The Short-Period Planetary Population of A Type Stars with TESS

Marshall C. Johnson (Las Cumbres Observatory)

TESS' all-sky survey enables studies of the demographics of exoplanets around stars too rare to have been observed in significant numbers by previous missions, or which were simply ignored by earlier observations. One such class is main sequence A stars, which are relatively rare and were mostly avoided by Kepler. Measuring the occurrence rate of short-period planets around these stars will inform our knowledge of planet formation and migration. Protoplanetary disks around A stars are more massive, shorter-lived, and have larger dust sublimation radii than those around FGKM stars. By comparing the short-period planetary population of A-type stars to those around FGKM stars, we can better understand the effects of these protoplanetary disk properties upon planet formation and migration. I will present initial results on the planetary occurrence rate for A stars from TESS, highlighting the particular challenges of confirming or validating these planets. Finally, I will discuss the consequences of these results for planet formation theory.

TESS Planet Candidates

Kepler produced excellent results on the planet occurrence rates of FGKM stars, but observed too few A stars to measure a good occurrence rate. TESS' all-sky survey solves this issue; it has observed tens of thousands of A stars, including a few thousand at 2-minute cadence. The TESS mission pipeline has identified dozens of planet candidates around these stars (Fig. 1), many of which are undergoing follow-up. Zhou et al. (2019, AJ, 158, 141) measured an occurrence rate for hot Jupiters around these stars, so I here focus on smaller planets (i.e., hot and warm Neptunes).

There is a distinct drop in the incidence of both planet candidates and multi-candidate systems (which are the least likely to be false positives) for stars hotter than mid-F. However, the Teff distribution of the candidate host stars is similar to that of the TIC as a whole (Fig. 2), suggesting that there may be no significant drop in incidence. Firm conclusions will need to wait for a more thorough quantitative analysis, but this may also be in conflict with the tentative result of a low hot Neptune occurrence rate for A stars found in the right column of this poster.

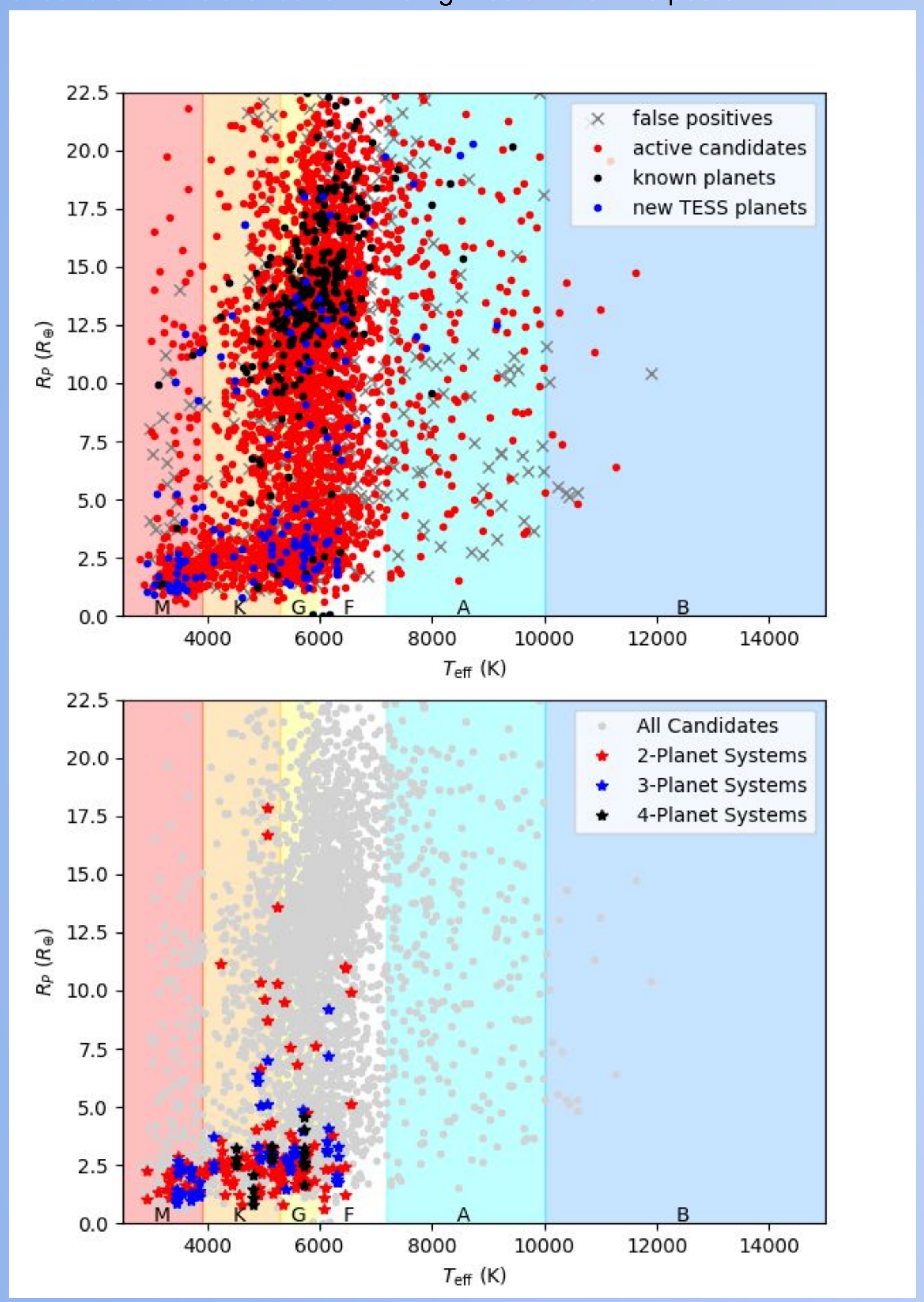

Fig. 1. The population of TESS candidates as a function of stellar Teff (from the TIC) and planetary radius. Top: all candidates. Bottom: multi-planet systems are highlighted. In both cases there is a relative paucity for A (and B) stars (blue background).

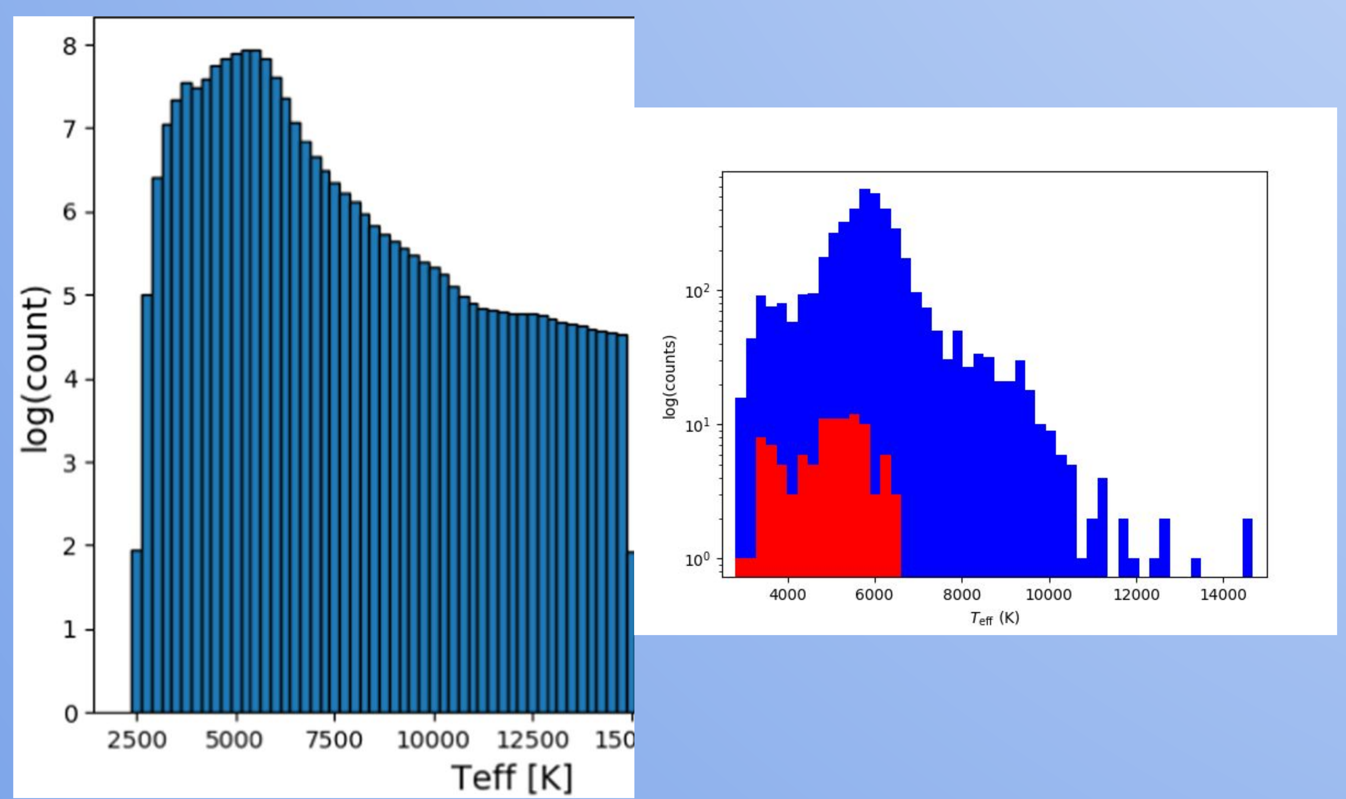

Fig. 2. Left: the Teff distribution of stars in the TICv8 (Fig. 14 of Stassun et al. 2019, AJ, 158, 138). Right: the Teff distribution of non-false-positive TOIs (blue) and multiple systems (red). The shapes of the distributions are qualitatively similar.

LCO Follow-Up of TESS Candidates

TESS planet candidates require follow-up observations to exclude false positive scenarios and confirm or validate them. These include ground-based time-series photometry to verify that the transit occurs on the target star, or exclude background eclipsing binaries as the source of the transit signal; high-resolution spectroscopy to search for additional spectral lines or velocity shifts due to an on-target eclipsing binary; and high-resolution imaging to detect stellar companions within a few arcseconds of the target star. The facilities of Las Cumbres Observatory (LCO) can produce the first two types of data. I am leading an LCO program to follow up TESS planet candidates around A stars, which has already obtained observations of dozens of planet candidates. These have identified some candidates as false positives, and passed others on to the next stages of vetting (Fig. 3 and 4). This is particularly challenging for A stars, as many planets have shallow transit depths that cannot be detected from the ground, and the hot, rapidly rotating stars are not good RV targets.

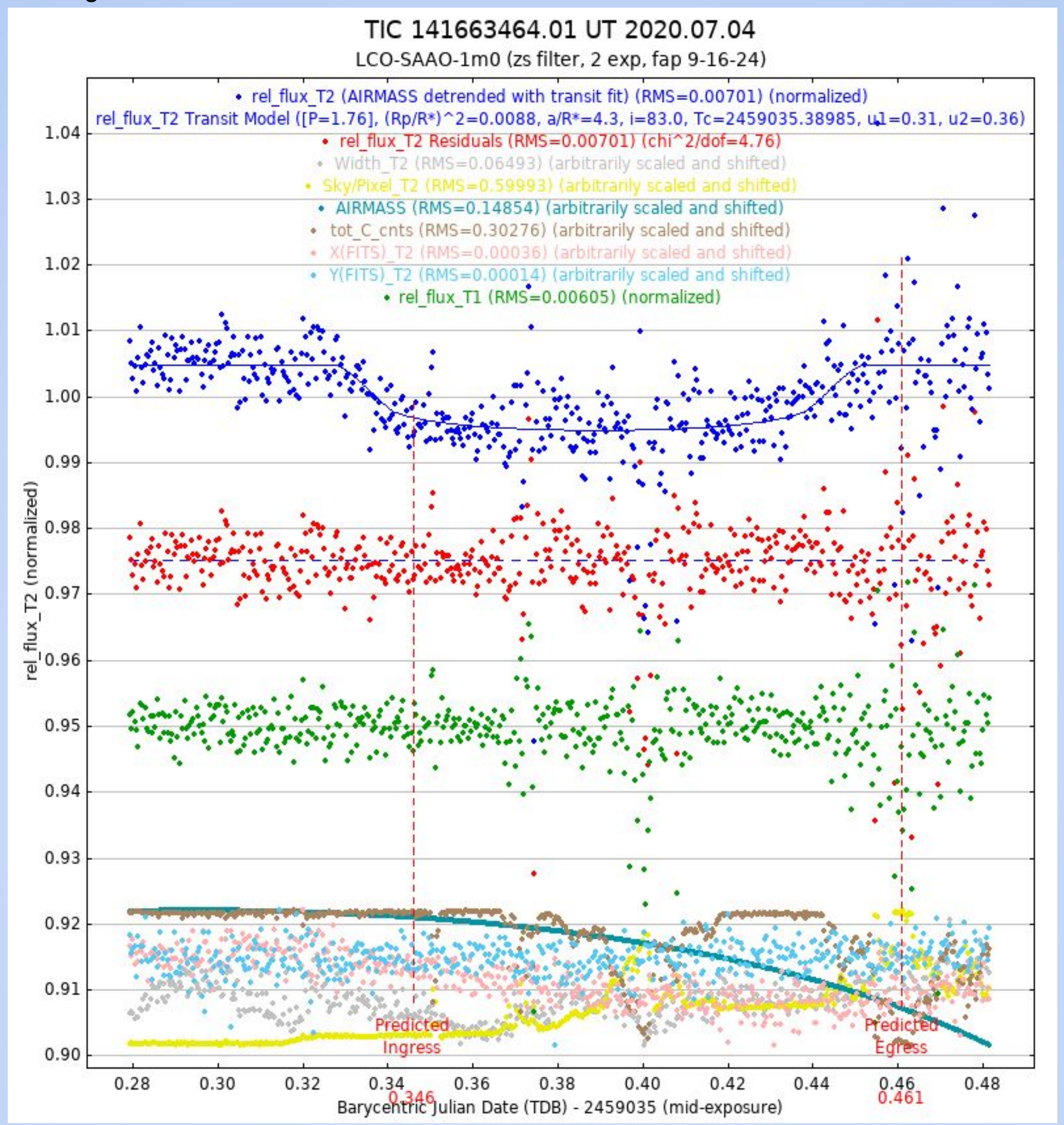

Fig. 3. Example of our TESS Follow-Up light curves, for the A star hot Jupiter candidate TOI-1962.01. These observations showed that the candidate does not transit the primary star (green), but rather the 10" secondary proper motion companion (blue; also an A star). Unfortunately this candidate was later shown to be a low-mass star, not a planet (A. Shporer, private communication).

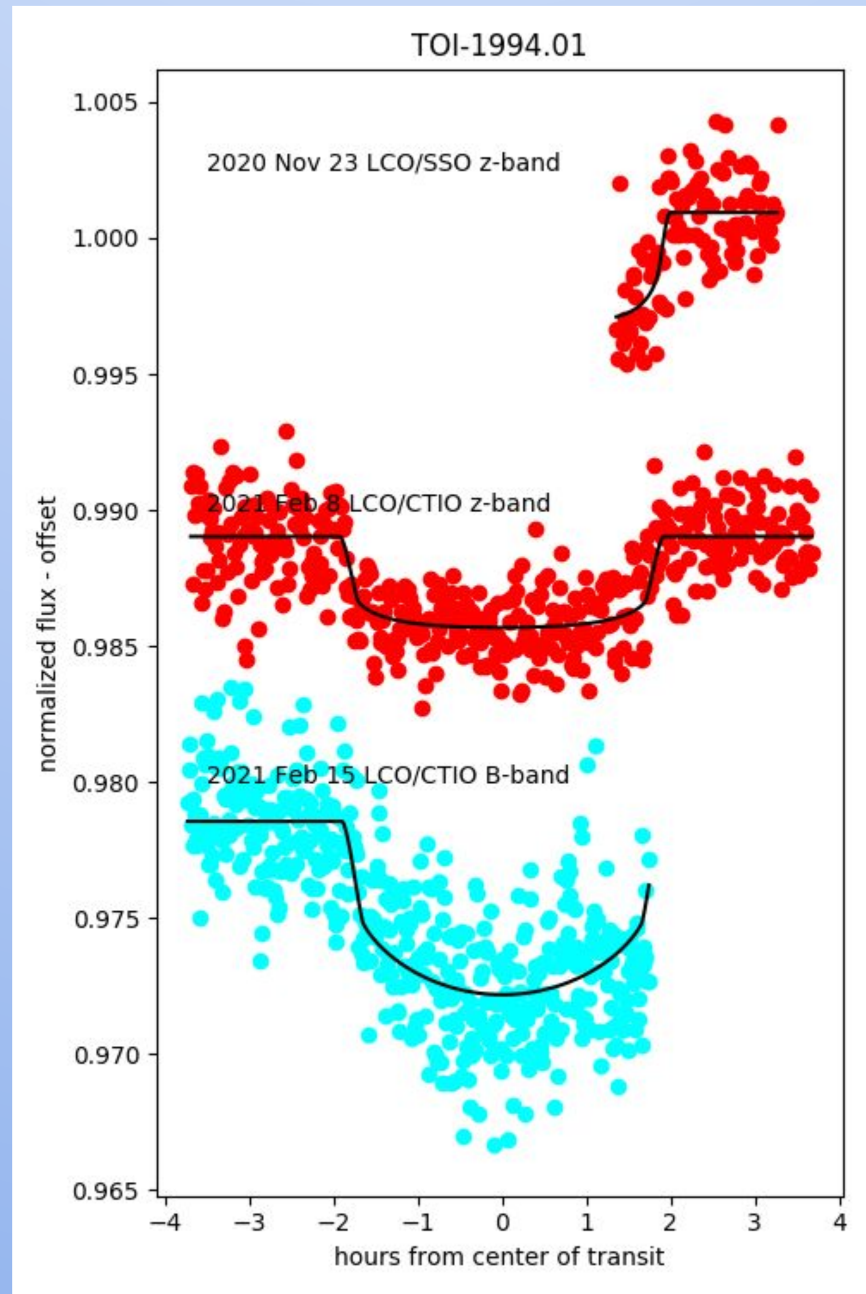

Fig. 4. LCO follow-up light curves of TOI-1994.01. The first transit showed that the event occurred on the expected target star, and the second confirmed this with a full transit. The z and B-band light curves show broadly consistent transit depths, indicating an achromatic transit. Radial velocity follow-up has confirmed this giant planet candidate, which will be presented in Page et al. in prep.

Custom Planet Search

We were granted 1,801 2-minute-cadence targets in TESS Years 1 and 2 for a survey focused on warm and hot Neptunes around A stars. We chose A stars with the lowest expected contamination factors to aid in the ease of validation.

The mission pipeline found only a single planet candidate around these stars, TOI-1475.01, which we are following up. However, **many of these stars are delta Scuti variables**, and I am building a custom pipeline to remove these pulsations and search for transits, which should improve the completeness of the planet search. A custom pipeline is also necessary to perform injection/recovery testing to measure the completeness and compute a robust occurrence rate. I show some initial light curves produced from this pipeline in Figs. 5 and 6.

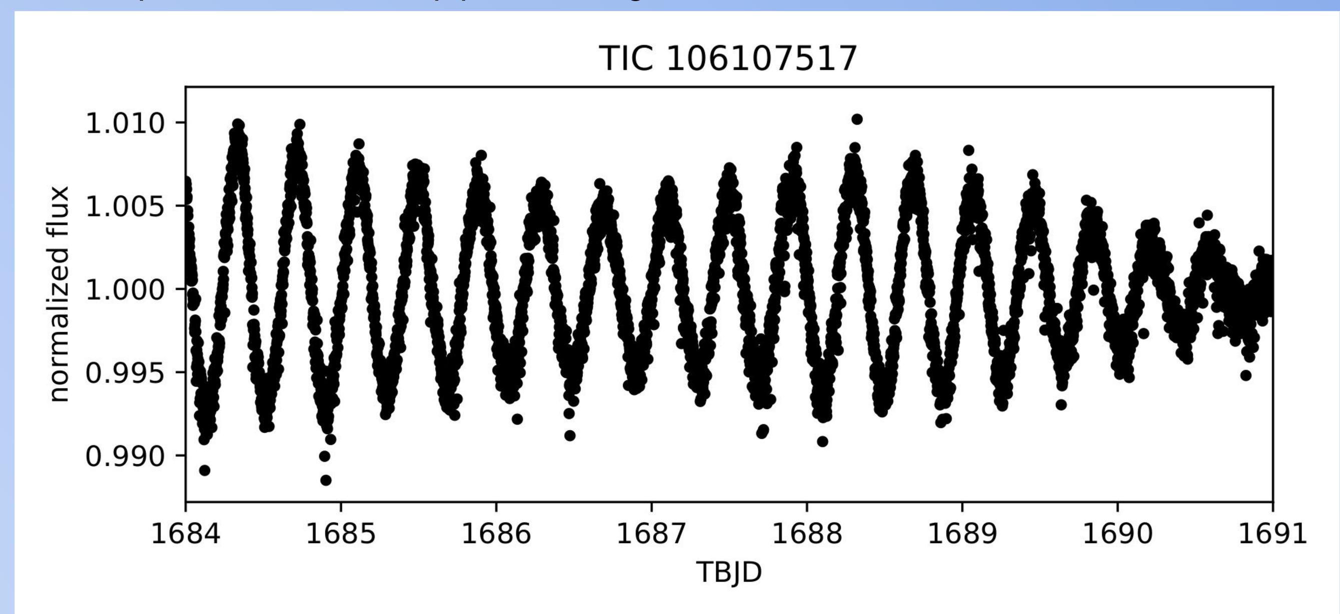

Fig. 5. A portion of the TESS Sector 14 light curve of TIC 106107517, a pulsating star; the beating of two frequencies is easily visible in the light curve.

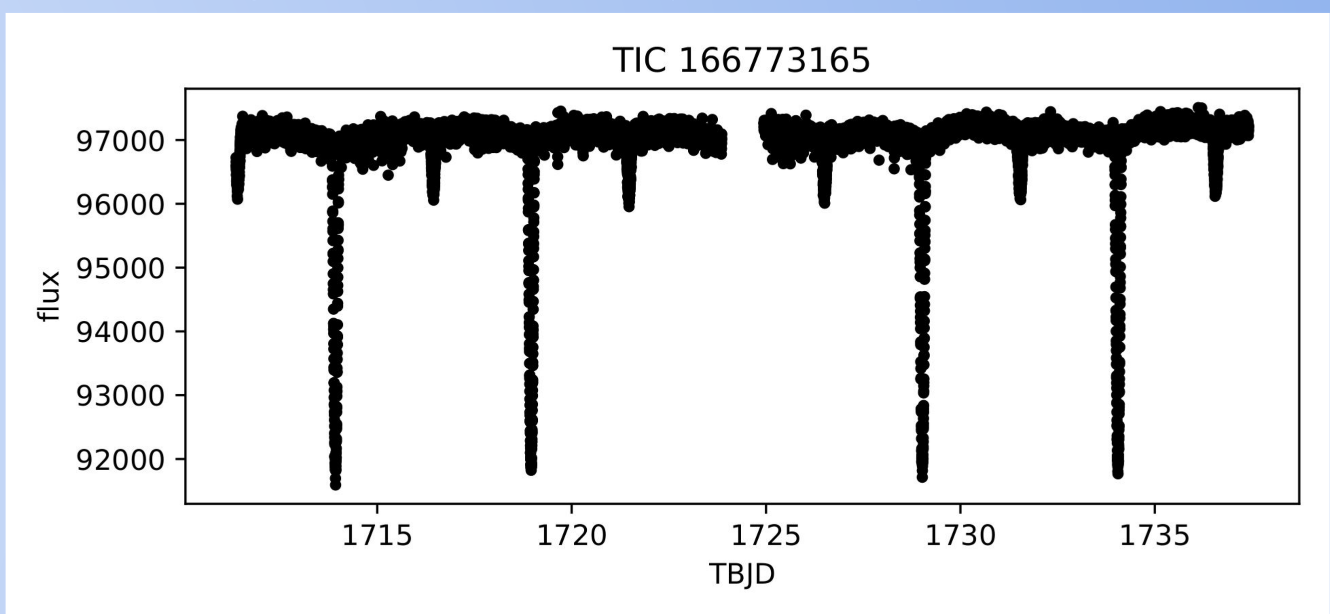

Fig. 6. TESS Sector 15 light curve of TIC 166773165, an eclipsing binary with a 5.029-day period. The secondary eclipse depth is similar to that of a hot Jupiter transit.

A (Very, Very Preliminary!) Back-of-the-Envelope Occurrence Rate Estimate

- During TESS Year 1 and 2, our program observed 1,801 unique A stars, and produced 1 planet candidate
- Given the Mulders et al. (2015, ApJ, 798, 112) occurrence rate for planets around F stars from Kepler, we might expect up to **~100** transiting hot Neptunes (4-5.7 R_Earth, P<17 days) around the stars in our sample.
- The TESS pipelines actually detected only **1** candidate.
- This suggests that the completeness of the TESS pipelines for these planets around these stars is very low (unlikely, given the quality of many of the light curves), or **that the occurrence rate of hot Neptunes around A stars is much lower than that around F stars**.
- If this result is borne out by a more careful analysis, it would suggest that short-period Neptunes **may form in situ**--there should not be enough dust in the hot inner disks of A stars to form planetary cores, explaining the lack of planets (cf. Chiang & Laughlin 2013, MNRAS, 431, 3444). Alternately, these stars' **protoplanetary disks could disperse before these planets can form, accrete a gaseous envelope, or migrate close to the star**.

Acknowledgments

This work is supported in part by NASA grant 80NSSC19K1730 through the TESS Guest Observer Cycle 2 Program.

Contact Information

Marshall C. Johnson
mjohnson@lco.global
@captexoplanet.