Characterizing the Impact of Undetected Stellar Companions on Derived Planetary Radii

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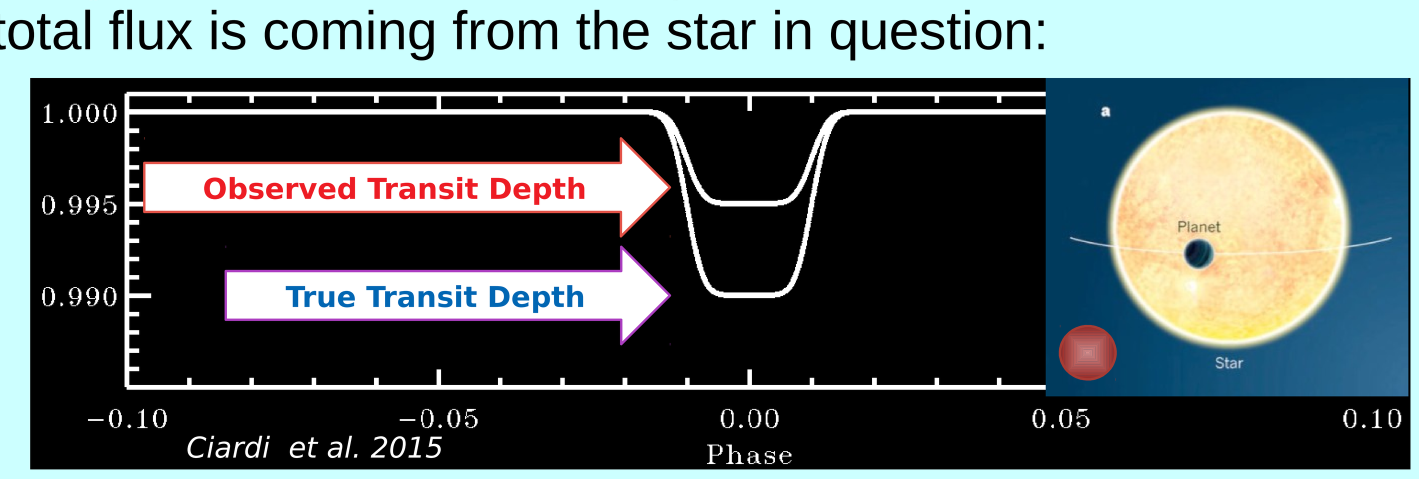
Abstract

The calculation of the radii of TESS Objects of Interest (TOI) includes within it an assumption that the planet is passing in front of a single star. The presence of a second star, however, can create a systematic error in the derivation of the planetary radii. This bias can moderately reduce the calculated planet size if the planet orbits the primary star and can significantly reduce the calculated radius if the planet orbits the fainter secondary star. Radial velocity follow-up can identify cases of a second star on short orbits, and high-resolution imaging can do the same for stars with sufficient angular separations. Between these two regimes, however, there is likely a population of stellar companions that cannot be detected. These undetected stellar companions can create an apparent population of TOIs that are presumed to be roughly earth-sized but are actually larger. We explore the fraction of stellar companions that can be identified with high resolution imaging and how the remainder of undetected companions affect the derivation of the planetary properties including radius, density, and surface gravity.

Background

Of the over 4000 exoplanets known to date, over 3000 have derived radii. For transiting planets, these radii come from presuming that the observed transit depth represents the ratio of the cross-sectional areas of the planet and star. While this is true for single, isolated stars, the equation should also include what fraction of the total flux is coming from the star in question:

$$\delta = \left(\frac{F_{t\star}}{F_{total}}\right)\left(\frac{R_p}{R_{t\star}}\right)^2$$



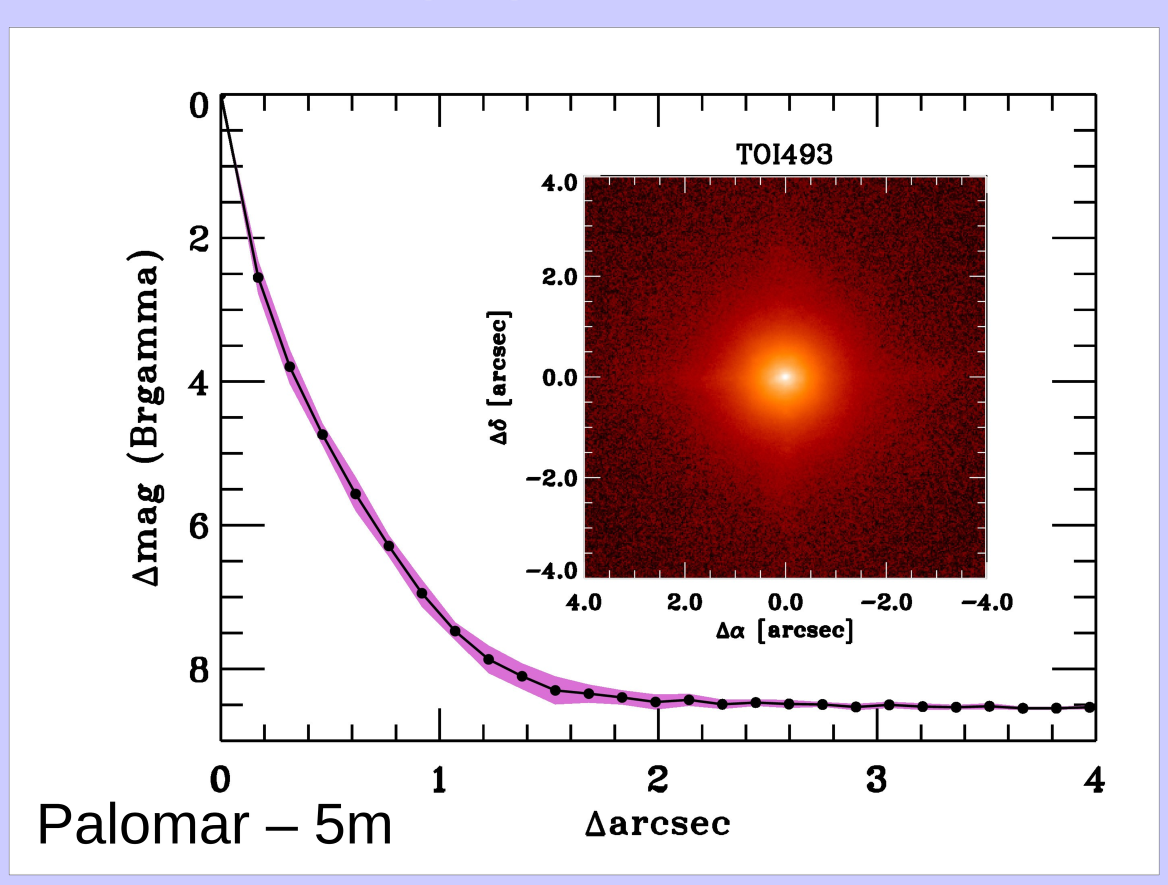
The impact of any unidentified stars will result in the measured transit depth being lower, and so the planet's true radius will be larger than what is calculated from the observed transit depth. The ratio of the true planet radius over the calculated planet radius is represented by the correction factor X_R.

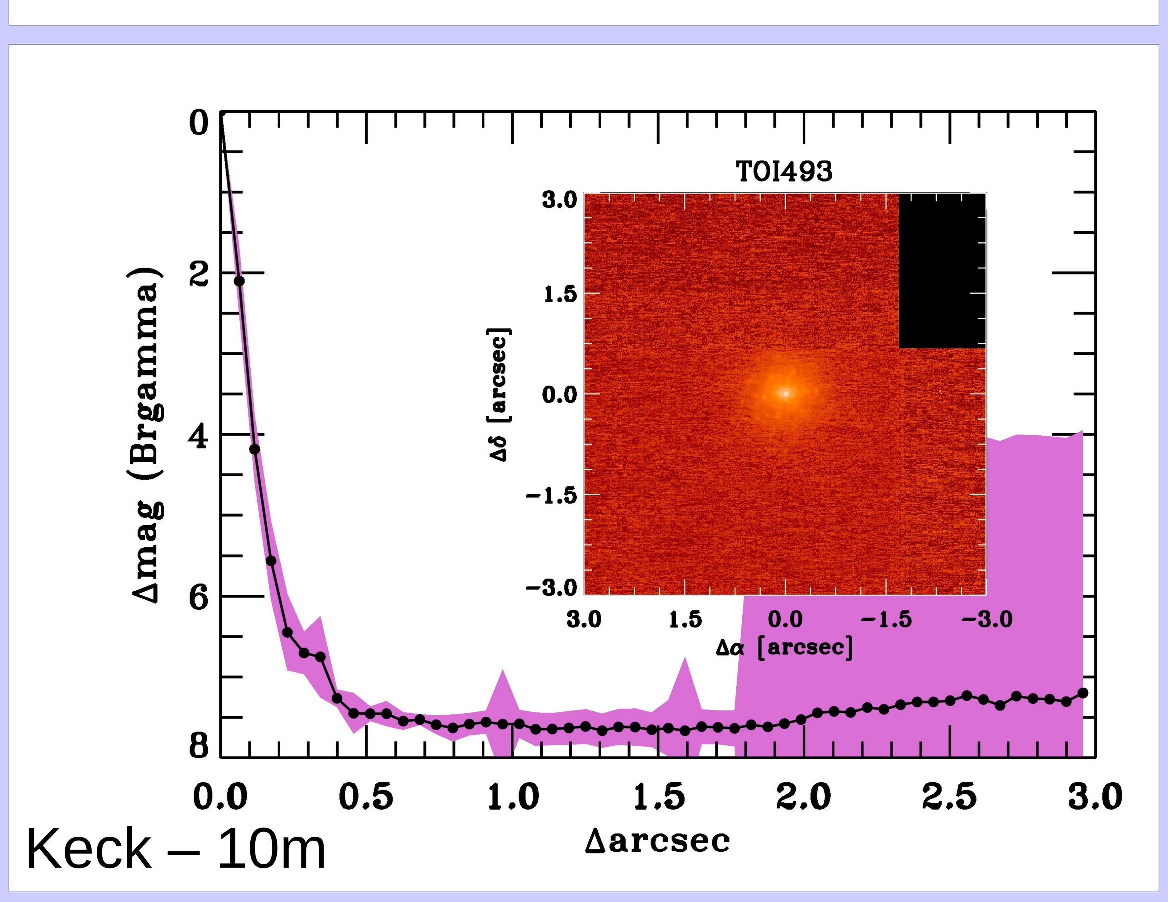
High-Resolution Imaging

Stellar companions that contribute contaminating flux can be identified with a few methods. Our observations are taken using the adaptive optics instruments at Palomar and Keck. The pixel scales for these observations are 0.25"/pixel and 0.1"/pixel, respectively. This data is also uploaded to ExoFOP-TESS.

These observations are sensitive to companions in between the range of more distant sources that seeing-limited observations can detect and close-in stellar companions that can be detected in the radial velocity measurements.

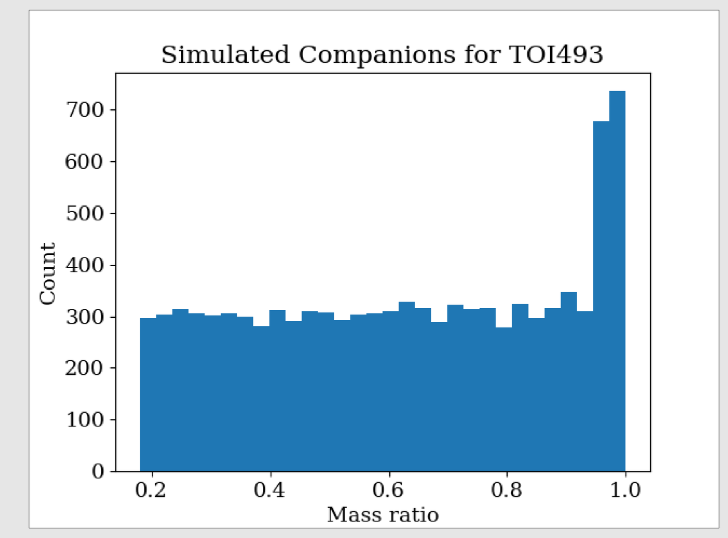
Contrast curves represent the faintest a companion could be and still be detected in the image as a function of separation. Any stellar companions above this contrast curve would be detectable and could be subtracted from total flux, and any stellar companions below this curve remain undetected and will contribute to the system's correction factor.



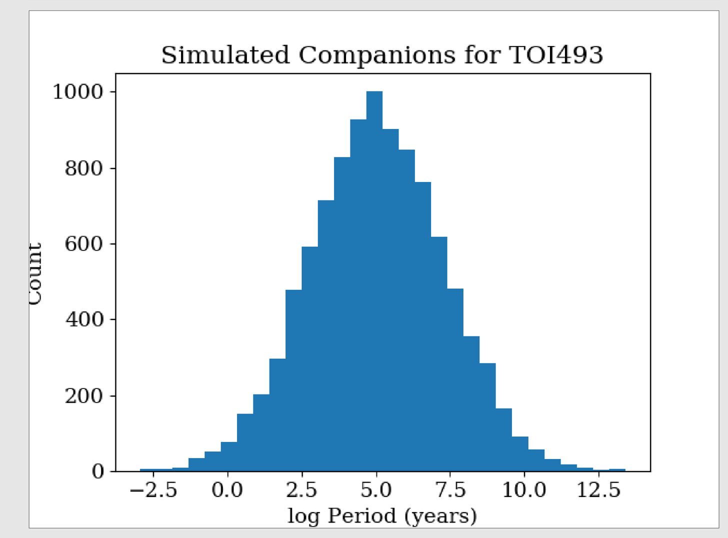


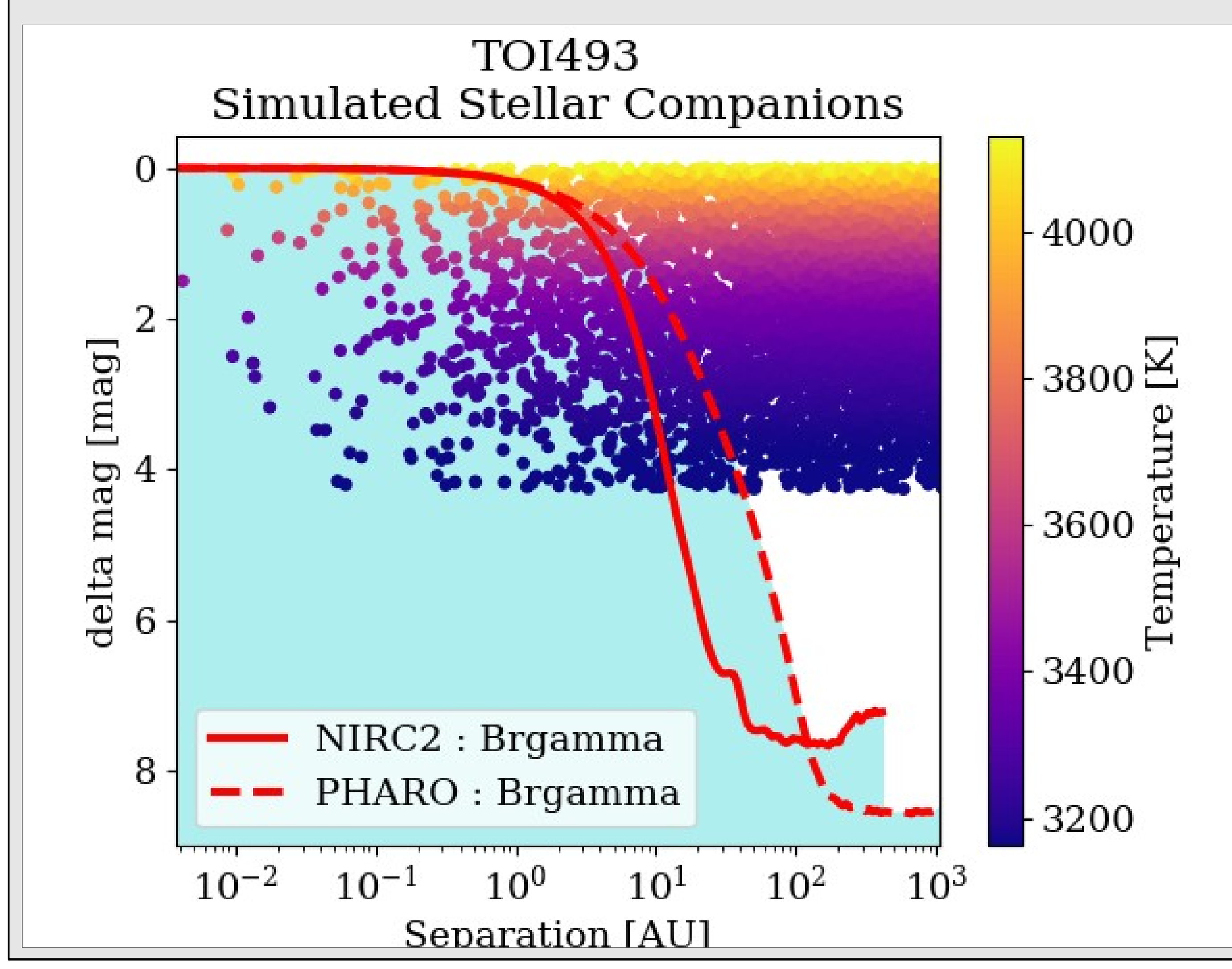
Simulated Stellar Companions

To identify the population of stellar companions that would not be detected, we first match the star to a best-fit stellar isochrone from the Dartmouth isochrones (Dotter 2008). We then create a stellar population by independently drawing from the mass ratio and period distributions for stellar companions (Raghavan 2010). The stellar separation and magnitude difference are calculated, and any stellar companions above any of the contrast curves are considered detectable.



We determine a mean correction factor by considering the different system possibilities. 56% of stars are single, and have a correction factor of 1. The simulated stellar companions represent 44% of possibilities, however we can remove any stellar companions that would have been detected and weren't. The remaining stars have correction factors calculated presuming that 75% of the time the planet is around the primary and 25% of the time the planet is around the secondary star





TOI493 is a 0.65 solar mass star at ~100 pc.

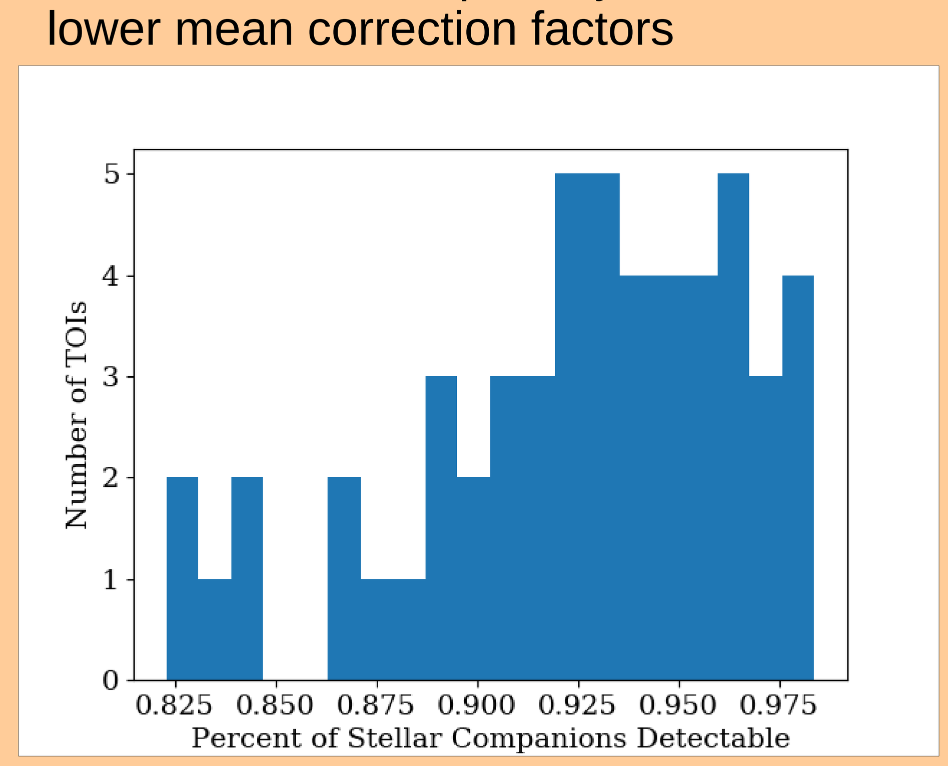
94% of its simulated stellar companions are detectable.

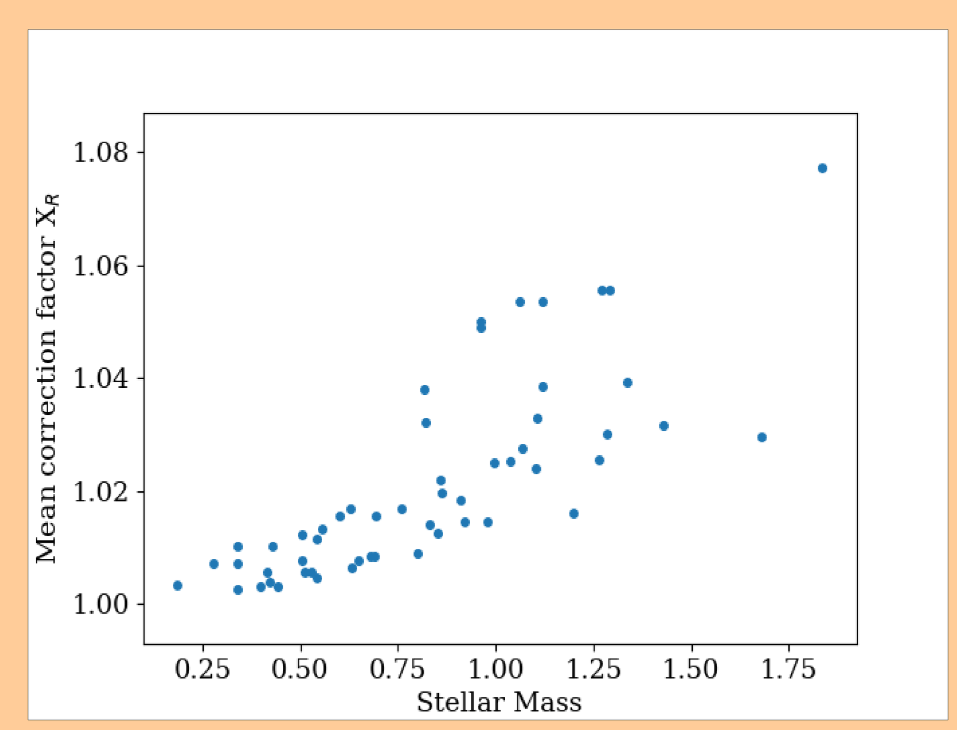
The mean correction factor X_R for TOI493 is 1.01.

With no visible companion, TOI493 is very likely to be a single star system with a well-measured planetary radius.

Early Results

- 54 TOIs have Palomar or Keck AO observations and stellar parameters in TIC v8
- Most TOIs exceed 90% of stellar companions detectable with AO vetting
- Vetting reduces mean correction factor from ~1.5 to less than 1.1 (sometimes much less)
- Lower stellar mass primary stars have a larger fraction of companions detectable, and lower mean correction factors





Next Steps

1. More TOIs to be observed and analyzed
2. Expand simulations to systems with more than 2 stars
3. Include RV vetting for identifying stellar companions at small separations (< few AU)

Publications

Ciardi et al. 2015 *The Astrophysical Journal* **805** 16
Dotter et al. 2008 *The Astrophysical Journal Supplement* **178** 1
Raghavan et al. 2010 *The Astrophysical Journal Supplement* **190** 1