Detection of the Occultation of 55 Cancri e with TESS

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ABSTRACT

55 Cancri e is an ultra-short period transiting Super-Earth observed by TESS in Sector 21. Using this photometry, we measure the occultation depth in the TESS bandpass, leveraging the precise transit light curve and comparing multiple detrending methods. We measure the occultation depth to be $(15.0 \pm 4.8)$ ppm - a staggeringly small change in brightness, yet one detected by TESS in just a single sector of data. This implies a brightness temperature of $2800^{+130}_{-160}$ K, which is around 1.5σ greater than expected given the mean depth measured with Spitzer. This is not a formally significant difference, and may be accounted for by the known variability, or by an albedo of $\sim 0.5$. In any case, future TESS observations of this system will provide an exciting opportunity to further study this diminutive world’s atmosphere.

Keywords: planets and satellites: atmospheres — planets and satellites: detection

OBSERVATIONS

55 Cancri e is a $\sim 2 R_\oplus$ transiting exoplanet (Winn et al. 2011) orbiting a naked-eye star with an ultra short-period of 0.74 days (Dawson & Fabrycky 2010). The star was observed by TESS during Sector 21 of its second year of observations. We downloaded the publicly available processed PDC lightcurves (Jenkins et al. 2016) and removed outliers with a moving median filter and the photometric error flags. We detrended the photometry in individual orbital period segments centered on the expected time of transit by deweighting in-transit points and using four different standard algorithms: cofiam, polyam, local (a local linear regression) and gp (a Gaussian Process with a Matérn 3/2 kernel). These resulting time series were then combined by evaluating the median flux at each time stamp, and propagating the error between methods into the new fluxes, dubbed methmarg (see Teachey & Kipping 2018 for a detailed description of this and the individual algorithms used). We then repeated this process, centering instead on the times of occultation.

The 34 useable epochs present in the methmarg for the transit light curve were regressed using a Mandel & Agol (2002) model with $q_1$-$q_2$ limb darkening (Kipping 2013) coupled to MultiNest (Feroz et al. 2009). This provided a precise estimate of the ratio-of-radii ($p = 0.01807^{+0.00014}_{-0.00016}$), first-to-fourth contact duration ($T_{14} = 1.5499^{+0.0110}_{-0.0093}$ hours) and second-to-third contact duration ($T_{23} = 1.486^{+0.010}_{-0.010}$ hours). Since the occultation event is unaffected by limb darkening, and the orbit is nearly circular (Dawson & Fabrycky 2010), then the occultation will manifest as a trapezoidal-like decrease in brightness half-a-period after the transit events. The depth of the occultation event is unknown, $\delta_{occ}$, as is the out-of-occultation baseline flux level (although this is very close to unity due to the detrending), but the two duration parameters are tightly constrained from the transit fits. We can thus simply regress this trapezoidal model to the TESS occultation photometry in order to constrain $\delta_{occ}$.

We use a simple Metropolis MCMC algorithm to explore the two-dimensional parameter volume, with uniform priors on the baseline level and $\delta_{occ}$. The trapezoid durations are drawn from Gaussians approximating the transit posterior results. For the methmarg occultation, the marginalized posterior indicates $\delta_{occ} = (15.0 \pm 4.8)$ ppm - thus indicating that the occultation event was indeed positively detected. We repeated this on the four different versions of the occultation light curve using the different detrending approaches. local and polyam are in close agreement with each other (and not surprisingly the method marginalized result), as shown in Figure 1. The cofiam method finds

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Table 1. One sigma credible intervals for the seven transit parameters regressed to the TESS transit light curve of 55 Cnc e.

| Parameter | Value               |
|-----------|---------------------|
| $p$       | 0.01807$^{+0.00014}_{-0.00016}$ |
| $\rho_\star$ [g cm$^{-3}$] | 1.540$^{+0.061}_{-0.060}$ |
| $b$       | 0.347$^{+0.039}_{-0.045}$ |
| $P$ [days] | 0.7365270$^{+0.000086}_{-0.000085}$ |
| $\tau$ [BJD-2570000] | 1882.47729$^{+0.00111}_{-0.00111}$ |
| $q_1$     | 0.51$^{+0.16}_{-0.13}$ |
| $q_2$     | 0.115$^{+0.118}_{-0.077}$ |

Note—Fits assume a circular orbit.

a depth nearly twice as large, whereas gp finds one $\sim$50% smaller. Thus, the presence of an occultation is broadly recovered across the different methods, but the differences highlight how this is at the limit of TESS’ sensitivity, where detrending choices become influential. Although the occultation was not detected by MOST in a similar bandpass, the 2$\sigma$ upper limit obtained by Dragomir et al. (2014) is consistent with our measurement (< 35 ppm).

INTERPRETATION

To briefly interpret the result, we integrated a blackbody curve for the star multiplied by the TESS response function to solve for the brightness temperature implied by our result. We find 2800$^{+130}_{-160}$ K, which is larger than the equilibrium temperature expected of a pure blackbody at 55 Cancri e’s orbital separation (1970 $\pm$ 15) K). The occultation depth has been previously shown to exhibit significant variability in the 4.5 $\mu$m band of Spitzer (Tamburo et al. 2018), with brightness temperatures of up to (2700 $\pm$ 250) K. One possibility, then, is that TESS caught 55 Cancri e in an unusually bright episode in Sector 21. Another possibility is that some reflected light is contributing to the occultation. For a geometric albedo of unity, our transit posteriors indicate an expected reflectance occultation depth of (26 $\pm$ 1) ppm. The Tamburo et al. (2018) Spizter depths have a mean of (84 $\pm$ 26) ppm, corresponding to 2200$^{+350}_{-370}$ K after integrating over the 4.5 micron bandpass. In Figure 1, we plot the TESS occultation depth where one can see that the observed value is 1-2$\sigma$ higher than would be expected from a blackbody curve derived from the brightness temperature of the Spitzer occultations. Although not formally “significant”, it could be explained by an albedo of $\sim$0.5, but we hesitate to place too much confidence in that claim given the poorly understood nature of this planet’s variability. Nevertheless, future observations with TESS will provide excellent opportunities to continue to monitor this planet’s variability in the post-Spitzer era.

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Figure 1. Left: Four different detrendings of the TESS photometry of 55 Cancri e, surrounding the expected time of occultation. Right-top: Combination of the four occultation light curves into a single “method marginalized” light curve, indicating positive evidence for an occultation event. Right-middle: TESS transit photometry of 55 Cancri e, which we use to learn the system parameters to high precision. Right-lower: Emission spectrum of 55 Cancri e, plotting blackbody curves consistent with the Spitzer measurement of Tamburo et al. (2018).

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