A Dearth of Stellar Companions to M-dwarf TESS Objects of Interest

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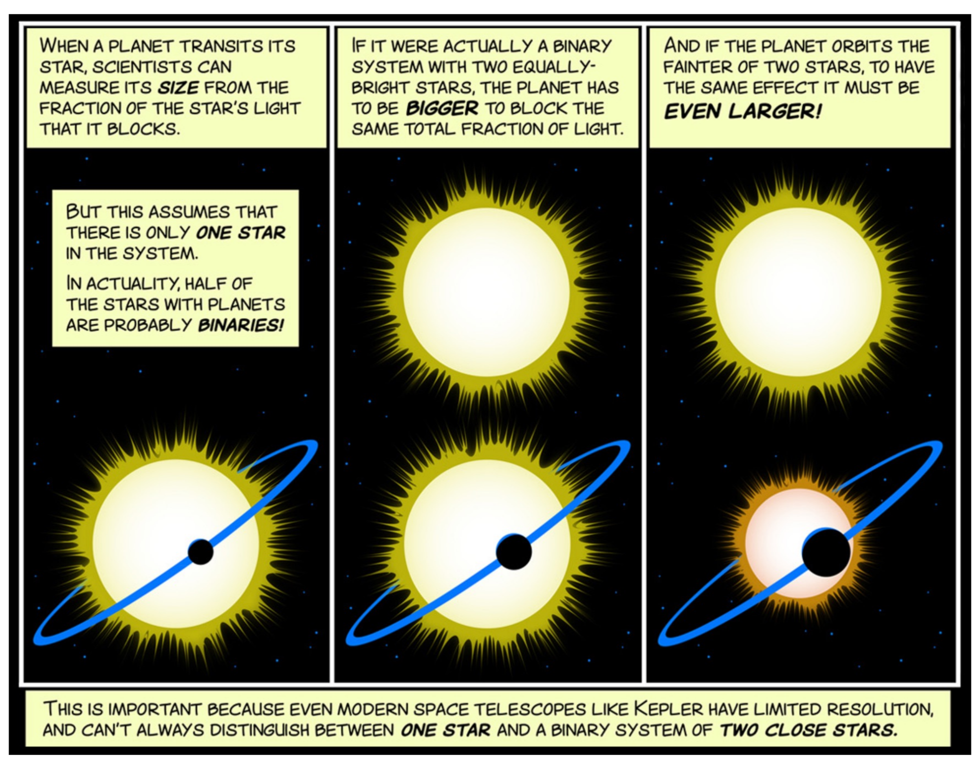
ABSTRACT

The Transiting Exoplanet Survey Satellite (TESS; Ricker+2015) has proven to be a powerful resource for uncovering planets, and the M-dwarfs have been established as favorable planet hosts. It has also become apparent that stellar multiplicity has wide-ranging implications for exoplanet detection and characterization (e.g. Ciardi+ 2015; Teske+ 2018; Bouma+ 2018; Furlan+ 2020; Howell+ 2020), and that speckle imaging is one of the most efficient tools for probing these multi-star systems (Howell+ 2011). We therefore present high-resolution imaging observations of 63 M-dwarf TOIs using speckle imagers at the 3.5m WIYN telescope, the 4.3m Lowell Discovery Telescope (LDT), and the twin 8.1m Gemini North and South telescopes. However, only one companion was detected. This finding is in contrast to the established 46% binarity rate in exoplanet host stars (e.g. Horch+ 2014; Deacon+ 2016; Matson+ 2018; Ziegler+ 2018; Howell+ 2021) and the established 27% stellar multiplicity rate for field M-dwarfs (Winters+ 2019). These results indicate that M-dwarf TOIs have a much lower multiplicity rate than field M-dwarfs. Our observations also imply that planet signals detected from M-dwarf TOIs are more likely to be real than those from higher-mass stars. Finally, these data support the observation that exoplanet-hosting binary stars have, in general, wider separations than field binaries.

WHY DOES STELLAR MULTIPLICITY MATTER FOR TESS?



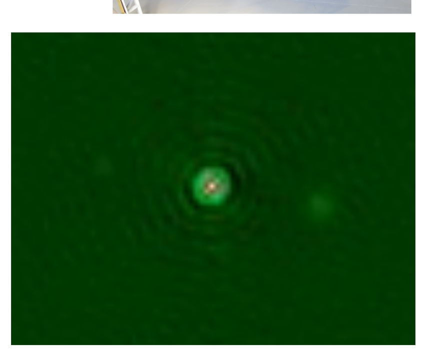
Credit: NASA/JPL - Caltech

HOW DO WE DETERMINE STELLAR MULTIPLICTY?

1. Observing at the LDT

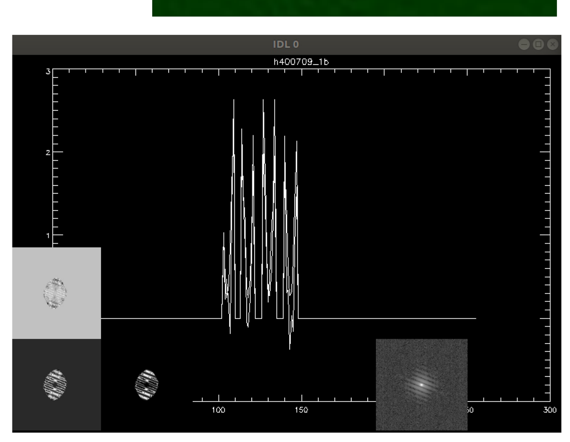
The LDT is a 4.3m telescope located roughly one hour southeast of Flagstaff, Arizona. Lowell Observatory operates the LDT in partnership with Boston University, Northern Arizona University, the University of Maryland, the University of Toledo, and Yale University.

2. Data Reduction Pipeline (Horch+ 2009)



Use the main pipeline program to make reconstructed images via bispectral analysis.

3. Visual Analysis

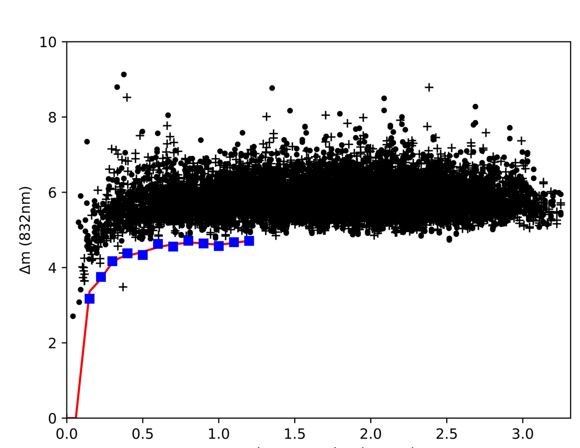


Visually analyze each image to determine a potential location for each binary position.

4. Analysis in the Spatial Frequency Domain

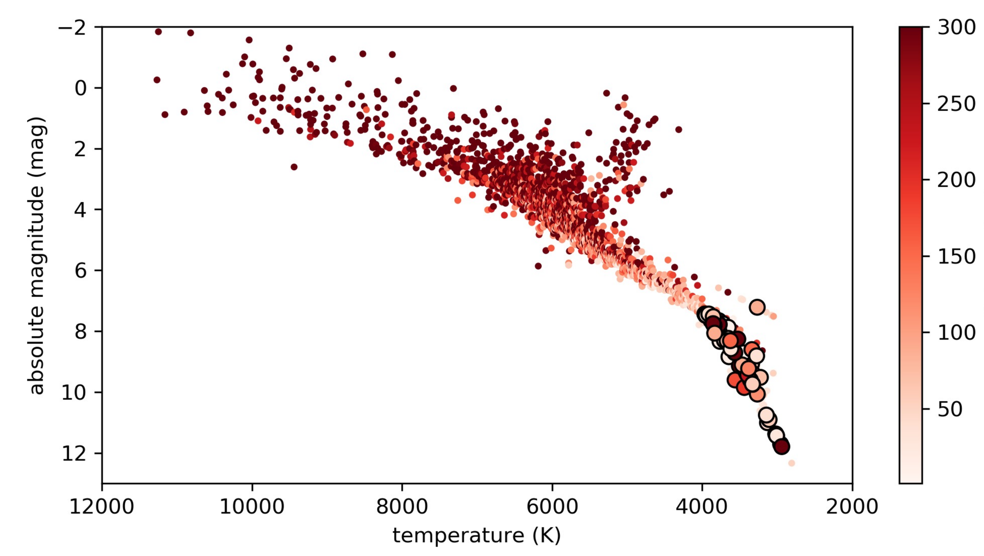
Analyze the power spectrum, the power spectrum divided by the point source, the spatial frequency fit, and the subtracted image. If there is a clear fringe pattern, then there is a binary star present.

5. Inspection of the SNR Plots



Analyze companion limits on detection or non-detection.

WHY M-DWARFS?



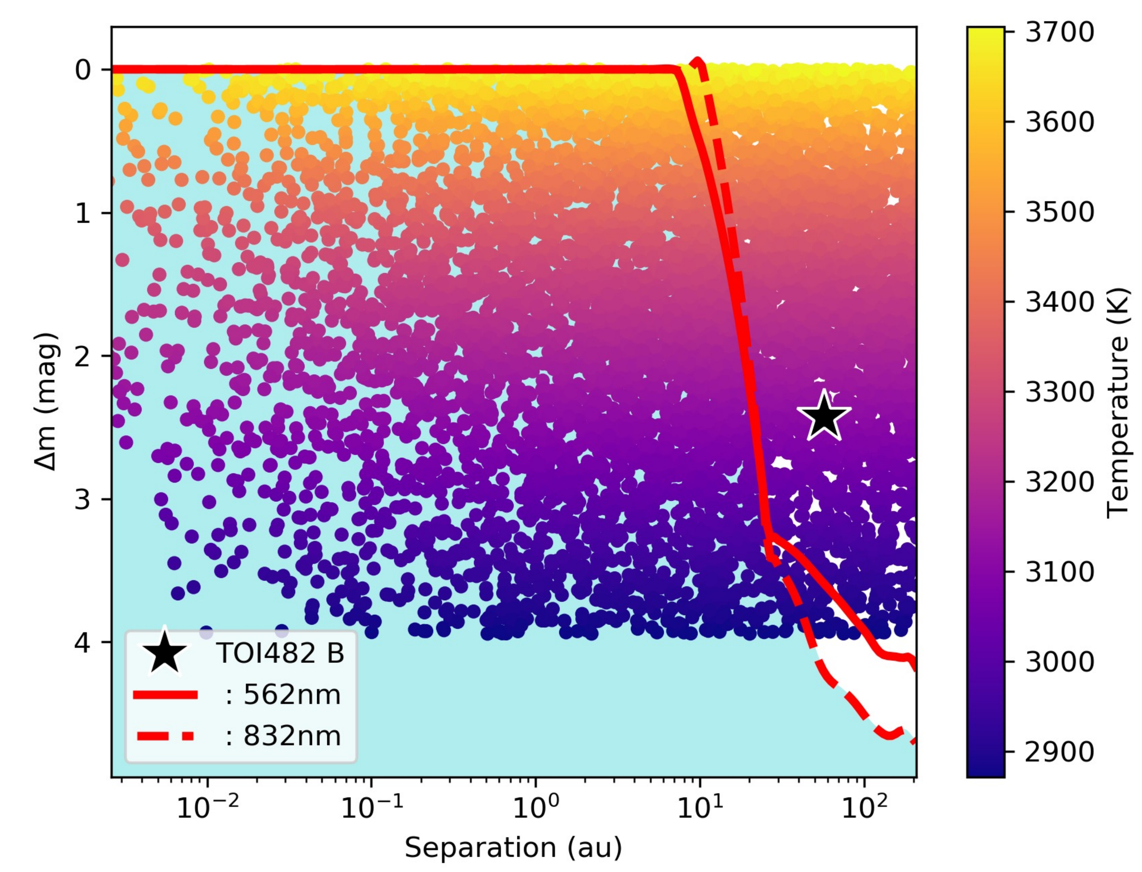
H-R diagram comparing the TESS stars in our sample (larger, outlined circles) to the full sample of TOIs. The color of each point corresponds to the distance. This plot uses ExoFOP TOI database properties.

Host stars at the bottom of the Main Sequence --- M-dwarfs --- have proven to be the most favorable targets for detecting Earth-sized planets in the habitable zone. This is due to the fact that Earth-sized planets are easier to detect via the radial velocity and transit methods when they orbit small stars like M-dwarfs as a result of the smaller star-to-planet mass and diameter ratios. Furthermore, the lower luminosity of M-dwarfs requires potentially habitable planets to reside much closer to their host star, leading to more frequent transits. These transit observations can then be stacked to aid in exoplanet detection and characterization.

THE COMPANION TO TOI 482

Though we observed 63 M-dwarf TOIs with these speckle cameras, we detected only one likely bound stellar companion. We observed TOI 482 on UT 2019 October 11 with NESSI at the 3.5m WIYN telescope. The companion was detected at a separation of 0.398", a position angle of 267°, and a delta magnitude of 2.43 at 832nm.

We used this observational data to derive additional astrophysical parameters for this companion: a projected physical separation of 57 au, a mass ratio of 0.56, an orbital period of 859 years, and spectral types of M4.5 for the primary and M7 for the secondary.



The population of simulated stellar companions to TOI 482, overlaid with the contrast curves from NESSI at 582 and 832nm in red. Yellow dots indicate simulated companions with higher temperatures, while purple dots indicate simulated companions with lower temperatures. TOI 482 is marked with a star.

We also simulated the population of stellar companions to this object that would not be detected by our technique (above; Lund & Ciardi 2020). We find that 57.5% of stellar companions to TOI 482 would be detected by our method, and that the planetary radius correction factor for this object is 1.03. We are also using this technique to assess the possible companions to the other 62 stars in our sample.

SUMMARY AND FUTURE WORK

We have presented speckle observations for 63 M-dwarf TOIs using four speckle imagers in both the northern and southern hemispheres. Throughout this survey, we detected only one companion, which is bound to TOI 482. This low companion fraction to M-dwarf TOIs is in contrast to the established 46% binarity rate in exoplanet host stars, and the established 27% stellar multiplicity rate for field M-dwarfs.

As speckle imaging probes close binaries (usually within 100 au for nearby objects), and we detected only one likely bound stellar companion, our observations support the fact that exoplanet hosting binary stars have, in general, wider separations than field binaries. These results also indicate that candidate exoplanets detected around M-dwarfs are likely real objects, rather than false positives caused by unresolved binaries.

A control sample of non-planet-hosting M-dwarfs is needed in order to vet observational biases. The upcoming POKEMON survey (Clark+, in prep) will provide this critical sample of M-dwarfs not seen to show a transit event. The POKEMON survey utilized both DSSI (Horch+2009) as well as QWSSI (Clark+ 2020) at the LDT to complete this volume-limited survey of of nearby M-dwarfs. With this survey, we will be able to learn more about the population of M-dwarfs that host exoplanets, and continue to detect Earth's cousins among these low-mass stars.

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