An Update on the Young V1298 Tau System as observed by CHEOPS, HST and *Spitzer*

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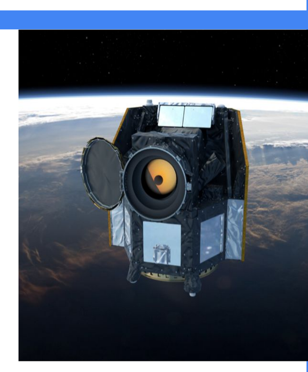
Why V1298 Tau?

- Young system (~23 Myr) - pre-main sequence K-type star.
- Multi-planetary system (4 confirmed planets [3, 4]) in mean motion resonance.

Why CHEOPS?

- High-precision time-series observations to constrain mid-transit time of each planet (constrain mass via TTVs, difficult to constrain with RVs).
- Better precision on transit parameters e.g. radius.



We observed transits of planets V1298 Tau c, d, and b using CHEOPS.

#1 Stellar Variability → A Challenge!

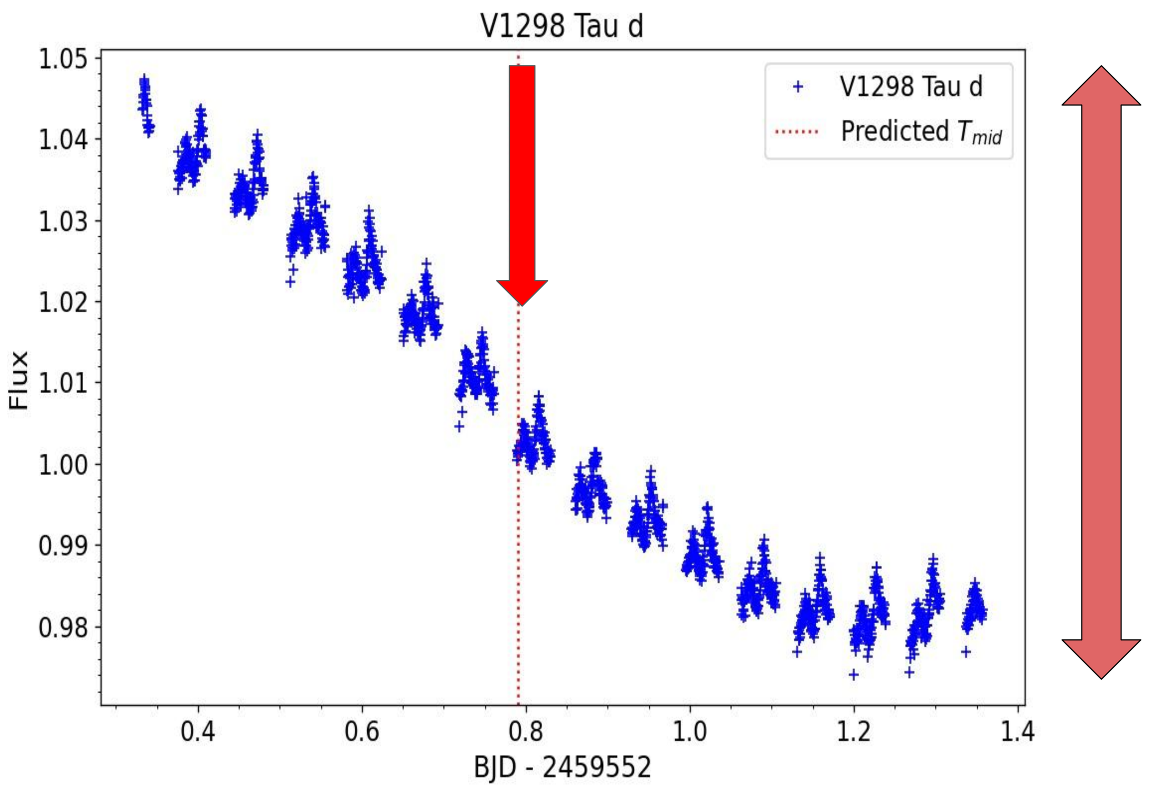


Fig 1: Raw transit light curve of V1298 Tau d (no decorrelation with systematics and stellar variability). The small red arrow indicates the predicted mid-transit time for planet d and the large red arrow indicates the variation in flux due to stellar variability (~7%).

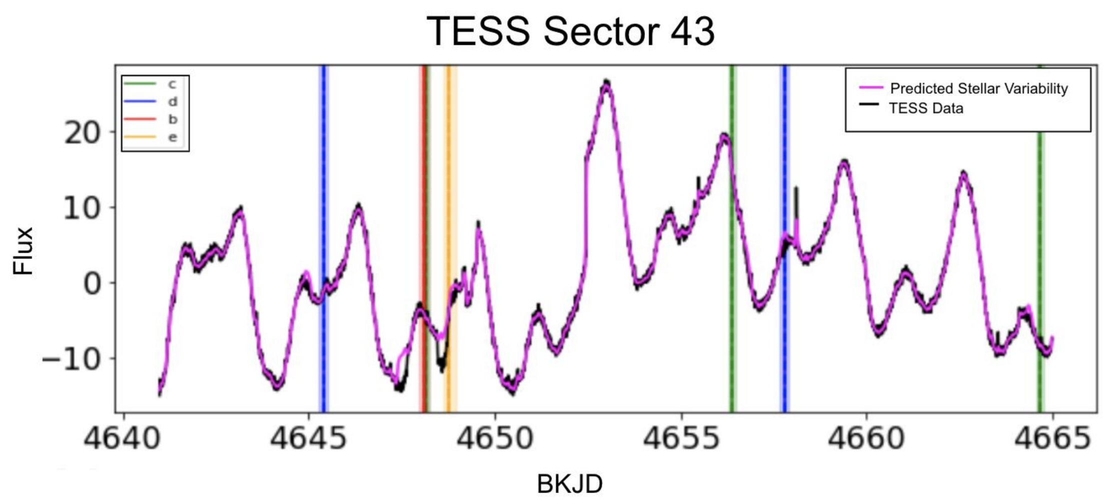
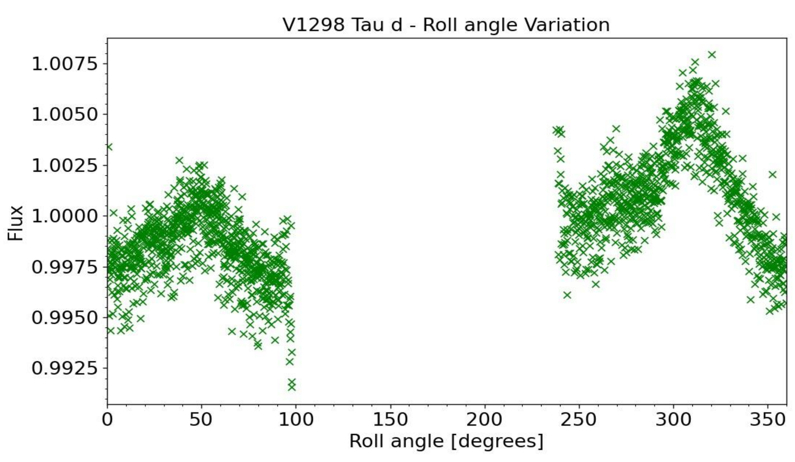


Fig 2: Stellar variability of V1298 Tau predicted using Gaussian processes on TESS observations of the system for Sector 43. Figure Credit: Georgia Mraz.

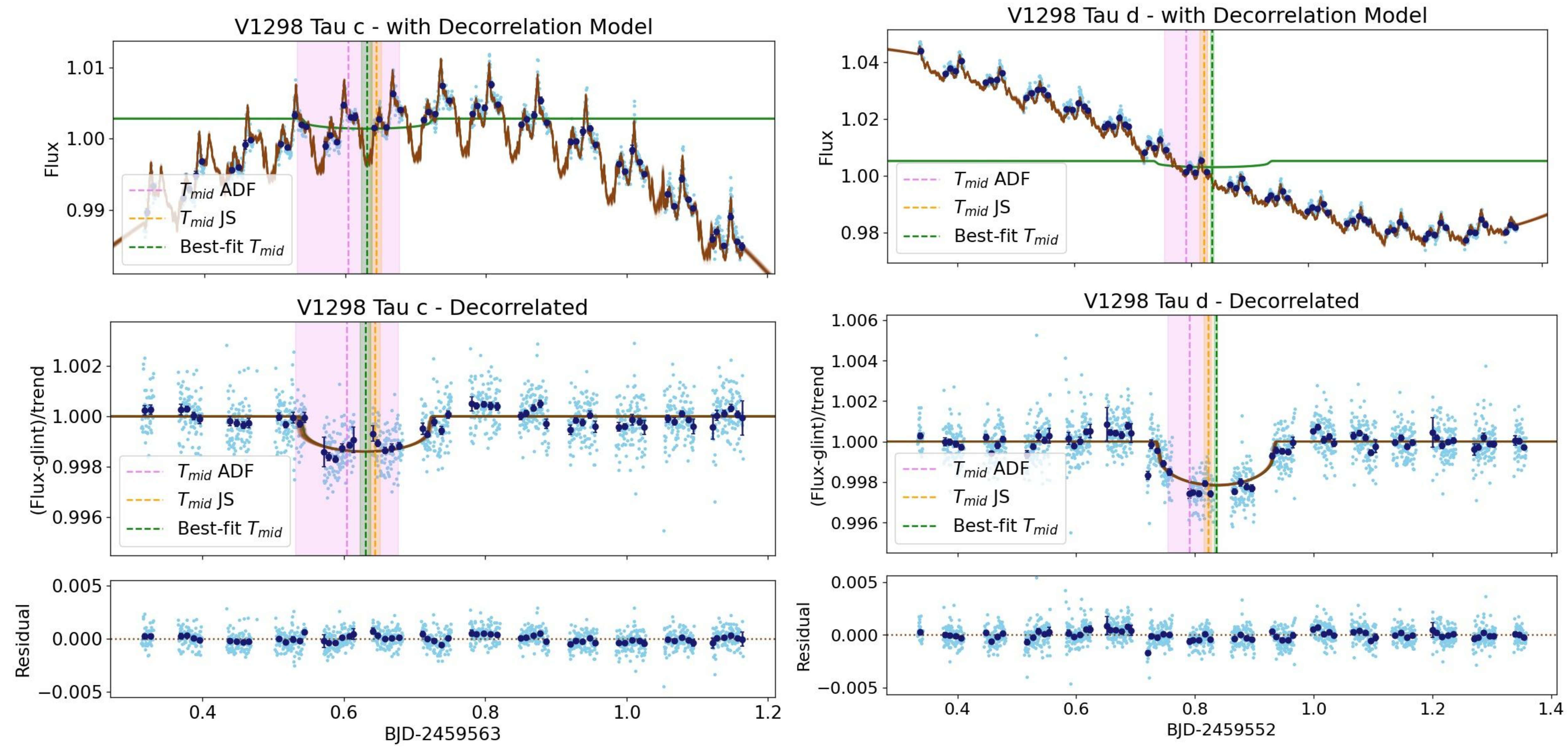
#2 Systematics → Flux variation → Need to Decorrelate!

Main source of systematics → roll-angle due to field of view rotating as telescope orbits Earth.

Fig 3: Variation in flux as a function of roll-angle for planet d.



#3 Results → Decorrelated Transit Light Curves of planets c, d, b



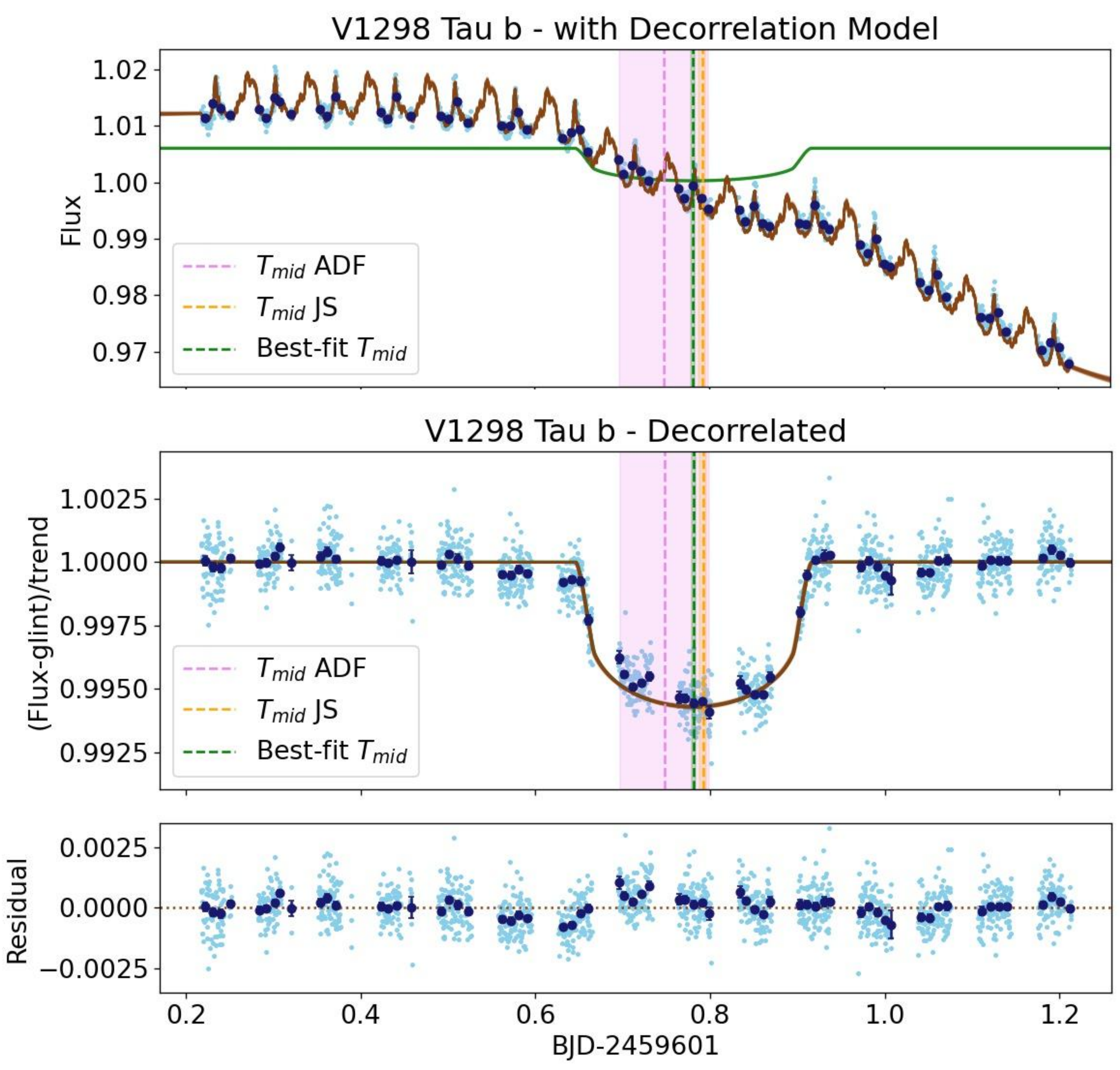


Fig 4: ***Top panels*** - Raw light curves of planet b (top left), c (top right), and d (bottom left). Skyblue points are the raw data, dark blue points are binned data. The MCMC samples of the decorrelation model is shown in brown. The transit model is shown in green. The analysis is done using the package *pycheops [1]*.
Bottom panels - Detrended light curves of planet b (top left), c (top right), and d (bottom left), c, and d and residuals from the best-fit models. The brown models show the samples from an MCMC run. The pink, orange and green lines and shaded regions represent the mid-transit time and 3-sigma region predicted using linear ephemeris from [2], [5] and this work, respectively.

- $T_{mid, planet\ c}$ = 2459563.631 BJD ± 3.831 mins
- $T_{mid, planet\ d}$ = 2459601.781 BJD ± 0.836 mins
- $T_{mid, planet\ b}$ = 2459552.836 BJD ± 1.435 mins

#4 Deviation from linear ephemeris

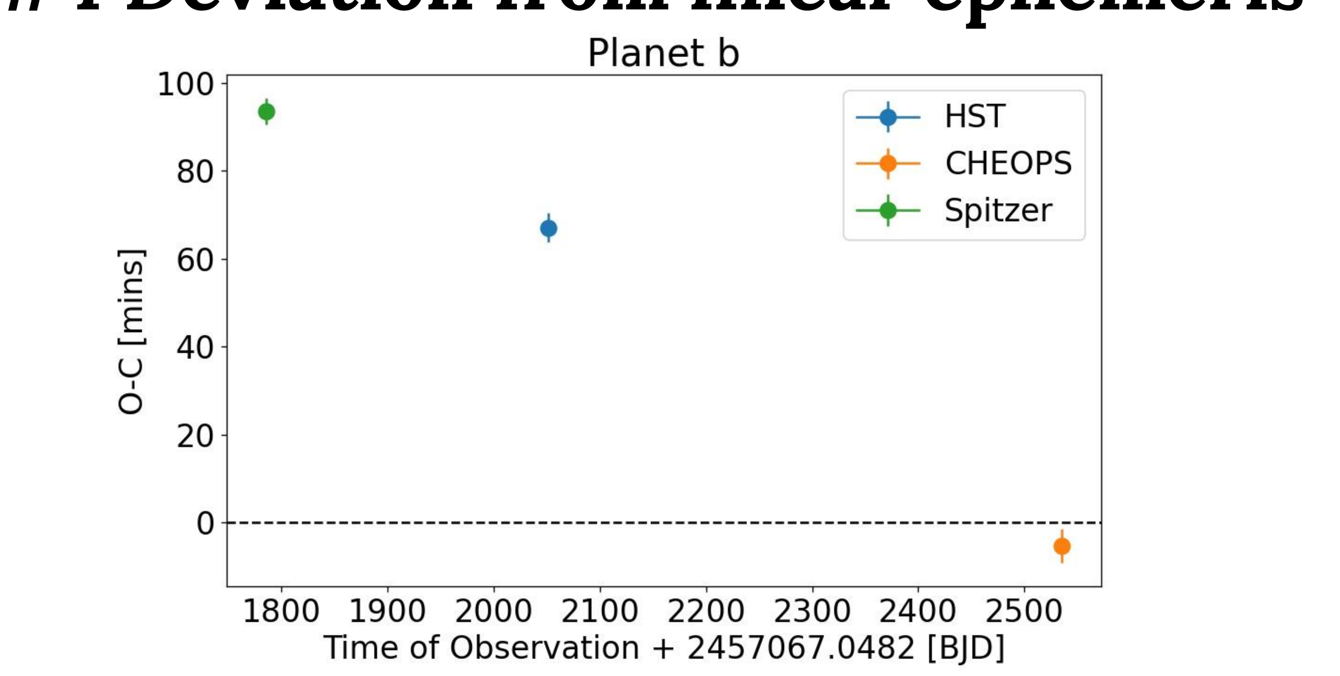


Fig 5: Observed-Calculated (O-C) diagram, for which O-C has been calculated with respect to a linear ephemeris from [5]. We include calculations from HST [Barat et al. in prep] and *Spitzer* observations.

#5 Improvement in Radii

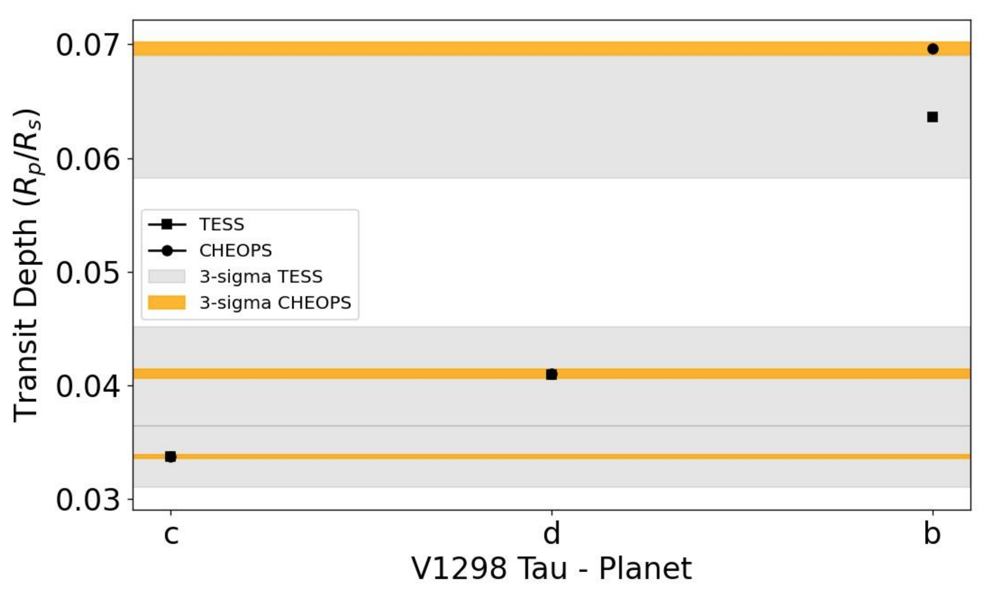


Fig 6: Best-fit transit depths for each planet compared to those from TESS. Orange and grey regions indicate 3-sigma error from CHEOPS (this work) and TESS observations [2], respectively.

+ Improvement in Mass (TTV modeling, work with collaborators [Livingston et al. in prep])

→ **Improvement in:**

a) **Bulk composition**
b) **Early radius evolution (atmospheric loss)**
c) **Predict formation and evolution of young (sub-)Neptunes → progenitors of super-Earths? Retain most mass?**

For more V1298 Tau science, check out the poster by **Saugata Barat - "Constraining planet formation with atmospheric observations of V1298 Tau system"**!

References:

[1] Maxted et al. 2021, MNRAS
[2] Feinstein et al. 2022, ApJ, 925
[3] David et al. 2019, AJ, 158, 79
[4] David et al. 2019, ApJL, 885
[5] Sikora et al. 2022 (submitted)

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