ASTRO 461 Sp19 MDM OBSERVING PROPOSAL

Due: Friday, May 10, 6:00 PM

TITLE: "I Don't Want No Scrubs: Identifying Eclipsing Binary False Positives in TESS Objects of Interest"

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ABSTRACT:

We present a proposal to observe three TESS objects of interest (TOIs) with the goal of offering quantitative evidence that the objects are either planets or false positive eclipsing binary systems. The Transiting Exoplanet Survey Satellite (TESS) mission has so far logged 583 TOIs by observing dips in the light of bright dwarf stars, confirming 25 planets and 104 false positives via follow-up observations. Ground based observations from facilities such as MDM are critical in TESS's mission of confirming planet candidates and eliminating false positives, and therefore play an important role in opening up a new parameter space of exoplanet studies. In order to advance this mission, we aim to utilize the 1.3m McGraw Hill telescope to perform seeing-limited photometry which will contribute to the first subgroup of TESS candidate follow-up. We will observe transit events for three stars, TYC 4889-00995-1, TYC 243-1528-1, and BD-11 3209. Over the course of each event, we will take 20 second long exposures at 3 minute intervals, producing light curves for each. These resulting light curves will reveal information about the nature of the "transit" event. Transit depths greater than 5% allude to a background eclipsing binary, and for events with periods less than 0.5 days, we can provide quantitative evidence that the TOI is a false positive rather than a transiting planet. Observing these TOIs with the MDM facilities is an ideal and exciting opportunity to contribute to the characterization of the new planet candidates produced from initial TESS observations, aiding in frontier-pushing work in exoplanet science.

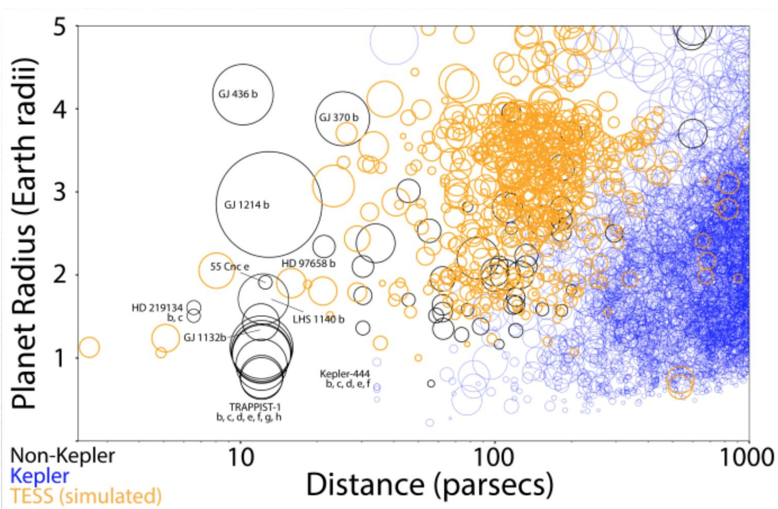
1.3-m + B4K CCD	Request	2.4-m + CCDS	Request
Filters	*V*	**Wavelength range**	
Number of hours	9	**Number of hours**	
Time range	5/11: 8 pm - 2 am 5/12: 8 pm - 11 pm	**Time range**	

Notes about observing setup: Basic setup should be sufficient.

SCIENTIFIC MOTIVATION

Exoplanet science is one of the most exciting and active frontiers in astronomy right now. Since the discovery of the first exoplanet, 51 Peg b, in 1995, over 3000 exoplanets candidates have been discovered through missions such as Kepler and more recently, the Transiting Exoplanet Survey Satellite (TESS). A critical component of exoplanet science is confirming these candidates, and over 2000 Kepler planets have been confirmed using techniques such as the radial velocity method, which allows astronomers to constrain the mass of the planets.

Reaching the end of the Kepler era, astronomers now look to TESS as a tool for understanding the diversity of the exoplanet population. This mission observes the brightest dwarf stars across the entire sky, looking for dips in brightness which may indicate the presence of a transiting planet. TESS has already discovered over 500 planet candidates, but only 11 have been fully confirmed! Confirmation of TESS candidates, or "TESS Objects of Interest" (TOIs), is a critical step toward probing the exciting new parameter space of super-Earth and sub-Neptune planets, as demonstrated in Figure 1. The TESS follow-up observing program (TFOP) aims to confirm candidates using five methods, outlined in Figure 2.



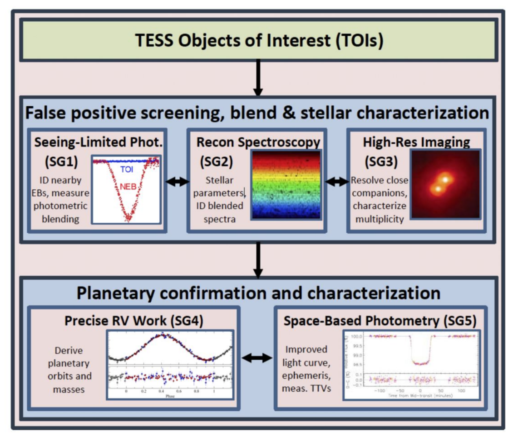


Image credits (clockwise from top left): KELT Survey, NOAO/AURA/NSF, Buchhave et al. (2011), Berta et al. (2012), Malavolta et al. (2016).

Figure 1. Tess Parameter space.

Figure 2. TOI follow-up methods.

We aim to contribute to the first subgroup of TFOP by ruling out false positives through seeing-limited photometry. There are three main kinds of astrophysical false positives, several of which are illustrated in figure 3, whose signals may be confused with those of transiting planets:

1. Eclipsing binaries (EBs): target star is part of a binary system in which its companion grazes across the observer's line on sight during eclipse.
2. Hierarchical eclipsing binaries (HEBs): target star is part of a multi-star (3 or 4) system which includes at least one eclipsing pair.

3. Background or nearby eclipsing binaries (BEBs or NEBs): an eclipsing binary system is located within the target field of view, nearby or in the background of the target star.

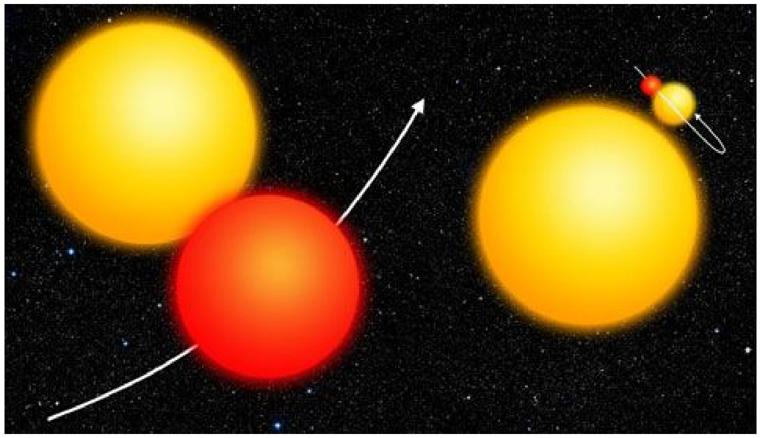


Figure 3. Illustrations of grazing eclipsing binary (type 1 false positive) and background eclipsing binary (type 3 false positive).

Sullivan et. al (2015) state that both EBs and HEBs may potentially be ruled out using the TESS data itself, while BEBs/NEBs make up 78% of stubborn, difficult to distinguish situations. We therefore plan to follow recommendations that ground-based observations be made to rule out false positives in TESS candidates. Light curves from photometric time-series observations will provide the necessary data to identify any of the three false positive scenarios, should they occur, and will be particularly useful to the TFOP program if we are able to identify evidence of BEBs/NEBs.

The light curves produced from our time-series observations will show the change in observed flux during the transit. Based on the equation for transit depth $\delta = (\frac{R_p}{R_s})^2$, we expect to observe a greater change in observed flux for larger objects of interest than for smaller objects. Since TESS has a goal of observing planets smaller than Neptune, as seen in Figure 1, we would expect the transit depth for a transiting planet to be much smaller than that of a background eclipsing binary. Following the analysis in Sullivan et. al (2015), a 5% change in the flux would indicate the object of interest is definitely a false positive. We can provide further confirmation on the nature of the false positive by examining the morphology of the light curve, as false positives will exhibit longer ingress and egress times than a transiting planet.

TECHNICAL AND SCIENTIFIC FEASIBILITY

Using the 1.3m McGraw Hill telescope at MDM Observatory, we will be able to improve upon the TESS angular resolution and therefore provide useful follow-up photometry of candidate systems. It is critical that we observe the TESS objects of interest during their transits. We have verified transit event timing using the NASA exoplanet archive Transit Service Query Form, which takes inputs of target period, coordinates, known transit midpoint, and known transit duration to provide information about upcoming transit events for that target. We aim to take data points throughout the full transit windows. We request time for the duration of the three transit events. Our objects will be visible throughout the transit periods, as shown below in Figure 4.

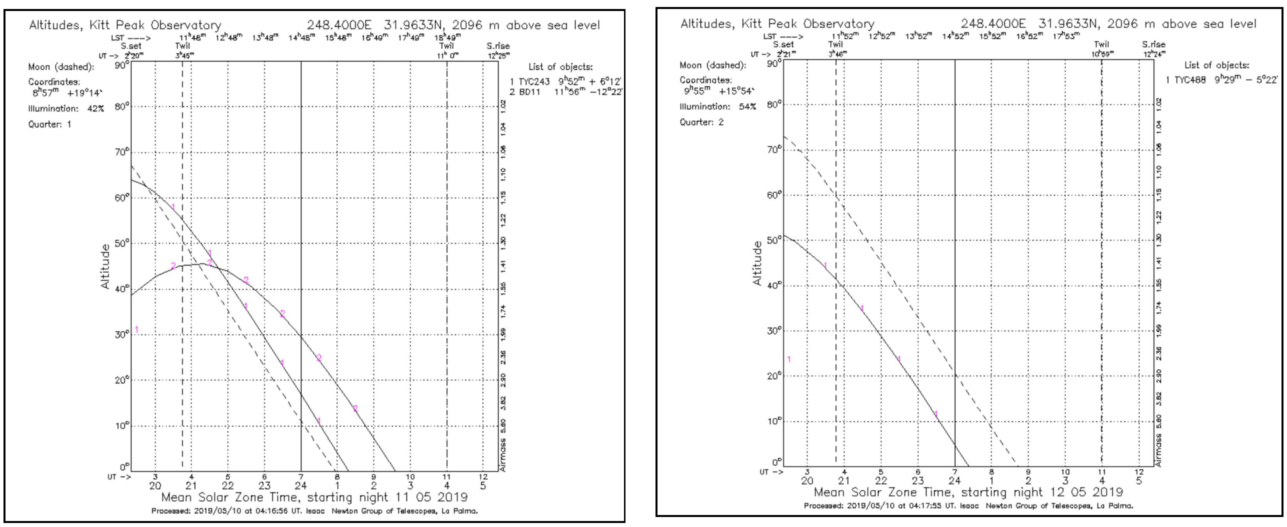


Figure 4. Visibility of Objects on observing nights 5/11 and 5/12.

Using the V band filter on the 1.3m telescope, we are able to observe the systems at their brightest magnitudes. As our target stars have magnitudes less than 11, observing these with the 1.3m telescope will be feasible. Given our bright dwarf star targets, we will take 20 second exposures at intervals of 3 minutes, giving a theoretical signal to noise ratio well above 200. The high signal to noise ratio is necessary to see the 5% change in flux during the course of the transit. This will yield approximately 30 images for the transits which last approximately 1.5 hours in total. The images will be used to create light curves of the transit. Taking as many images as possible during the transit will allow us to detect changes in the flux. Changes in flux greater than 5% generally indicate the presence of an eclipsing binary, rather than a planet.

We will use both standard and reference stars to ensure that our magnitude measurements are accurate and consistent. Given the telescope's 21.3 arcmin FOV, we have identified bright reference stars (V band magnitudes < 10.6) within the FOV, shown in figure 5. This gives us thorough opportunities to calibrate our flux measurements with standard stars as well as reference stars within each exposure. We will also check the instrument clock accuracy and confirm at what point in the exposure the time is recorded. These checks will allow us to get precise information about transit times, if we see transits, and will help to further constrain TOI orbits even if a transit is not observed.

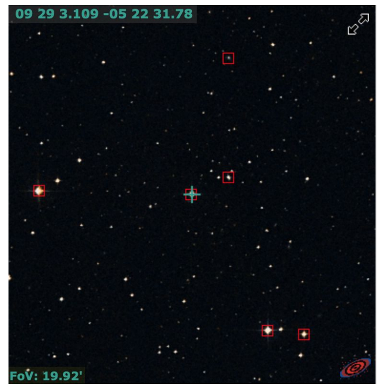
Our observations will utilize the 4k imager and V-band filter on the 1.3m McGraw Hill telescope, providing extremely useful data for characterizing TOIs as either a false positive or a potential planet. We expect our data to reveal background eclipsing binaries on periods ~0.5 days which will produce transit depths greater than 5%. Even if we are unable to make confident quantitative claims that the TOI is either a false positive or a planet, our data will be a valuable contribution to the ongoing TFOP program under subgroup 1.

TARGET LIST

Object	**RA**	**Dec**	***V*mag**	**other parameters**
TYC 4889-00995-1	9:29:03	-5:22:32	10.842	transits 8:13 pm to 10:45 on 5/12
TYC 243-1528-1	9:52:44	6:12:58	10.252	transits 8:13 to 11:45 on 5/11
BD-11 3209	11:56:39	-12:22:39	9.529	transits 8:12 to 1:54 on 5/11

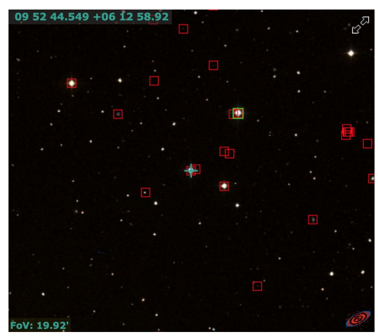
Reference Stars:

For TYC 4889-00995-1 we choose two bright calibrator stars in the FOV:



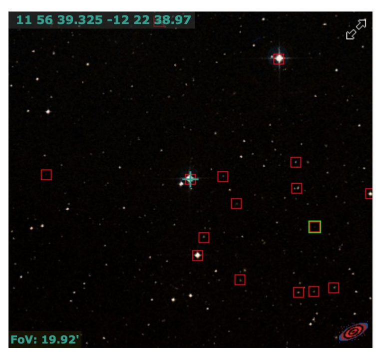
Reference Star	RA	Dec	Vmag
BD-04 2635	09:28:47.08	-05:29:41.34	10.013
BD-04 2639	09 29 35.05	-05 22 21.73	9.742

For TYC 243-1528-1 we choose two bright calibrator stars in the FOV:



Reference Star	RA	Dec	Vmag
TYC 243-994-1	09:53:10.88	06:17:42.62	10.09
TYC 243-1909-1	09:52:37.30	06:12:07.41	10.56

For BD-11 3209 we choose two bright calibrator stars in the FOV:



Reference Star	RA	Dec	Vmag
HD 103677	11:56:19.28	-12:16:01.81	9.09
BD-11 3208	11:56:37.51	-12:26:52.34	11.35

Figure 5. Reference stars in FOV.