Discriminating between Conflicting Measurements of Exoplanet Transit Parameters through Joint Analysis of Observations by TESS and CHEOPS

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Abstract

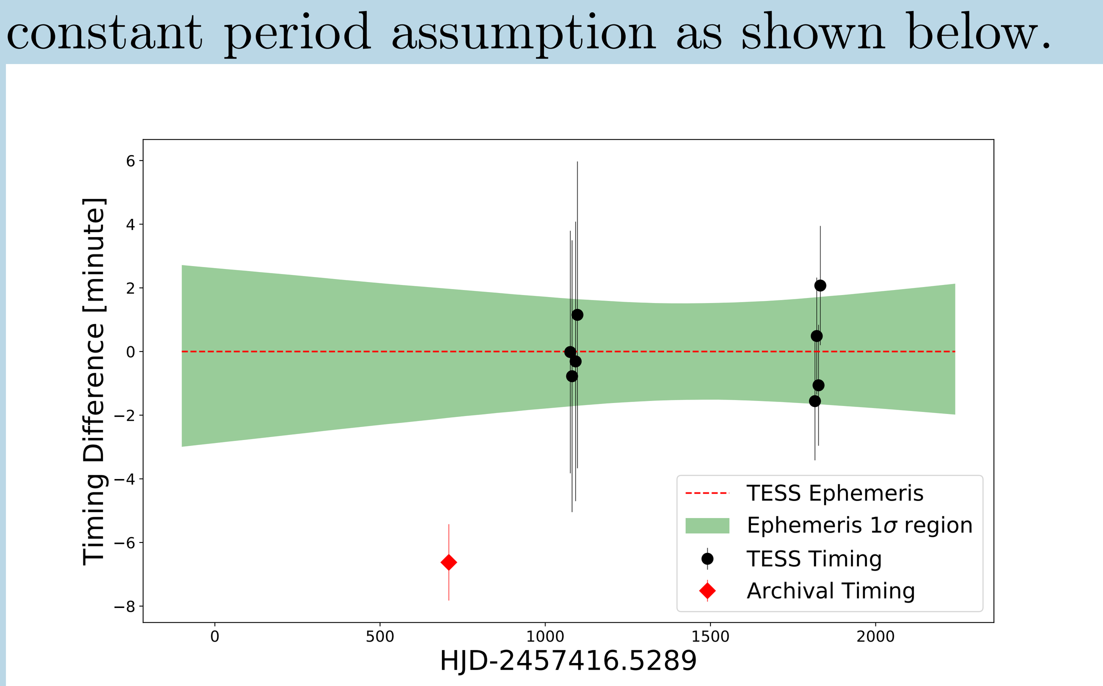
Analyses of TESS data of certain exoplanets reveals differences in transit depths and timing compared to published values, typically obtained from discontinuous light curves. We specifically examine the cases of KELT-19Ab, WASP-156b, WASP-121b, and WASP-161b [1, 2, 3]. We model and remove the systematic effects in the light curves, and identify the physical origin of these differences. The transit depth differences could potentially be due to atmospheric features. The timing conflict of WASP-161b reveals a transit mid-point discrepancy of about 6 minutes. This could be connected to tidal dissipation processes which approved CHEOPS observations later this year will reveal.

Major Highlights

TESS Light Curve: We generated a photometric pipeline to obtain light curves from the raw TESS images. The pipeline includes modules for e.g., astrometry checking, aperture photometry, deblending of the contaminating flux from nearby stars using Gaia, and light curve detrending [1]. The pipeline is independent of the TESS Science Processing Operations and has been shown to give consistent results (in transit modeling) among the comparison samples.

Transit Depth Comparison: The light curves are fitted with the exoplanet transit model [4], using the MCMC technique. The derived transit depth is compared with the archival transit depth (usually in different bands). The resultant multi-band transmission spectra are fitted with atmospheric models [1].

WASP-161b TTV Derivation We measure 8 transit midpoints for WASP-161b in TESS data [3] which reveal significant inconsistencies with the previous ephemeris [5]. We re-analyze the archival light curves from [5] and find that their light curve is consistent with their ephemeris, but not consistent with TESS timings under a constant period assumption as shown below.



Iterative Method for Limb Darkening: We present an iterative method using an empirical Bayesian approach for modeling the limb-darkened WASP-121b transit, motivated by the need to improve R_p/R_* estimates for exoplanet atmosphere modeling [2].

References

[1] Yang, F., Chary, R.-R., & Liu, J.-F. 2020, submitted to AJ, arXiv:2012.08744

[2] Yang, F., Long, R. J., Liu, J.-. feng ., et al. 2021, AJ, 161, 294. doi:10.3847/1538-3881/abf92f

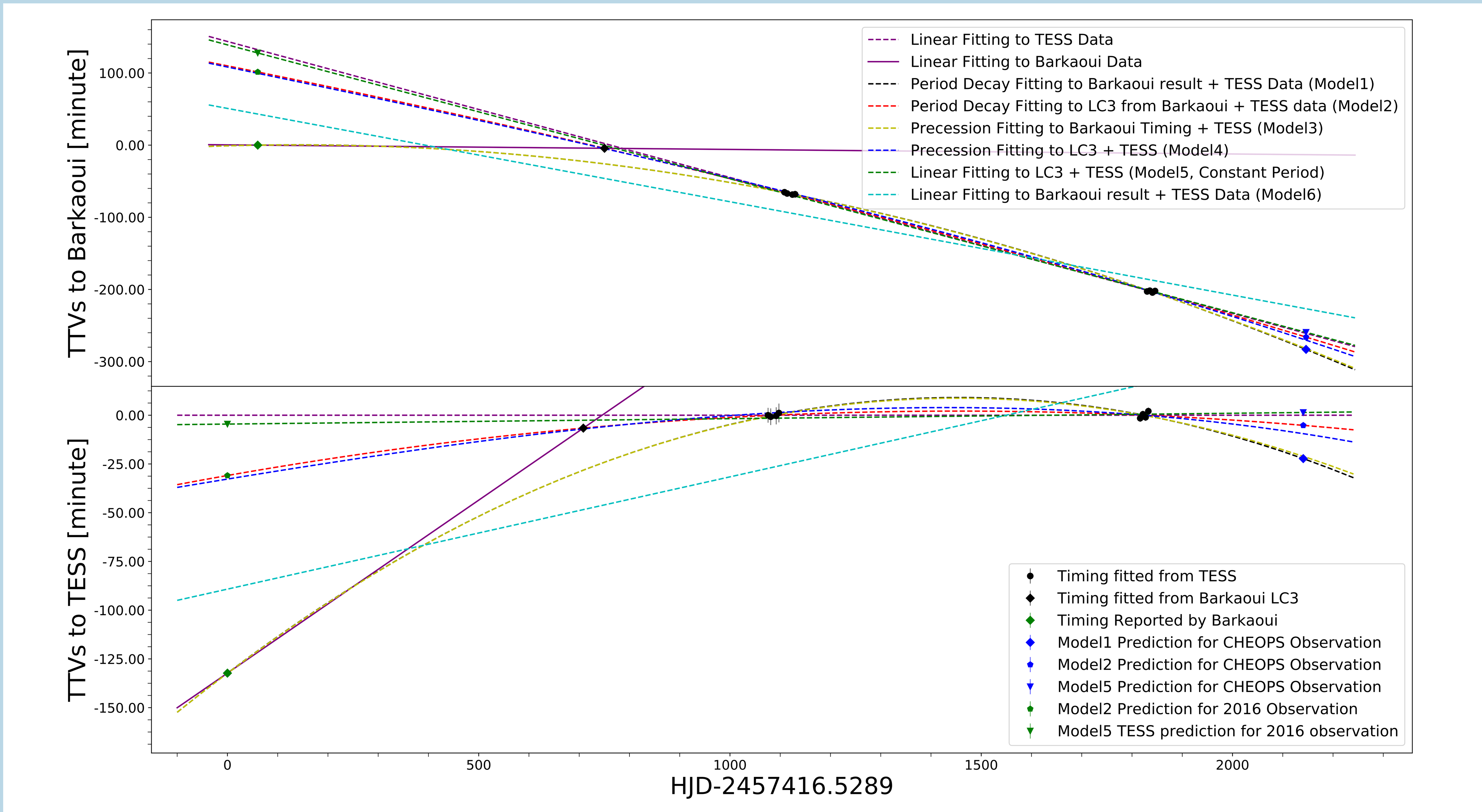
[3] Yang, F., Chary, R.-R. 2021, submitted to AJ

[4] Mandel, K. & Agol, E. 2002, ApJ, 580, L171. doi:10.1086/345520

[5] Barkaoui, K., Burdanov, A., Hellier, C., et al. 2019, AJ, 157, 43. doi:10.3847/1538-3881/aaf422

WASP-161b TTV Evidence

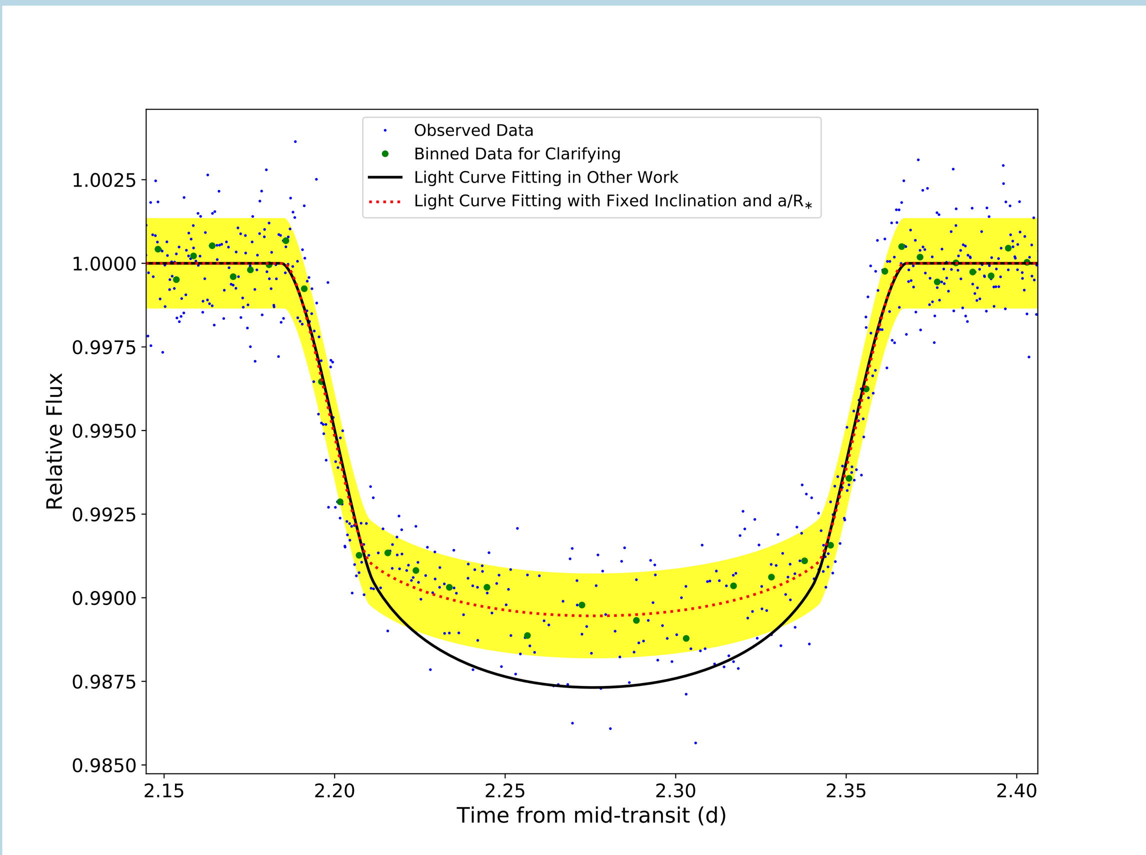
The midpoints of TESS transits are significantly offset when compared to the ephemeris published in [5] as well as the timing reproduced from the archival light curve in the same paper (LC3). The TTVs could be modeled with a quadratic function, yielding a constant period derivative. A tidal dissipation model appears to be the best explanation for the available transit measurements. We have approved CHEOPS observations for stronger constraints on the origin of the TTV. In addition, more exoplanet TTV discoveries from TESS data are in preparation, since the long time baseline of TESS allows for accurate transit midpoint modeling.

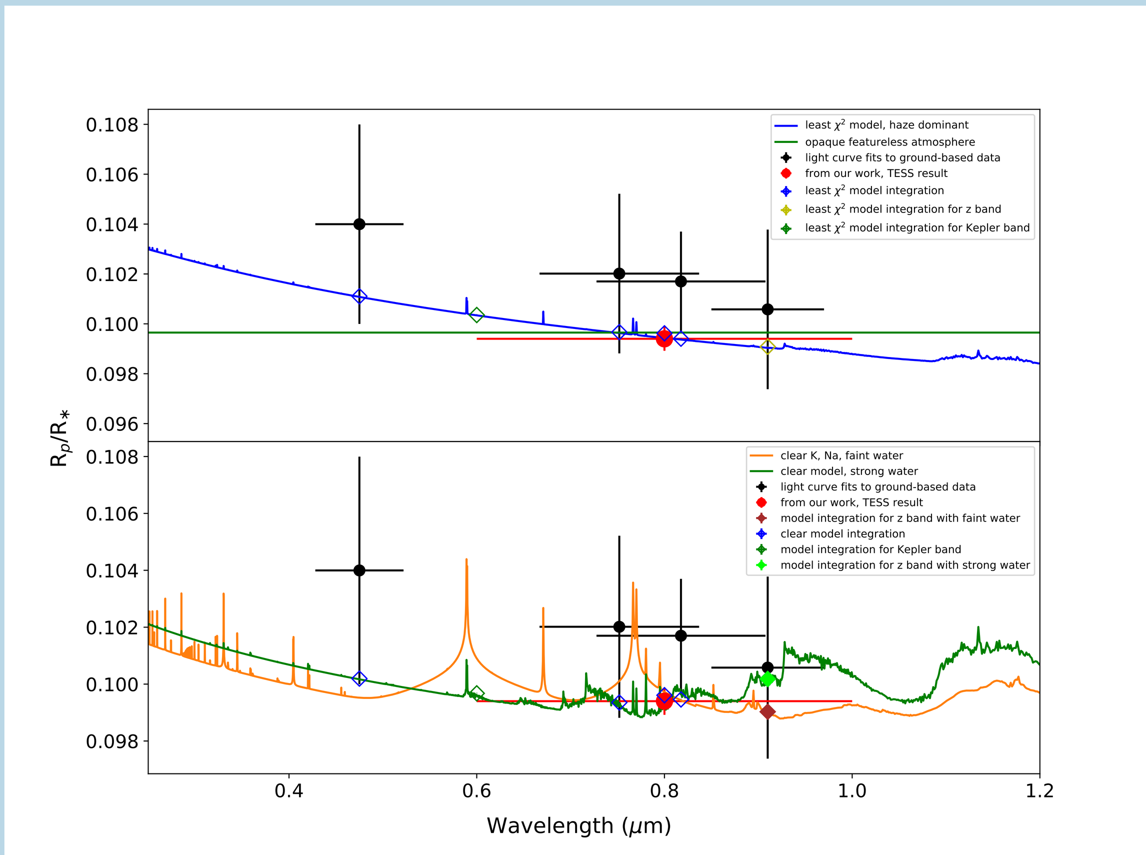


Evidence for TTV in WASP-161b: the constant ephemeris scenario from [5] is shown as the zero level line (upper panel), constant period model fitted to TESS timings as zero level line (lower).

Constraints on Atmospheric Properties of KELT-19Ab

R_p/R_* of KELT-19Ab in the TESS band is 2σ smaller than previous work in different bands which possibly indicates a haze-dominated atmosphere.

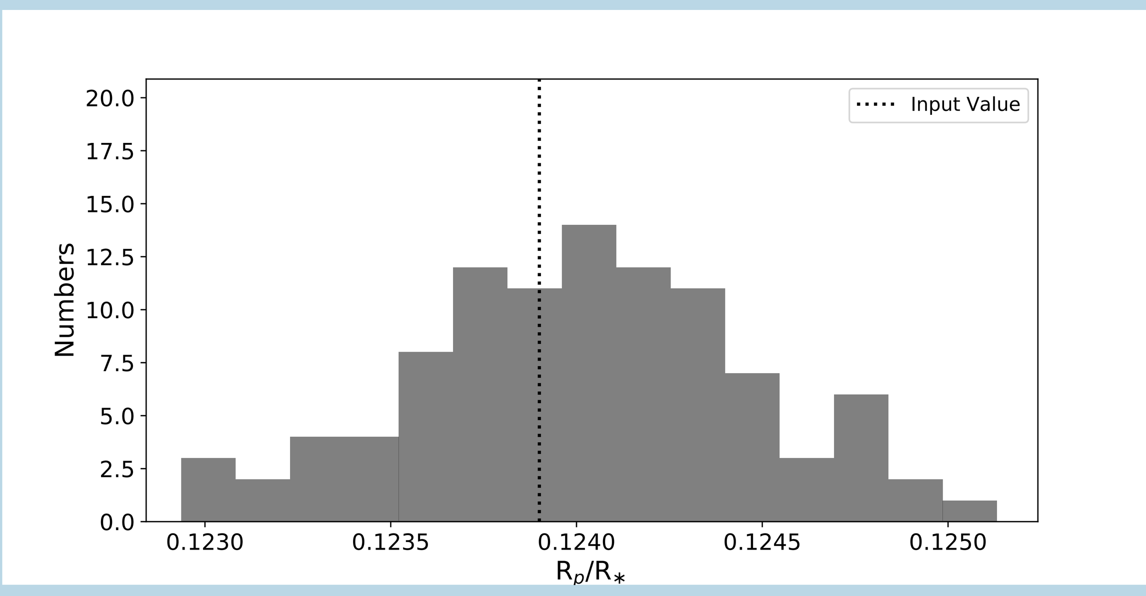


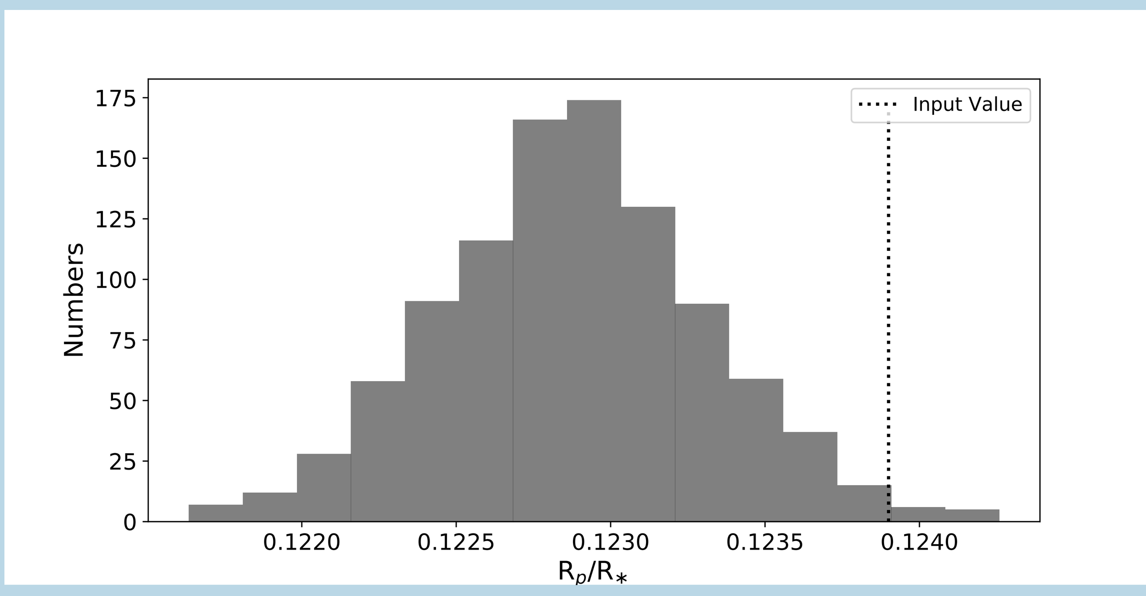


Fits of the TESS generated transit light curves of KELT-19Ab compared to the transit depth in other work (left); Transmission spectra of KELT-19Ab showing the TESS value in red (right).

Iterative Limb Darkening Approach for High Precision R_p/R_*

The uncertainty in limb darkening parameters combined with the sampling of the light curve propagates into an error in R_p/R_* of up to 1% which needs to be corrected.





Simulation showing the derivation of accurate R_p/R_* for WASP-121b. The iterative approach to limb darkening corrections yields R_p/R_* (left) which is not biased while the classic stellar model predicted limb darkening induces a bias of 2.5 σ (0.82%).