Mass Constraints of Young Proto-sub-Neptunes:

Disentangling V1298 Tau's Planetary and Stellar Activity Radial Velocity Signals with MAROON-X

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Abstract:

- Planets orbiting young stars ($\lesssim 100\,\mathrm{Myr}$) serve as important windows into early planet formation and evolution
- Mass constraints of young proto-sub-Neptunes are necessary to test mass-loss processes (photoevaporation, core-power mass-loss, boil-off) that have a dramatic impact on observed population of super-Earth/sub-Neptunes [1].
- Constraining the masses of young planets is challenging due to the large and complex stellar activity that impacts photometric and radial velocity (RV) measurements.
- We present a recent joint analysis of photometric (K2, TESS) and high-precision RV (HARPS-N, CARMENES, MAROON-X) measurements of the keystone system, V1298 Tau (spectral type K1, $V = 10\,\mathrm{mag}$, $t_{\mathrm{age}} = 20 - 30\,\mathrm{Myr}$)

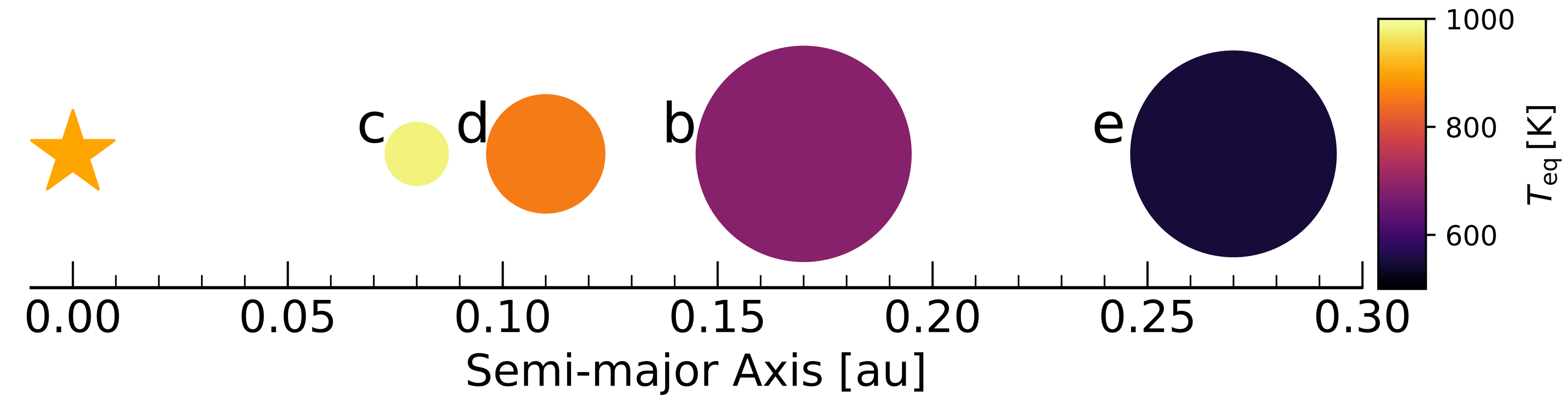

Fig. 1: Architecture of the V1298 Tau system. The planet radii range from $\sim 0.5\,R_{\mathrm{Jup}}$ to $\sim 0.9\,R_{\mathrm{Jup}}$. Depending on the stellar activity, planets c, d, and b are predicted to undergo substantial atmospheric mass-loss due to photoevaporation causing their radii to decrease by up to a factor ~3 [1].

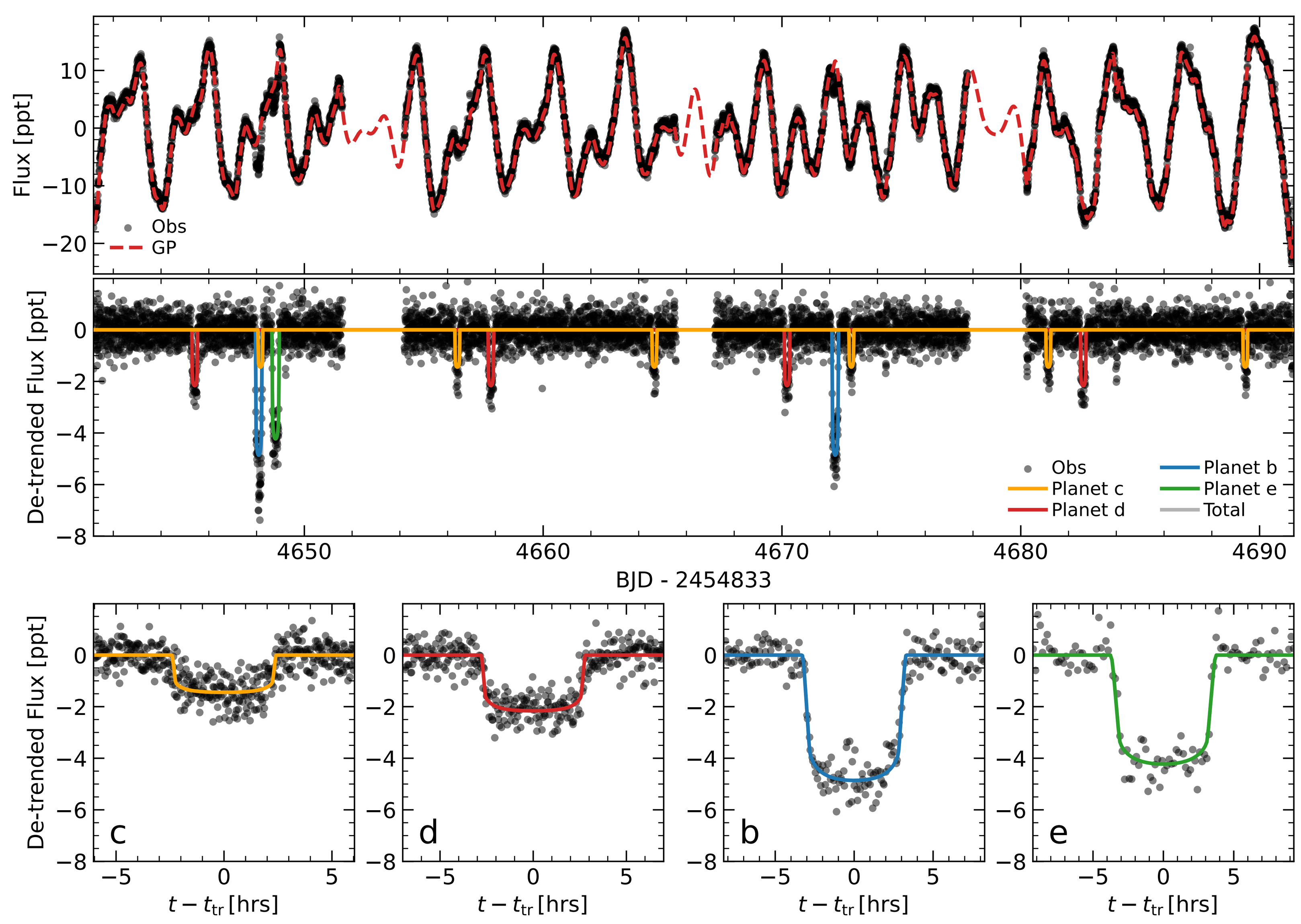

Fig. 2: Strong stellar activity causes high-amplitude photometric variations (top panel) in which the predominant variability can be attributed to V1298 Tau's 2.9 d rotational period. The middle panel shows the light curve after removing the stellar activity modelled using Gaussian Processes. The transits of the four planets are shown phase-folded by the orbital periods in the bottom panels.

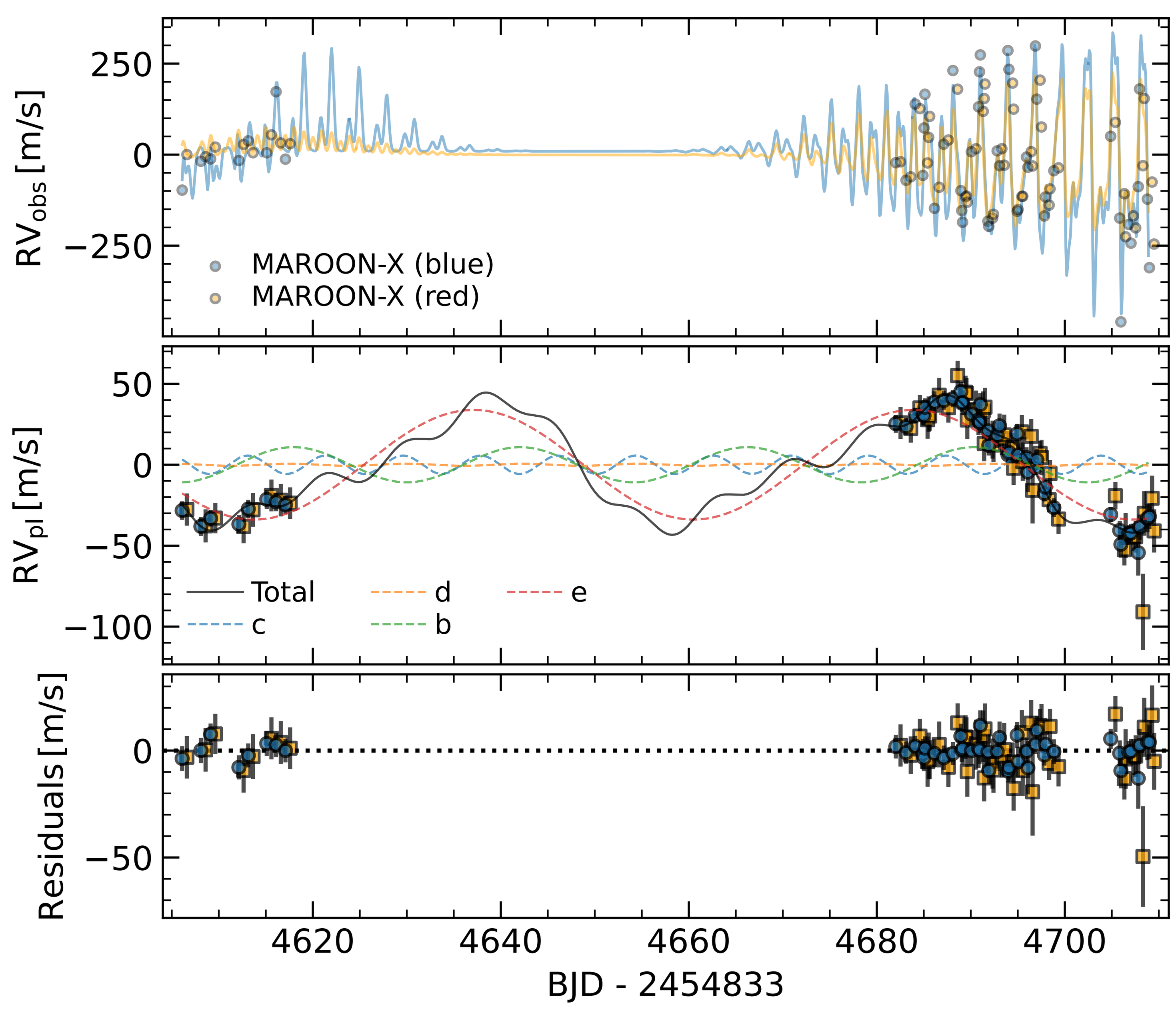

Fig. 3: By jointly modelling the photometric and RV stellar activity with GPs, the comparatively lower amplitude of the planetary Doppler signals can be revealed thereby allowing for mass constraints to be derived (Fig. 4).

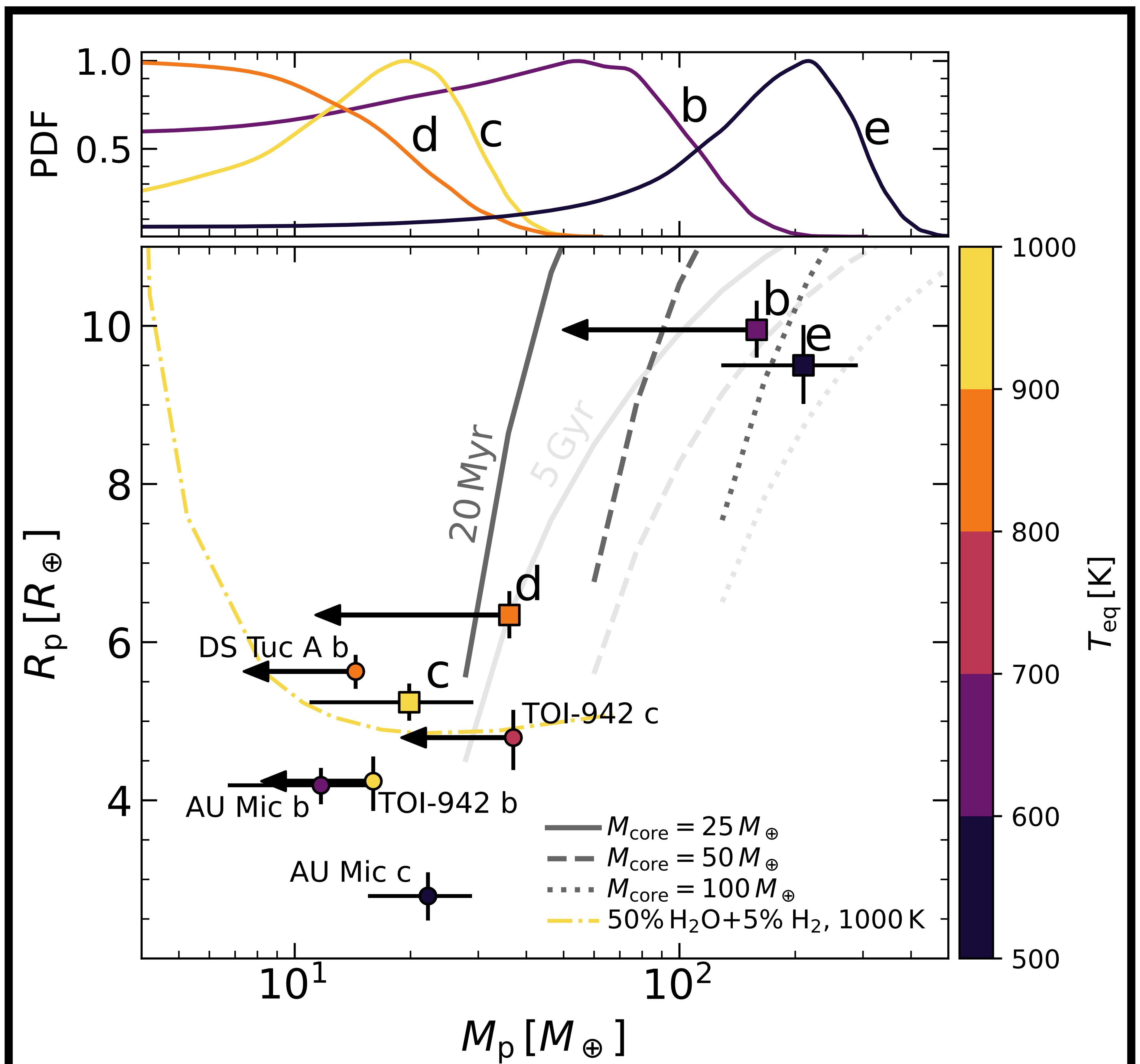

Fig. 4: Derived masses and radii of V1298 Tau c, d, b, and e are shown as coloured squares. Several young planets ($t_{\mathrm{age}} < 100\,\mathrm{Myr}$) characterized by other studies are shown as circles [4,5,6,7]. The new mass constraints derived in our study are in good agreement with published planetary evolution tracks (dark and light grey lines; [2]) and mass-radius relations (dash-dotted yellow line; [3]).

Conclusions:

- Using a Gaussian Process approach to disentangle photometric (Fig. 2) and RV (Fig. 3) stellar activity and planetary signals yields new mass and radius constraints of the V1298 Tau system that are in good agreement with theoretical predictions (Fig. 4).
- Such constraints are required to better understand how sub-Neptunes/super-Earths, which are the most commonly found type of planet, form and evolve and how this population is shaped by the behaviour of their host stars.

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