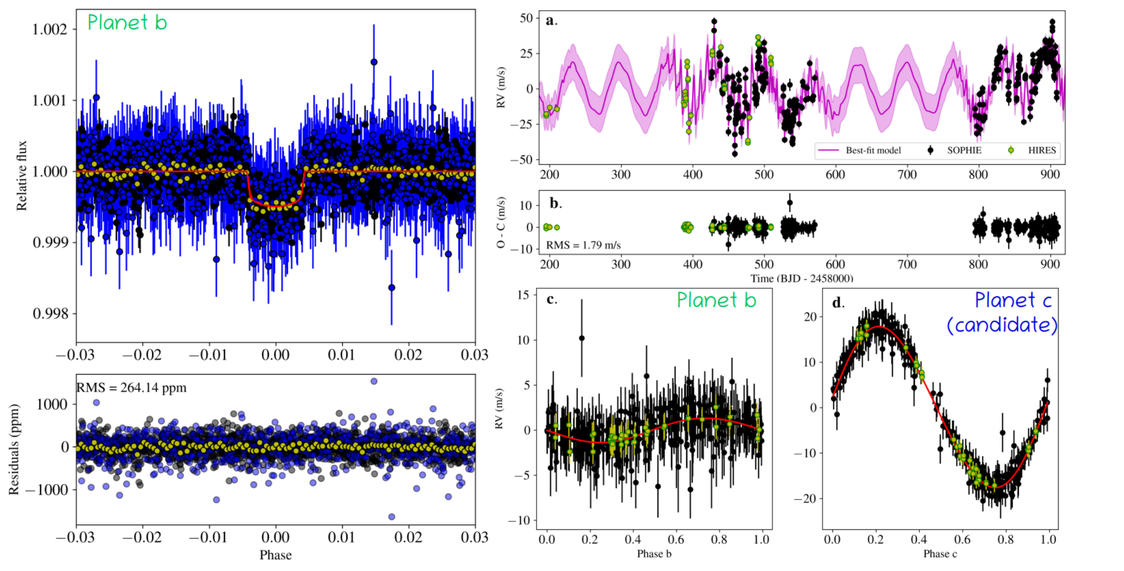

Fig.5 – Phased light curve (left) and RV (right) of HD 73344b resulting of the joint analysis of the photometric and RV data.

Conclusions (5)

HD 73344 is a very bright star, and planet b is a sub-Neptune planet with an ideal orbital period for transmission spectroscopy (according to the TSM metric). However, the high activity level of its host star may complicate the interpretation of transmission spectra (Rackham et al. 2023), and refining the planet mass should be considered first. On the other hand, if observed with ARIEL, this target could serve as a benchmark for testing stellar activity diagnostic tools and correction techniques.

KEY REFERENCES

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LAM LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

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