A Mass and Radius Determination of Exoplanets via Transits

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Introduction

Exoplanets are planets orbiting star systems other than our own. One of the ways to detect exoplanets is via transits. Occasionally, star systems have an angle of inclination such that an exoplanet will pass in front of its host star, blocking some of the light that reaches earth and causing a distinctive dip in the light curve. From this dip, much can be learned about the exoplanet including its mass and radius. There will, however, be an amount of uncertainty due to the unknown angle of inclination of the star system. Because transits are only able to be seen from earth for a relatively small range of angles, this uncertainty fortunately isn't very large. I plan to image several different known exoplanets and determine their mass and radius based on the data I collect. Comparing this information to what is known about Earth can help reveal the processes of planet formation and the typicality of our own star system.

Observational Plan

All of the exoplanet transits I plan to observe are visible from Wallace during September and October 2015 using the 16" telescope. Most of the transiting exoplanets I hope to view have host stars between 8th and 16th magnitude, so can all be seen by the 16" telescope at Wallace Astrophysical Observatory. One of the difficulties in observing exoplanets is locating the transit dip in the first place, however, the transits I have scheduled all have a transit depth of above 10milimags, so easily within the possible resolution at Wallace. The exact magnitude specifications for each transit are located in Table 1 below.

In addition, all of the transit candidates will be above the horizon for the entire duration of the transit. The exact right ascensions and declinations are also located in Table 1 below. Since some of them will be near the horizon towards the beginning or end of their transit, there will be added noise due to the high airmass that might make some of the transits difficult, but not impossible, to observe. While this is the case, all of the host stars I will be observing are brighter than the lower limit of the 16", so will still be visible.

Details about each transit are located in the table below. All of the transits I plan to observe are under 3hrs long, begin after we arrive at Wallace at 8:00pm, and end before we leave at 2:00am. I'll observe each target starting at half an hour before the start of the transit and continue to take data until at half an hour after each transit. The below table includes the time at the start, middle, and end of each transit. It also includes the elevation for the start, middle, and end of each transit to show that the transit candidates all fit within the acceptable parameters for observation at Wallace.

Table 1: Observational Circumstances for Exoplanet Transits Observable from Wallace Astrophysical Observatory in September and October

Date (EDT)	Transit	Apparent Magnitude (R)	Delta Magnitude (milimags)	Elevation (start, mid, end)	Time (EDT) (start, mid, end)	Right Ascension (J2000)	Declination (J2000)
9/28/2015	Kepler-45 b	15.7	34.2	77°, 71°, 65°	20:53—21:25—21:57	19 31 29.50	+41 03 51.3
9/28/2015	TrES-3 b	12.1	29.3	37°, 30°, 24°	22:44—23:24-00:04	17 52 07.02	+37 32 46.2
10/5/2015	TrES-1 b	11.2	19.8	53°, 39°, 26°	22:01—23:16—00:31	19 04 09.84	+36 37 57.5
10/12/2015	Kepler-447 b	12.6	29.1	64°, 59°, 53°	20:39—21:12—21:45	19 01 04.46	+48 33 36.0
10/19/2015	TrES-3 b	12.1	29.3	49°, 41°, 34°	20:19—20:59—21:39	17 52 07.02	+37 32 46.2
10/19/2015	HAT-P-23 b	11.94	14.7	46°, 34°, 22°	22:05—23:10—00:15	20 24 29.72	+16 45 43.7
10/26/2015	TrES-2 b	11.2	16.9	41°, 33°, 25°	22:18—23:12—00:06	19 07 14.04	+49 18 59.0
10/26/2015	WASP-33 b	7.7	12.3	69°, 83°, 78°	23:08—0:28—01:48	02 26 51.06	+37 33 01.8

All of the comparison stars used for each night will be on-chip standard stars. The standard stars selected (Table 2) are brighter than my target object so the signal/noise ratio is limited by my target and not my comparison stars. This will mean special care will need to be taken in order to avoid overexposing the comparison star. However if overexposing is unavoidable, there are several other on-chip standard stars I could use.

Finder charts with comparison stars are located in Figures 1-7.

Table 2: Comparison Star Specification for Transit Star Fields (see figures 2-9 for finder charts)

Transit	Right Ascension (J2000)	Declination (J2000)	Magnitude (R)
Kepler-45 b	19 31 15.435	+41 02 59.71	10.4
Kepler-447 b	19 01 04.887	+48 34 26.97	12
TrES-1 b	19 04 00.881	+36 39 55.96	7.5
TrES-2 b	19 07 10.722	+49 24 37.64	10.8
TrES-3 b	17 52 25.027	+37 34 22.38	11.7
HAT-P-23 b	20 24 20.856	+16 52 42.65	8.2
WASP-33 b	02 26 35.574	+37 33 01.8	9

The red filter will be used, as all of my transit candidates and comparison stars are brightest in the R band. From discussion with TAs experienced in taking data on exoplanets at Wallace Observatory, I have determined the SBIG STL-1001e camera currently on the 16” telescope will be sufficient to take these data. From similar discussions, I have determined my exposure times will range roughly from 20s to 45s based on the conditions each night.

Operational Procedure

1. Start up the telescope, camera, and relevant equipment/software
2. Focus the instruments
3. Sync the telescope on a bright star
4. Slew to target and star hop from there using finder charts (see figures 1-7)
5. Observe target 1
6. Slew to target 2 and star hop from there using finder charts if observing two targets
7. Observe target 2 if observing two targets
8. Take 10 dark images
9. Take 10 bias images

10. Shutdown telescope and relevant equipment/software

Calibrations

Each set of data will be reduced using dark and bias subtraction as well as flat division. Each night, I will take zero-second bias frames, and dark frames matching the exposure times of my science images. Due to the time restrictions faced when heading to and from Wallace Observatory, I will not get a chance to take my own flats but will instead use library flats taken previously.

The reductions and initial analysis will be done using AstroImageJ. Data are reduced in AstroImageJ by first creating master biases, flats, and darks by averaging the 10 frames of each type taken at the end of the observing night, or, in the case of flats, averaging the 10 provided images. The master bias is subtracted from all types of images to remove the counts produced by the camera simply being on, and the darks are subtracted from the science images to remove the thermal photons produced by the camera exposing. The flats are then divided from the science images to remove any effects from irregularities with the imaging equipment. AstroImageJ then provides a readout of the relative flux of the target star vs the comparison star.

Analysis Procedure

1. Reduce and calibrate images using dark, bias, and flat images using AstroImageJ
2. Plot the relative flux for comparison star and target
3. Convert relative fluxes into magnitudes using MATLAB
4. Plot the magnitude
5. Locate transit dip
6. Determine mass from transit dip
7. Determine radius from transit dip and published periods

Finding Charts

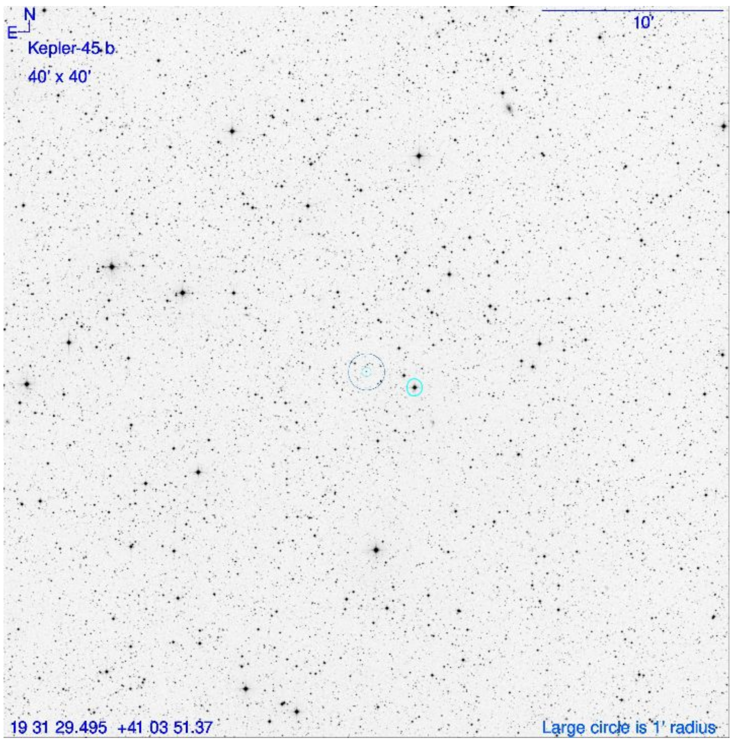

Figure 1: Kepler-45 b (target circled in center and comparison star circled in blue)

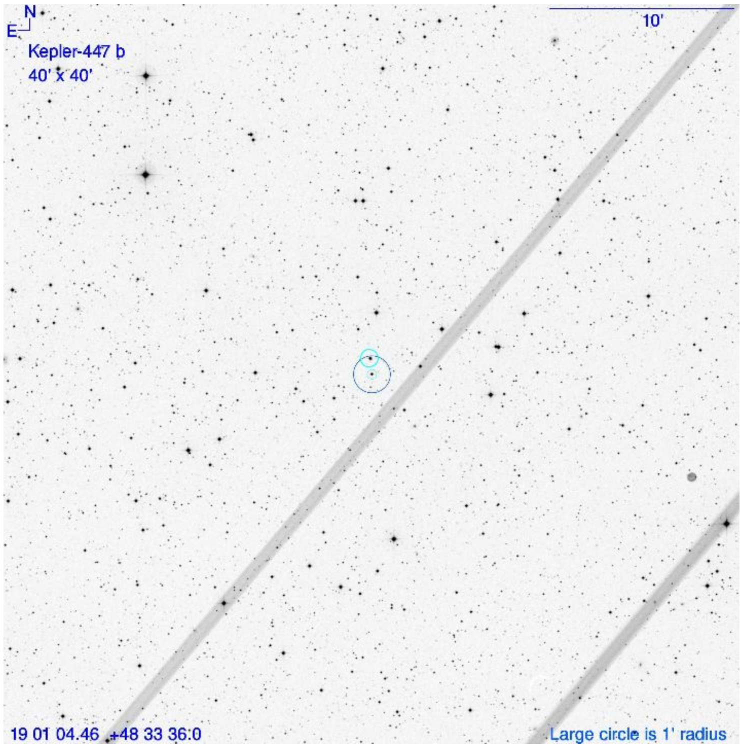

Figure 2: Kepler-447 b (target circled in center and comparison star circled in blue)

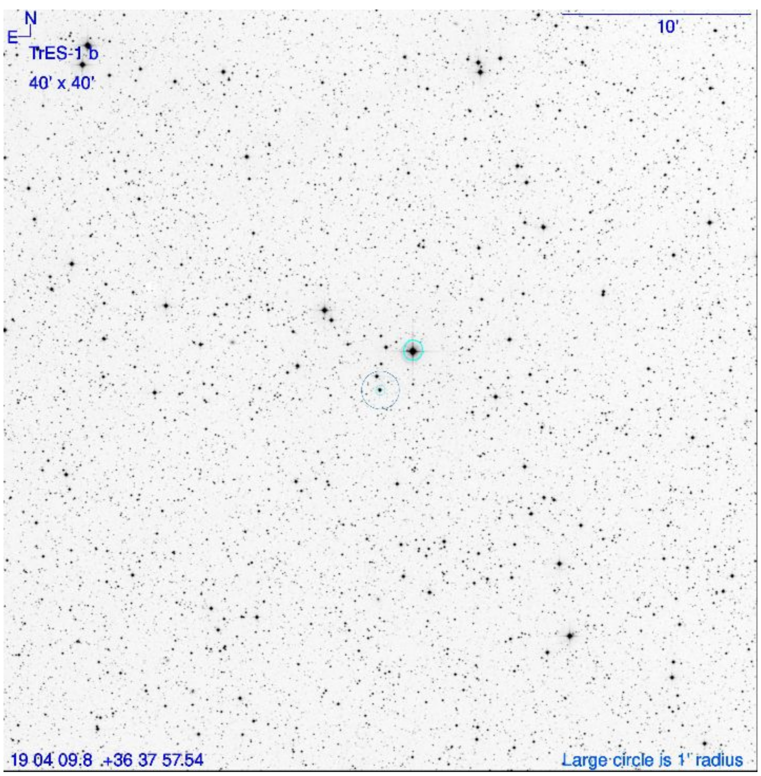

Figure 3: TrES-1 b (target circled in center and comparison star circled in blue)

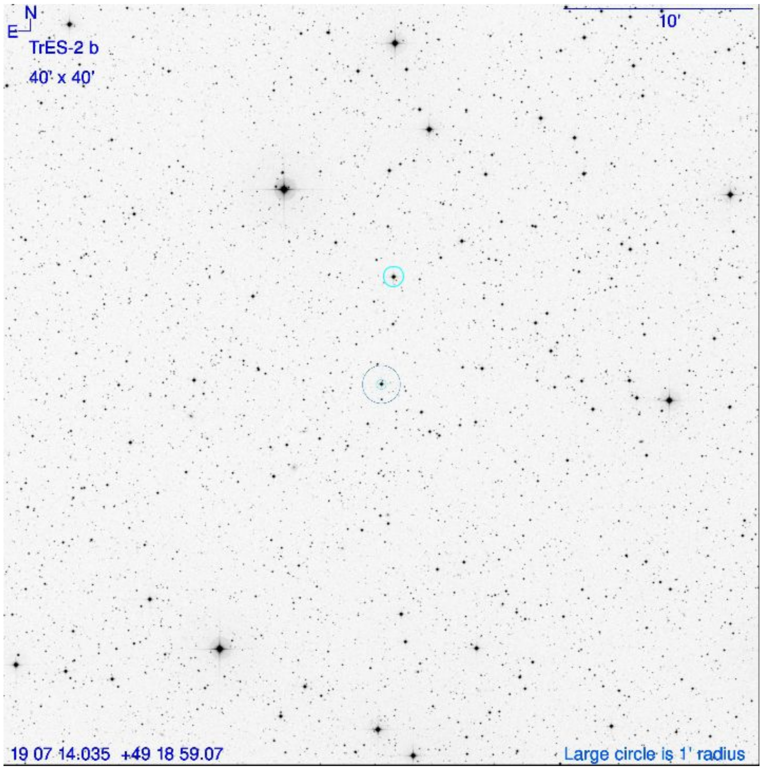

Figure 4: TrES-2 b (target circled in center and comparison star circled in blue)

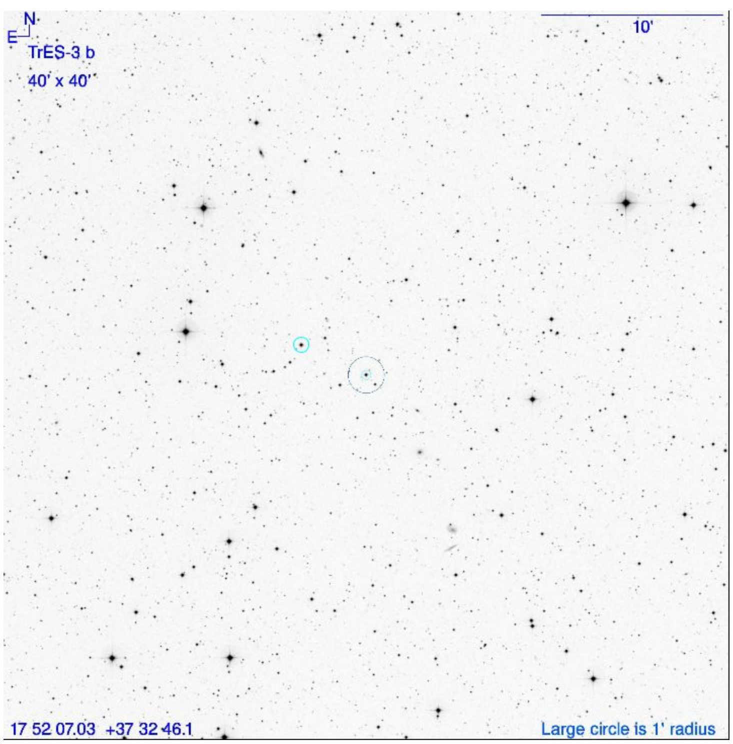

Figure 5: TrES-3 b (target circled in center and comparison star circled in blue)

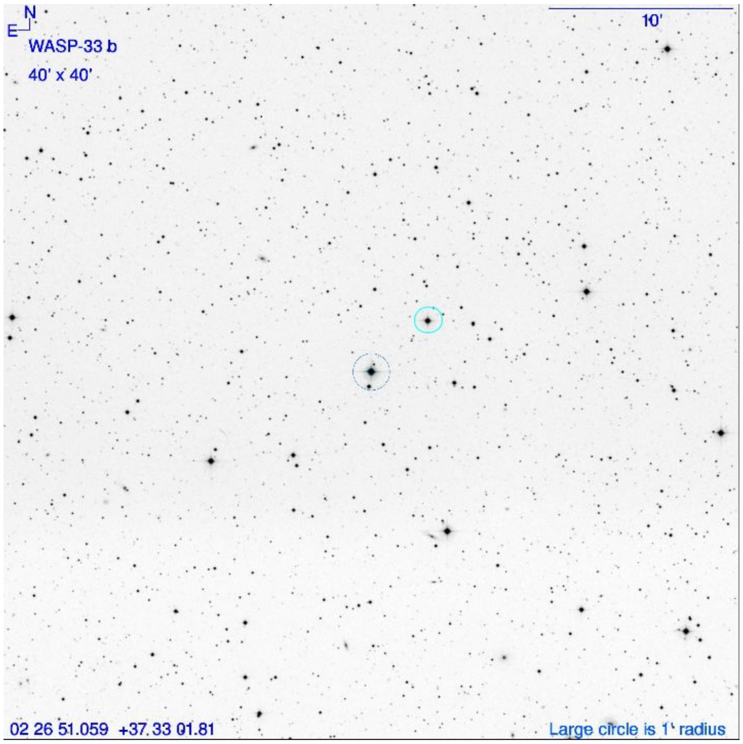

FIgure 6: WASP-33 b (target circled in center and comparison star circled in blue)

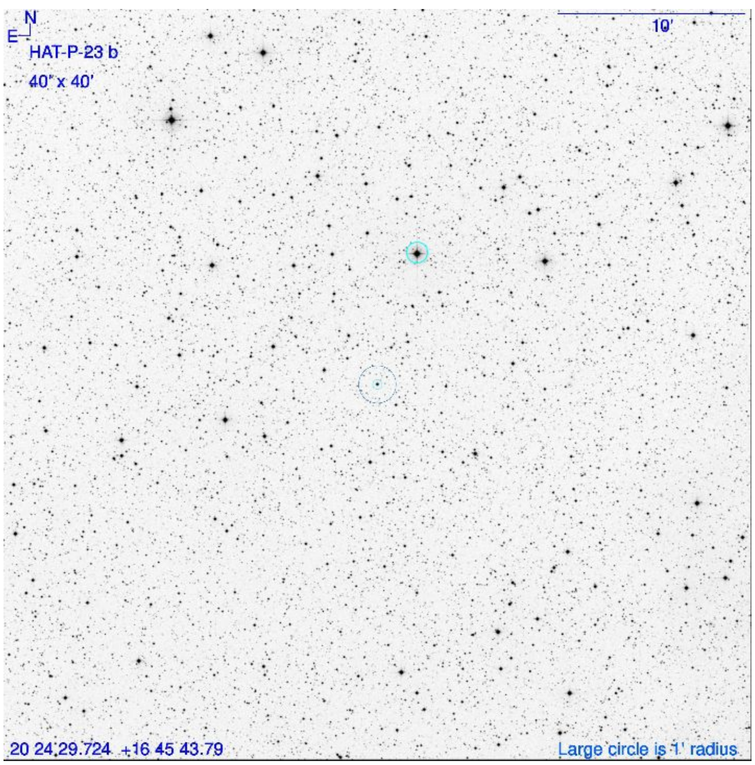

Figure 7: HAT-P-23 b (target circled in center and comparison star circled in blue)

References

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Schneider, J. "Interactive Extra-solar Planets Catalog". The Extrasolar Planets Encyclopedia.

The USNO-B1.0 Catalog. 2015. Retrieved from http://vizier.u-strasbg.fr/viz-bin/VizieR.