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Against the Planetary Interpretation of PTFO 8-8695b

L. G. BOUMA[1] AND J. N. WINN[1]

[1] *Department of Astrophysical Sciences, Princeton University, 4 Ivy Lane, Princeton, NJ 08540, USA*

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ABSTRACT

PTFO 8-8695b could be the youngest, shortest-period hot Jupiter known. However it has not been shown to be a planet. TESS recently observed PTFO 8-8695 for one month. The TESS light-curve shows that the dominant variability in this system is a sinusoidal modulation with a "long" period P_ℓ of 11.96 hours, likely caused by stellar rotation. Also present is a complex signal, previously identified as the planet candidate, that repeats with a "short" period P_s of 10.74 hours. The "long" and "short" signals show the expected beat every 4.48 days. There is a dip in the complex, short-period signal. However ground-based photometry from the past decade shows that the orbital phase of the dip seems to have instantaneously jumped, at least once, and maybe twice. The TESS epoch of the dip is consistent with recent observations by Tanimoto et al., and differs from the discovery epoch by 5.14 hours. Planets do not "jump" in orbital phase. PTFO 8-8695 therefore seems broadly consistent with the "transient dipping" phenomenology observed in many young M dwarfs, and seems unlikely to be a planet.

1. INTRODUCTION

If it were a planet, PTFO 8-8695b would be exceptional. A transiting hot Jupiter, orbiting a $\approx$3 Myr old M dwarf in ORION would make it the youngest hot Jupiter known. Its orbital period of only 12 HOURS would also make it the shortest period hot Jupiter known.

2. OBSERVATIONS

3. ANALYSIS

3.1. *Visual Inspection*

3.2. *Model Fitting*

Fourier analysis—Figure 1 could also be given in the frequency domain, rather than the time domain. The largest peaks in the Lomb-Scargle periodogram (CITE) of the raw light-curve are at P_s and P_ℓ. Both peaks of course have aliases. The P_ℓ peak has larger amplitude. Subtracting out the long-period signal, the short-period signal dominates the periodogram, and vice-versa. The periodogram of the final residual (Figure 1 bottom row) shows a weakly significant, poorly resolved peak at $\approx$8 days, consistent with the visual impression in the time domain that there could be a weak long-period signal present.

3.3. *Blend considerations*

The TESS pixels are $\approx$ 21" per side, and so we need to consider whether light from neighboring stars could affect the photometry. The scene is shown in Figure 3. The pixels used to measure the background level are indicated with an 'X' hatch, and the pixels used for the final light-curve are shown with the '/' hatch.

The target star, PTFO 8-8605 (TIC 264461976), has a T-band magnitude of 14.0, and its position is shown with a star. The other (unlabeled) star inside the target aperture, TIC 264461979, has $T = 16.8$ and so cannot contribute a signal with relative amplitude 10%. The only neighbor that is sufficiently close and bright that its light might contaminate the target star is TIC 264461980, with $T = 14.8$, which we denote "Star A". Star A is 23.6" NW of our target, and based on the magnitude difference could contribute up to 48% the flux of our target star, PTFO 8-8695.

Because PTFO 8-8695 has previously been identified to have periodicity consistent with our measurement of P_s, our main concern regarding blending is the degree to which we can be certain that the long-period signal at P_ℓ also originates from PTFO 8-8695. We took two approaches towards determining the source of the long-period signal.

First, we examined the CDIPS full frame image light-curves of the target, which are available on MAST (Bouma et al. 2019). The maximal peak-to-peak beat amplitude is consistently $\approx$10% across apertures of radii 1, 1.5, and 2.25 pixels. If Star A were the source of the long-period variability, we would expect the peak variability amplitude to be smallest in the 1 pixel aperture, based on the separation of the sources (Figure 3, bottom). From this test alone, it seems unlikely that Star A is the source of the long-period signal.

Second, we examined the light-curve of each pixel in the scene individually. We opted to use the interactive tools im-

Corresponding author: L. G. Bouma
luke@astro.princeton.edu

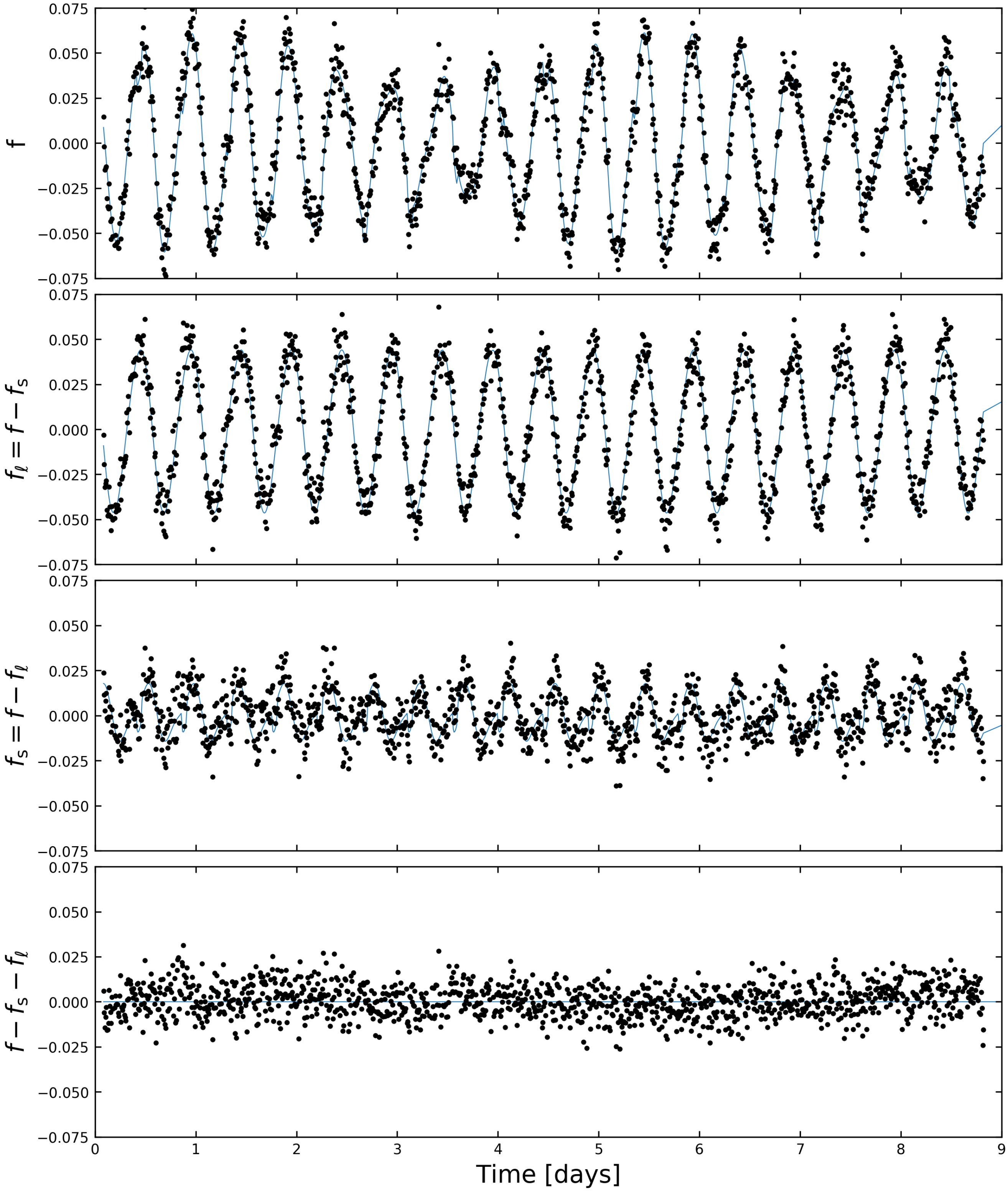

Figure 1. TESS light-curve of PTFO 8-8695 (Sector 6, Orbit 1). *Top*: "Raw" `PDCSAP` mean-subtracted relative flux versus time. The beat period of 4.48 days is visible by eye. The model plotted underneath the data includes 2 harmonics at the long period P_ℓ, plus 2 harmonics and a transit at the short period P_s. *Upper middle*: Long-period signal, equal to the raw signal minus the short-period signal. *Lower middle*: Short-period signal, equal to the raw signal minus the long-period signal. *Bottom*: residual. The data are binned from 2 to 10 minute cadence as a convenience for plotting and fitting.

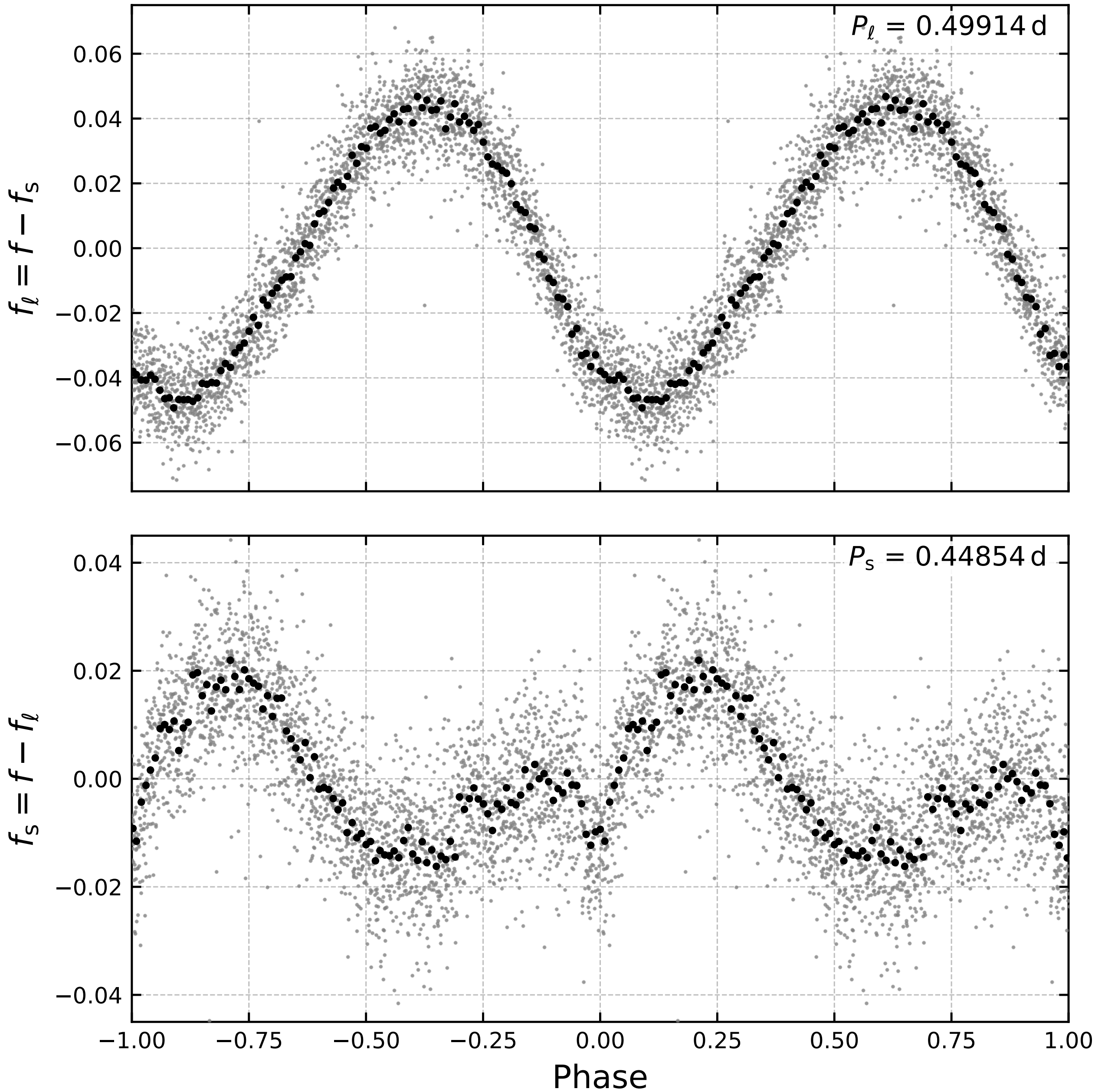

Figure 2. Phase-folded long and short-period signals. *Top*: Long-period signal, as in Figure 1. *Bottom*: Short-period signal. The reference phase is set to the "planetary" dip. Gray points are the 10 minute cadence `PDCSAP` flux. Black points are binned to 100 points per period.

plemented in `lightkurve` (Lightkurve Collaboration et al. 2018). If Star A were the source of the long-period variability, we would expect the pixels nearest to Star A to show a sinusoidal signal with amplitude exceeding 10%. We find no evidence for this being the case. The pixel directly below Star A does not clearly show the sinusoidal variability, and the peak-to-peak variability in that pixel is $\lesssim 8\%$. In contrast, the south-easternmost pixel within PTFO 8-8695's aperture (the pixel furthest from Star A that was used in the optimal aperture) shows the P_ℓ sinusoidal variability signal at $\approx 10\%$ amplitude.

As there is no evidence in favor of a blend scenario, we conclude that both the P_s and P_ℓ signals originate from PTFO 8-8695.

4. DISCUSSION

The TESS dip does not phase up where it is supposed to...

5. CONCLUSIONS

Software: `astrobase` (Bhatti et al. 2018), `astropy` (Astropy Collaboration et al. 2018), `astroquery` (Ginsburg et al. 2018), `corner` (Foreman-Mackey 2016), `emcee` (Foreman-Mackey et al. 2013), `IPython` (Pérez & Granger

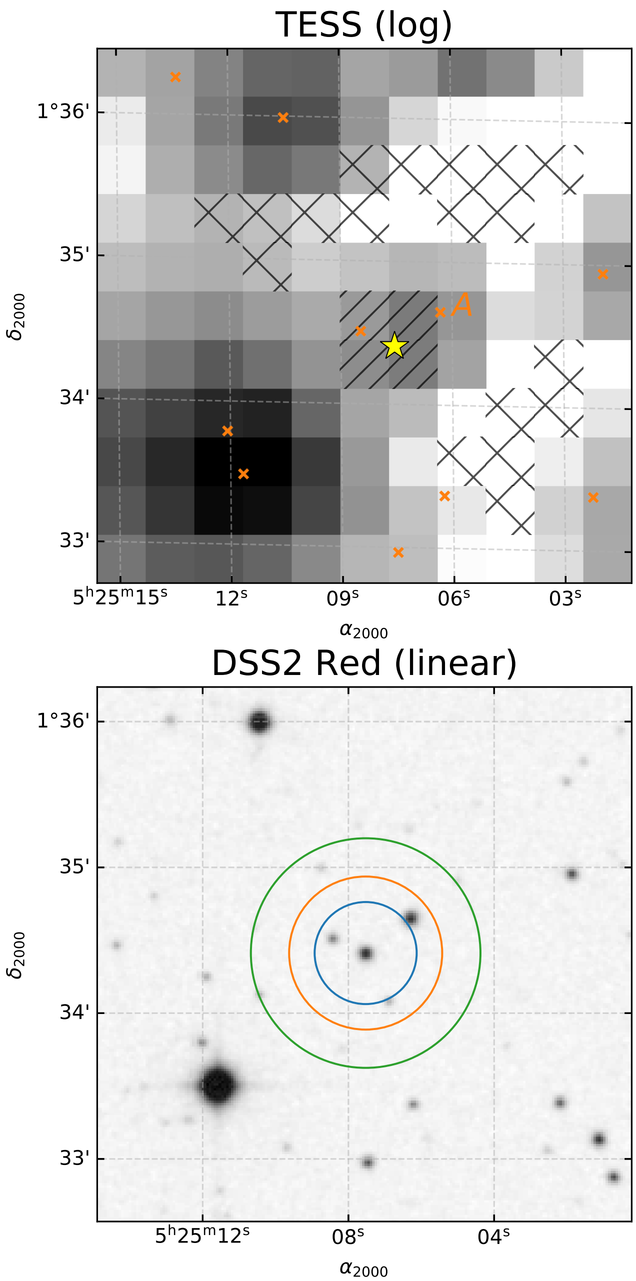

Figure 3. Scene used for blend analysis. *Top:* Mean TESS image of PTFO 8-8695 over Sector 6, with a log-stretch. The position of PTFO 8-8695 is shown with a yellow star. Neighbors with $T < 17$ are shown with orange crosses. The apertures used to measure the background and target star flux are shown with `X` and `/` hatches, respectively. *Bottom:* Digitized Sky Survey R-band image of the same field, with a linear stretch. The circles show apertures of radii 1, 1.5, and 2.25 pixels used in part of our blend analysis. The pixel level TESS data show that "Star A" does not contribute variability at either of the two observed periods (see Section 3.3).

2007), `lightkurve` (Lightkurve Collaboration et al. 2018), `matplotlib` (Hunter 2007), `MESA` (Paxton et al. 2011, 2013, 2015) `numpy` (Walt et al. 2011), `pandas` (McKinney 2010), `radvel` (Fulton et al. 2018), `scipy` (Jones et al. 2001).

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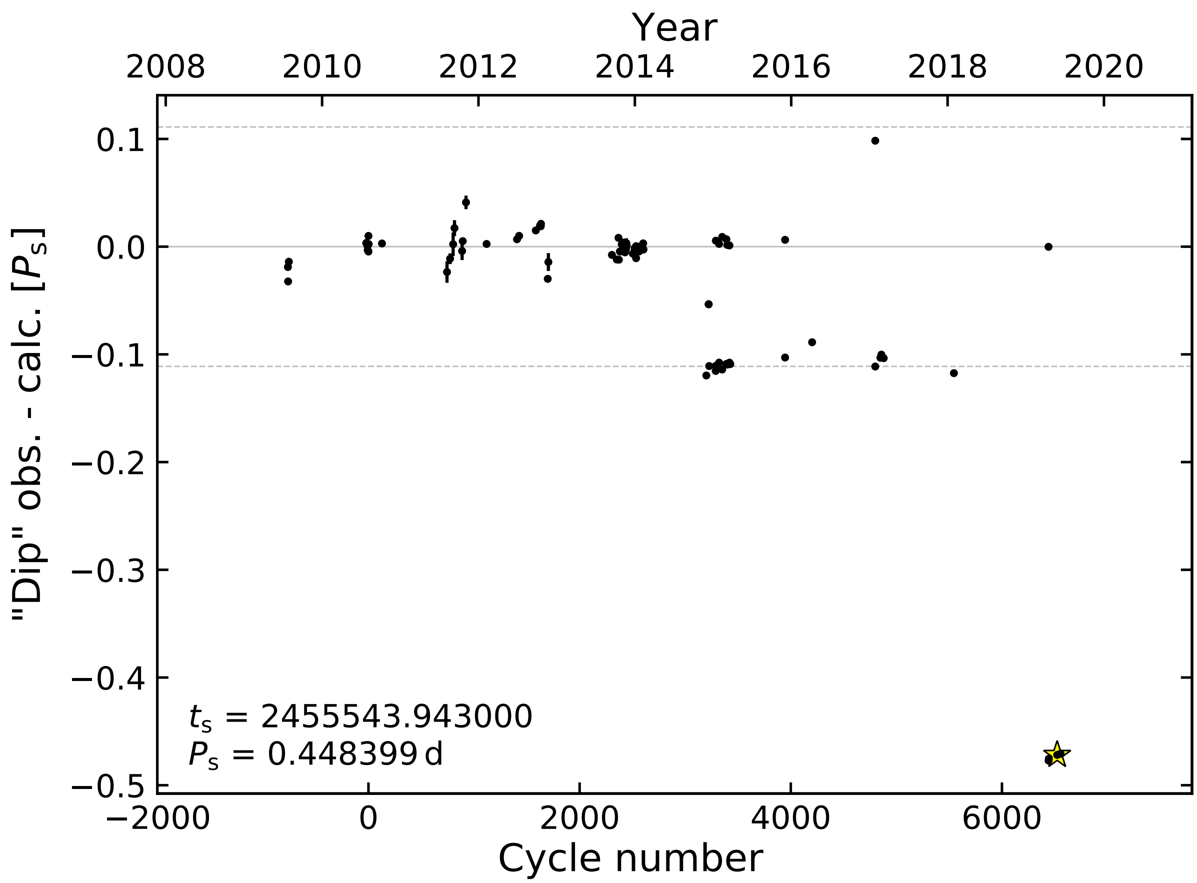

Figure 4. Timing residuals for PTFO 8-8695b from a decade of monitoring. Black points are times of "dips", minus the indicated linear ephemeris. The y-axis is given in units of phase for the short-period signal. The star shows the binned TESS ephemeris. "Dips" have been observed by van Eyken et al. (2012), Ciardi et al. (2015), Yu et al. (2015), Raetz et al. (2016), Onitsuka et al. (2017), and Tanimoto et al. (2020). Certain dips (*e.g.*, the one at phase 0 in mid-2019) are consistent with noise, and were likely reported because something was *expected*, rather than convincingly *observed*. Horizontal dashed lines are drawn at $\pm(P_\ell - P_s)/P_s$, highlighting what could be either a numerical coincidence or an observational bias. The orbital phase observed by TESS is consistent with that of Tanimoto et al. (2020), and quite different from the original phase.

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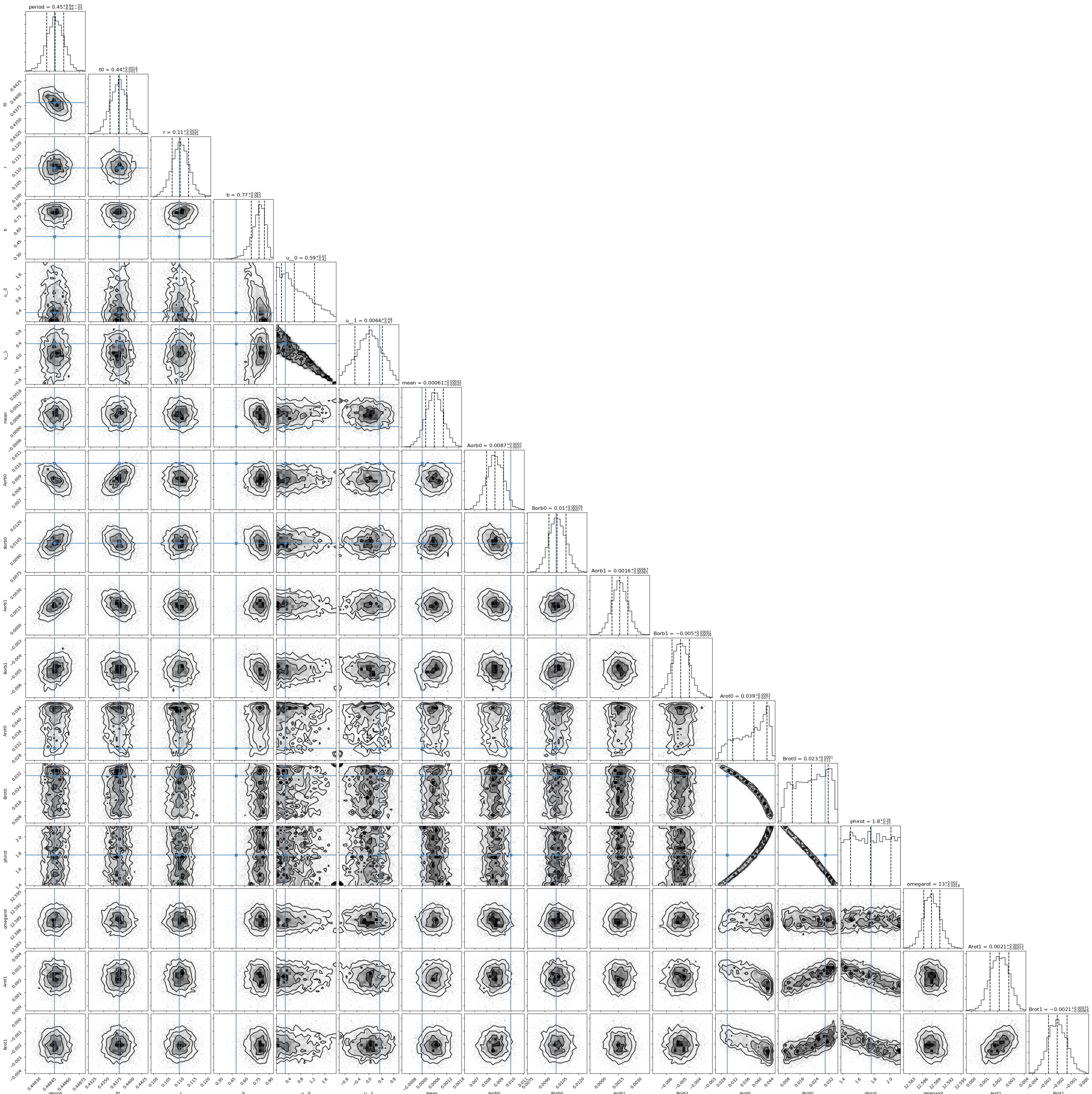

Figure 5. foo. bar

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