The TESS/MAROON-X survey for transiting planets around thick-disk stars: first results

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1. Introduction. Recent observations support the idea of a link between the stellar and planetary compositions, particularly for small-sized or low-mass planets (e.g, Adibekyan et al. 2021). Thus, it is expected that stars from different galactic populations host planets with different overall composition and structure. In particular, small-sized or low-mass planets orbiting thick-disk stars (that typically have lower metallicities and higher values of alpha-element abundances than their thin-disk counterparts) would tend to be less dense than those of similar mass around higher metallicity thin-disk stars. So far, only a few transiting planets with precise density measurements have been detected around thick-disk stars. In this context, **in 2021 we started a program to detect and characterize transiting planets to increase the number of well-characterized transiting exoplanets with precise mass measurements around thick-disk stars that can provide important observational constraints for planet formation theory and comparative planetology**. **Based on TESS photometry and Gemini/MAROON-X high-precision radial velocities, here, we present the first results of our survey, including the detection and characterization of a super-Neptune transiting a K-dwarf star chemo-kinematically identified as a member of the transition zone between the thin and thick Galactic disk populations (TOI-3568, Martioli, Petrucci, Jofré et al. A&A, 690, A312, 2024) and a hot Jupiter around a solar type star (Jofré et al. in prep).**

2. Sample, observations, stellar parameters, and chemical abundances. We selected two planet candidate systems from the TESS Object of Interest (TOI) catalog (Guerrero et al. 2021) with high thick-disk membership probability obtained from the kinematic classification of Carrillo et al. (2020). Both systems have been observed with the MAROON-X (R=85,000; Seifahrt et al. 2018) instrument at Gemini North for high-precision radial velocity (RV) monitoring and spectroscopic characterization. For the first planet candidate (TOI-3568) we obtained 34 spectra and 22 for the second one (MX-TESS-PC2). Based on the high-quality spectra, we derived precise stellar atmospheric parameters (Teff, log g, [Fe/H]) following Jofré et al. (2021). Figure 1 shows the location of both stars in the T_{eff} – *log* g plane in comparison with other confirmed exoplanet hosts detected via RVs and transits. In addition to iron, we derived chemical abundances of 19 elements via the strictly differential technique (see details in Jofré et al. 2021).

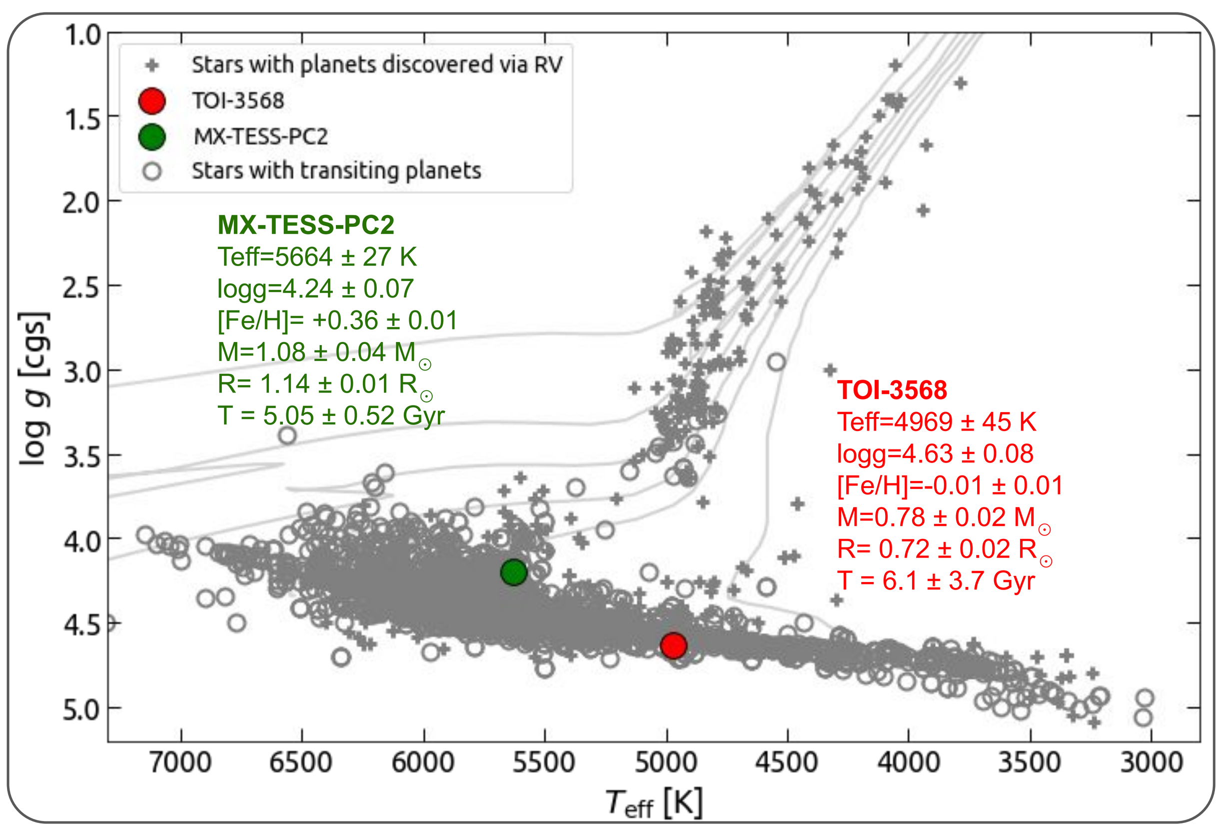

Figure 1. Locations of the planet host stars in the Teff – log *g* plane, based on the spectroscopic T_{eff} and log *g* measured in this work, in comparison with other confirmed exoplanet hosts. Evolutionary tracks, corresponding to masses of 3, 2, 1.6, 1.3, 1.0, and 0.6 $M_{\odot}$ (left to right) for [Fe/H] = +0.0 dex, from Girardi et al. (2000) are overplotted with solid lines.

3.1 Chemical and Kinematic Membership. The α content of TOI-3568, with [α/Fe]= 0.06 ± 0.03 dex, does not exhibit significant enhancement for its metallicity. In particular, TOI-3568 falls within the thin-disk region near the thick-thin disk transition zone (Figure 2). In order to check this result, we performed a kinematic classification based on the UVW velocity vectors that we derived and the probabilistic framework of Reddy et al. (2004). In good agreement with the chemical classification, we identified TOI-3568 as a thin/thick disk transition star (Figure 3). For MX-TESS-PC2, according to the kinematic classification this is also a thin/thick disk transition star. However, its chemical composition (α elements), metallicity, and age are more consistent with what is typically associated with the thin disk (Jofré et al. in prep).

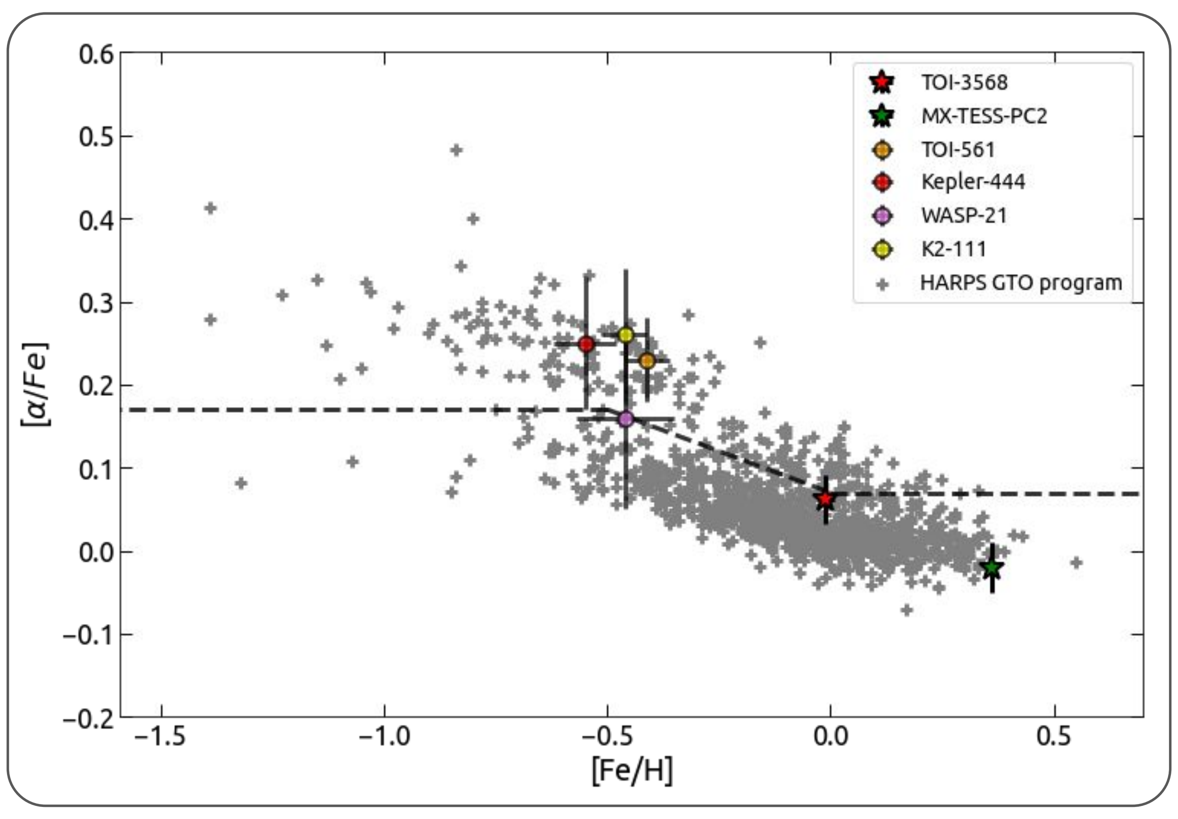

Figure 2. [Fe/H] versus [α/Fe] for stars in the HARPS GTO program. The position of TOI-3568 and MX-TESS-PC2 are marked by a red and green star, respectively. The black dashed line separates the galactic thin-disk (bottom) and thick-disk populations (top). For comparison, we also include the bona fide thick-disk stars with transiting planets Kepler-444, TOI-561, K2-111, and WASP-21.

3.2 Planet Characterization. Figure 4 (left) shows the TESS data and the best-fit model for the selected windows around the transits and the Figure 4 (right) illustrates the MAROON- X RV data and the orbit model for both systems. By performing a Bayesian MCMC joint analysis of RVs and photometry data, we determined the system's parameters following Martioli et al. (2022). **We find that TOI-3568 b is a transiting super-Neptune with a period of 4.4 d, mass of 26.2 $M_{\oplus}$, a radius of 5.20 $R_{\oplus}$, and a bulk density of 1.02 g/cm³**. In Figure 5 (left), we show the mass-radius diagram for the known exoplanets with masses in the range 0.5-500 $M_{\oplus}$ and radii in the range 0.7-25 $R_{\oplus}$. Comparison of the evolutionary models by Fortney et al. (2007) for Hydrogen-Helium (H/He) rich planets at 0.045 au and ages between 1 and 10 Gyr reveals that **TOI- 3568 b is likely a H/He-dominated planet with a core of heavier elements**, with a mass between 10 and 25 $M_{\oplus}$. Finally, with an orbital distance of 0.0485 au, and a equilibrium temperature of 899 K **this planet belongs to the hot super-Neptune class and is located in the Neptunian desert (Figure 5, right). The detailed analysis for this system can be seen in Martioli, Petrucci, Jofré et al. (2024).**
On the other hand, the preliminary analysis of the planet around MX-TESS-PC2 indicates that is a hot Jupiter (Period = 8.6 d; Radius= 0.98 R_{Jup}; Mass: 0.77 M_{Jup}; Density= 1.08 g/cm³, and Eq. Temperature= 1093 K; Jofré et al., in prep).

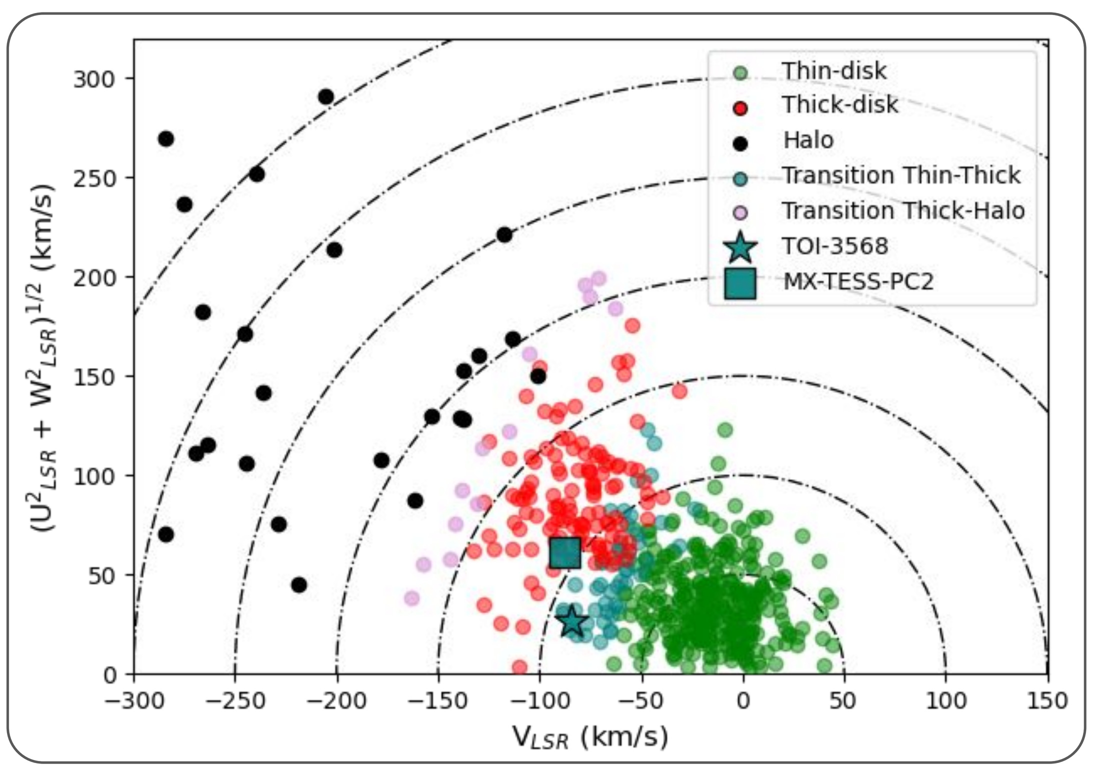

Figure 3. Location of TOI-3568 and MX-TESS-PC2 in the Toomre diagram in comparison with stars from different populations (from the thin-disk, thick-disk, and halo) of the Galaxy from Ramírez et al. (2007).

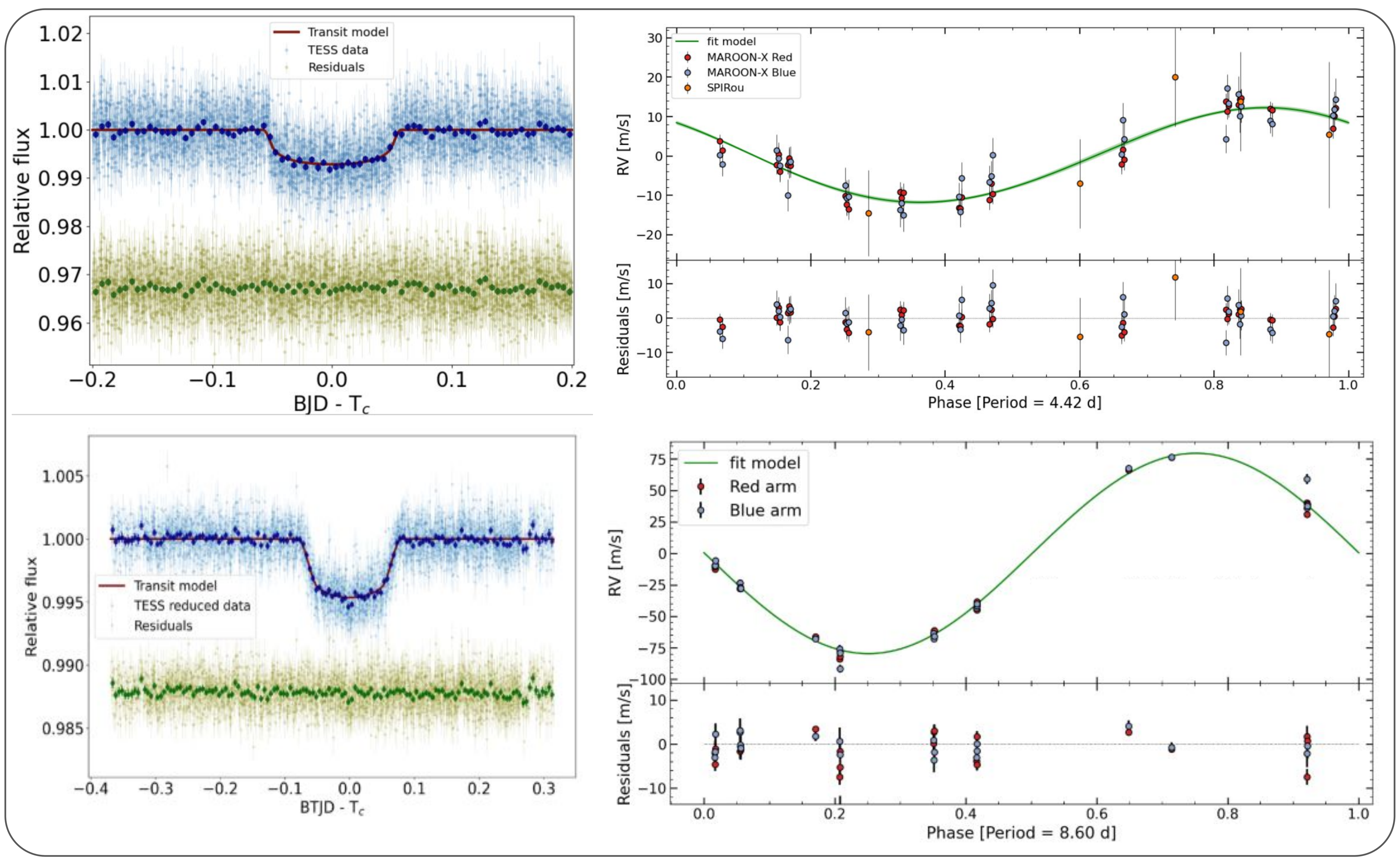

Figure 4. *Left*: Photometric observations of the transits of TOI-3568 b (top) and MX-TESS-PC2 b (bottom) observed by TESS. The red lines show the best-fit transit model and the green points show the residuals plus an arbitrary offset. The dark blue and green points represent the weighted averages of bins with a size of 0.01 d. *Right*: MAROON-X Radial velocity data of TOI-3568 (Top) and MX-TESS-PC2 (bottom). The red and blue points show the MAROON-X RV data for the red and blue channels. The green line shows the best-fit orbit models and the bottom panels show the residuals.

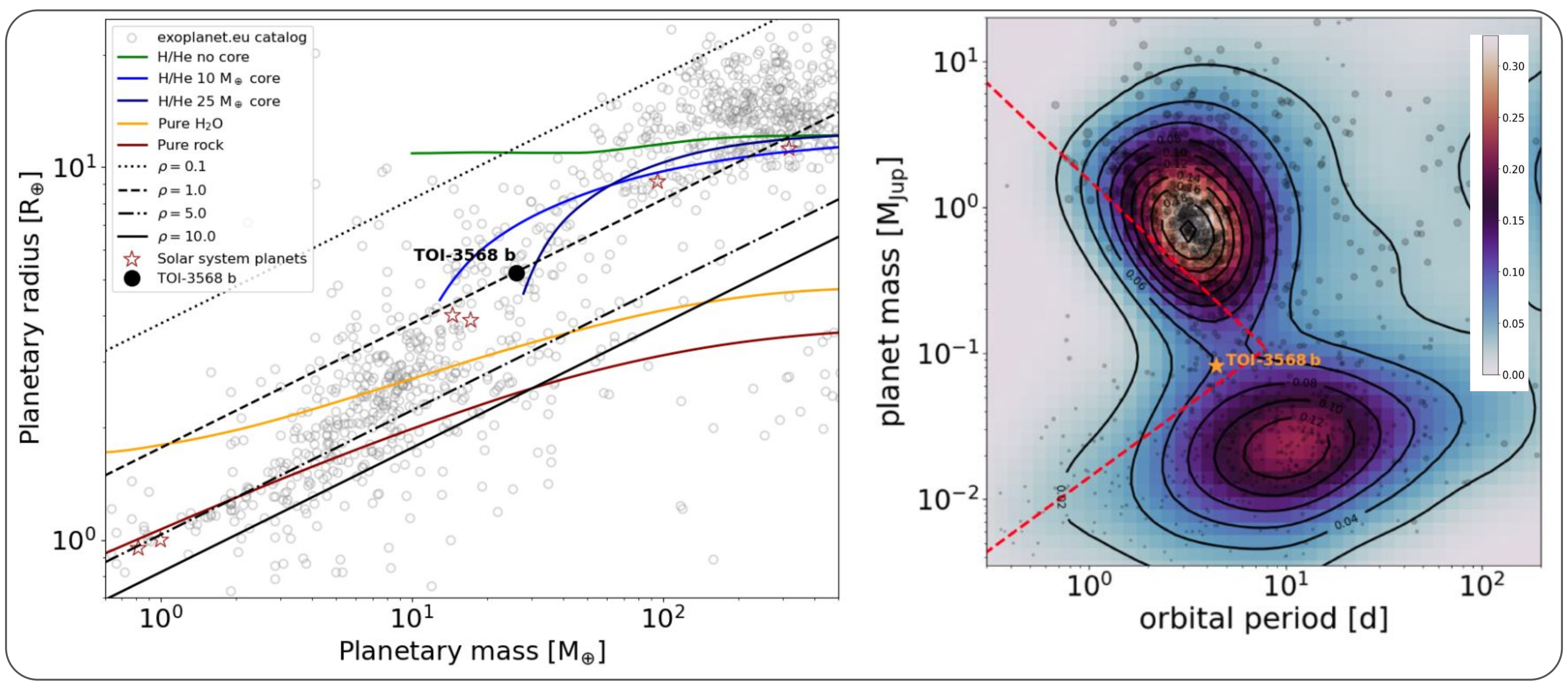

Figure 5. *Left*: Location of TOI-3568 b (black dot) in the Mass-radius diagram in comparison with other exoplanets from *exoplanets.eu*. The red stars show the solar system planets. Internal structure models for planets with pure rock and pure ice (H2O) compositions from Zeng et al. (2019) are depicted by the solid red and orange lines, respectively. Additionally, evolutionary models for H/He dominated planets from Fortney et al. (2007) are shown for a pure H/He without a core (green line), and for a core of 10 $M_{\oplus}$(blue line) and 25 $M_{\oplus}$ (dark blue line) of heavier elements. Iso-density curves are also represented by the black lines. *Right*: Location of TOI-3568 b (orange star) in the Mass–period diagram. TOI-3568 b, which lies within the desert right in the transition between the two populations of the most frequent types of exoplanets, hot-Jupiters (top), and warm super-Earths (bottom). The red dashed lines show the innermost limits of the sub-Jovian desert as defined by Mazeh et al. (2016). The color map depicts the planet-detection rate as a percentage normalized to the sum of all known exoplanets in the mass range between 0.003 M_{Jup} and 20 M_{Jup} and orbital periods between 0.3 d and 200 d (Martioli, Petrucci, Jofré et al. 2024).

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2025 Sagan Summer Workshop
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Acknowledgments: This work has been partially supported by PIBAA-CONICET ID-73669.