A Mass and Radius Determination of Exoplanets

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Introduction

Exoplanets are planets orbiting star systems other than our own. Exoplanets can be detected in a multitude of ways, but one of the best ways to detect exoplanets is via transits. Occasionally, star systems are so aligned that an exoplanet will transit 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, radius, and period. I hope to image several different known exoplanets and determine their mass, radius, and period based on the data I collect.

Observational Plan

All of the exoplanet transits I hope to observe should be able to be seen 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 12th magnitude. The 16” telescope can easily detect 8th magnitude objects, and can reasonably detect 12th magnitude objects. The transits I hope to observe 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 Fig. 1 below.

In addition, all of the stars I hope to observe will be above the horizon for the entire duration of the transit. The exact right ascensions and declinations are also located in Fig. 1 below. Since some of them will be near the horizon, there will be added noise due to the high airmass that might make some of the transits difficult, but not impossible, to observe. However, all of the host stars are brighter than the lower limit of the 16”, so the airmass shouldn’t be much of a problem.

Details about each transit is located in the table below. Transit Duration refers to the time between the start of the transit and the end of the transit. All of the transits I hope to observe are under 3hrs long, begin after we arrive at Wallace at 8:00pm, and end before we leave at 2:00am. I plan to 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 chart 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.

Figure 1: Observational Circumstances for Exoplanets Observable from Wallace Astrophysical Observatory in September and October

Date	Name	Apparent Magnitude (R)	Delta Magnitude (milimags)	Elevation (start, mid, end)	Time (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

Figure 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

From discussion with TAs experienced in taking data on exoplanets at Wallace Observatory, I've determined the SBIG STL-1001e camera currently on the 16" telescope will work fine for this data. From similar discussions, I've 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 on a bright star
3. Sync the telescope on a bright star
4. Slew to target and star hop from there using finder charts (see figures 2-9)
5. Observe target 1
6. Slew to target 2 and star hop from there using finder charts (if applicable)
7. Observe target 2 (if applicable)
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 we face 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 is 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 then subtracted from all types of images to remove the counts produced by the camera simply being on. The darks are then 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 will then provide 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. Convert relative fluxes into magnitudes using MATLAB
3. Plot the magnitude and locate transit dip
4. Make relevant calculations
5. Compare results and draw conclusions

Finder Charts

Figure 3: Kepler-45 b (target circled in center and comparison star circled in red)

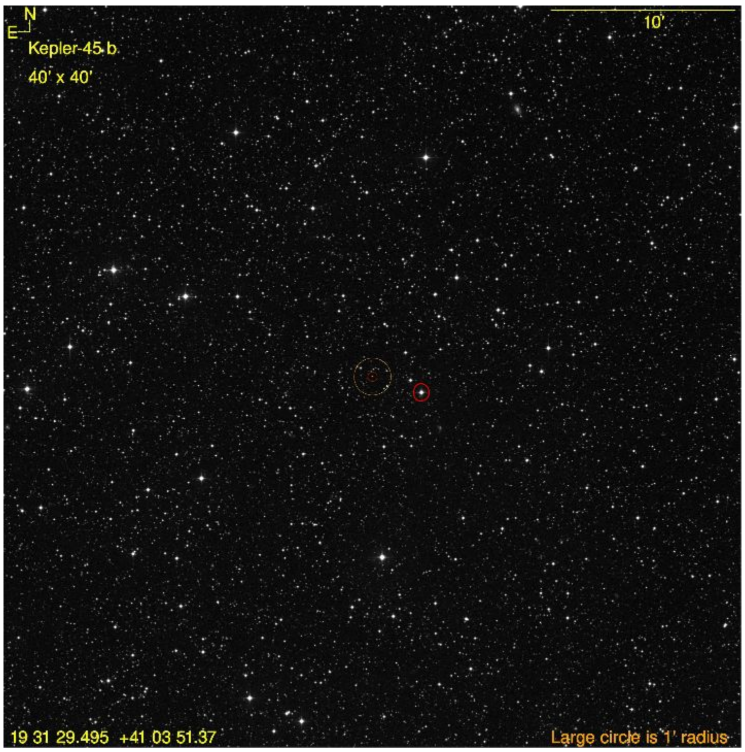

Figure 4: Kepler-447 b (target circled in center and comparison star circled in red)

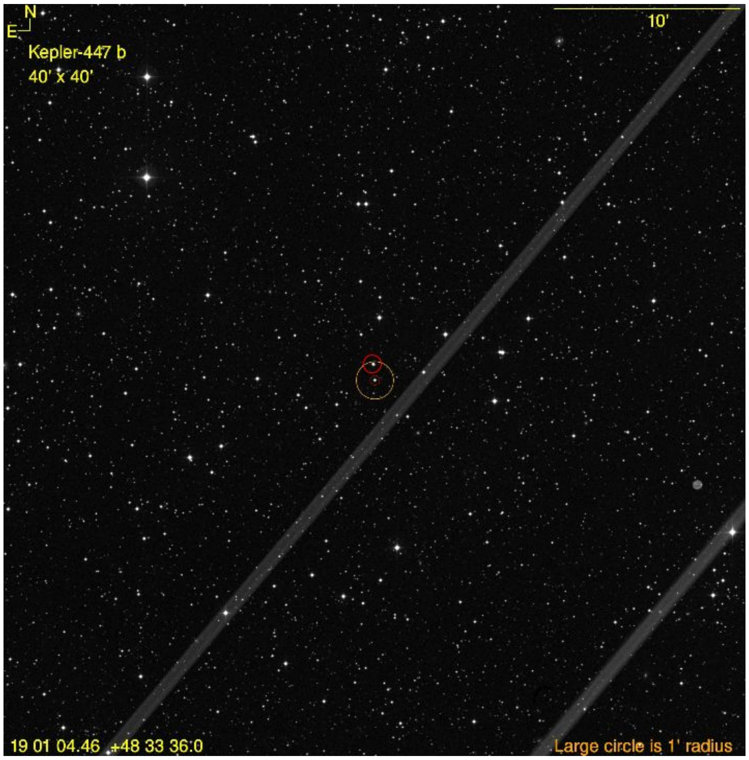

Figure 5: TrES-1 b (target circled in center and comparison star circled in red)

Figure 6: TrES-2 b (target circled in center and comparison star circled in red)

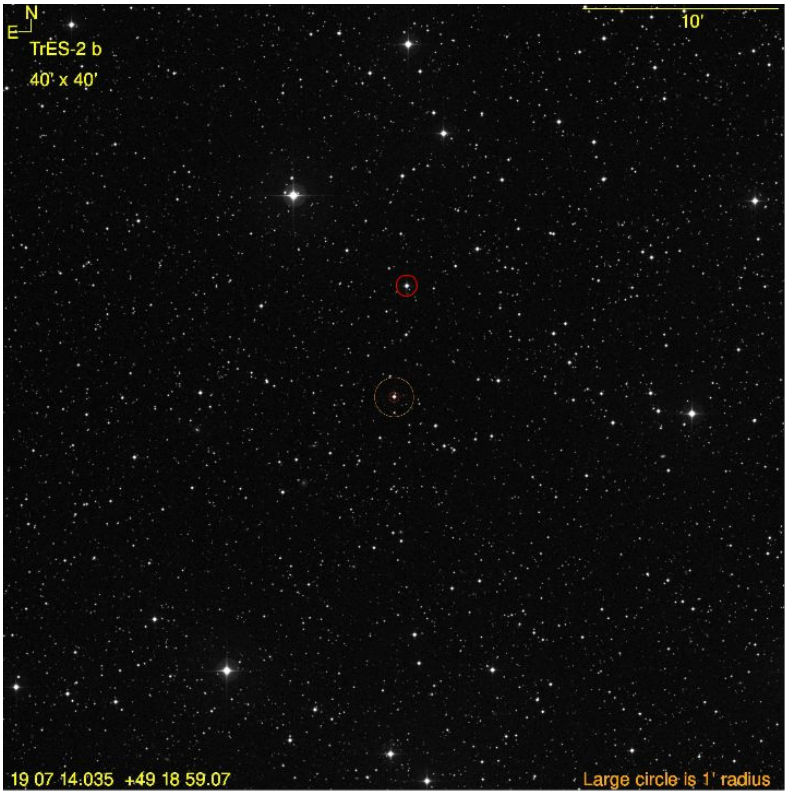

Figure 7: TrES-3 b (target circled in center and comparison star circled in red)

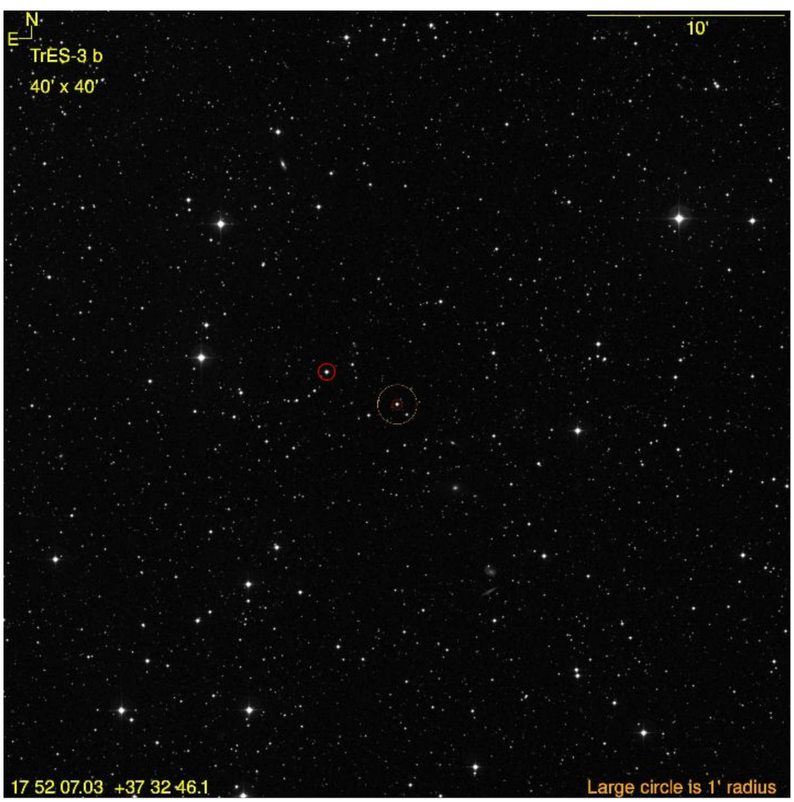

FIgure 8: WASP-33 b (target circled in center and comparison star circled in red)

Figure 9: HAT-P-23 b (target circled in center and comparison star circled in red)