Ensemble Photometry of Exoplanets at the BSU Observatory: Improving Previous Measurements and Streamlining New Ones

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Abstract

When an exoplanet transits in front of a star, the subtle light curve dip can be difficult to identify if the data are noisy. The main goal of my research is to improve measurement results. The main method used is ensemble photometry, but initial improvements were also made to decrease error. Analysis of Tres-1b and Wasp-43b data showed that ensemble photometry had 10% less average measurement error and a smaller residual than differential photometry if high signal to noise stars were used, though the results of ensemble photometry are heavily dependent on which comparison stars are chosen. I have also created a procedure manual on ensemble photometry for other student researchers at BSU to follow.

Introduction

Research done in the observatory involves imaging against a variable and light-polluted sky, so minimizing its contribution to measurement error is critical to ensuring quality data. The summer's goal was to do so mainly by refining a measurement method called ensemble photometry. This method uses multiple reference stars in the field to create an artificial magnitude which is used to determine the target's magnitude. This ideally improves results compared to differential photometry because random variations are more likely to average out, making it easier to Identify changes we look for in a target's light curve. This research was conducted studying exoplanet targets. When the exoplanet passes in front of the star it dims the brightness we see, creating a small dip in the light curve. Ensemble photometry should make finding shallow dips (<0.02 mag) easier.

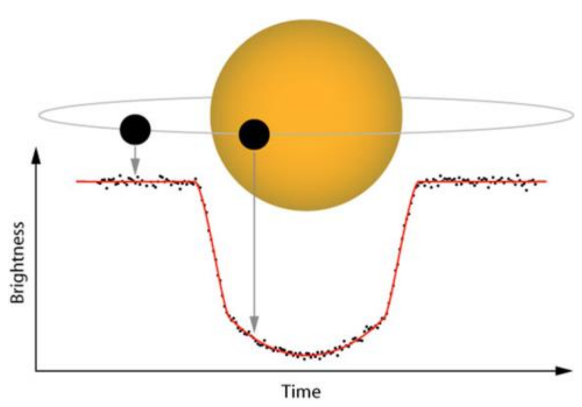

Figure 1: Example image of an exoplanet transit.

Methods/Equipment

Transits of exoplanets XO-1b, Wasp-3b and Tres-1b were imaged in the R passband using 2x2 binning. Flat calibration images applied were no shorter than 3 seconds (standard dark/bias calibrations were also applied). No transits of XO-1b were recorded due to weather. Reference stars for ensemble photometry were chosen through online AAVSO or VizieR databases for high signal-to-noise ratios (SNR) and magnitude stability. Maxim DL's photometry tool was used to create a lightcurve for each target. Differential photometry was also performed for comparison (Fig. 1). Targets previously imaged were also analyzed.

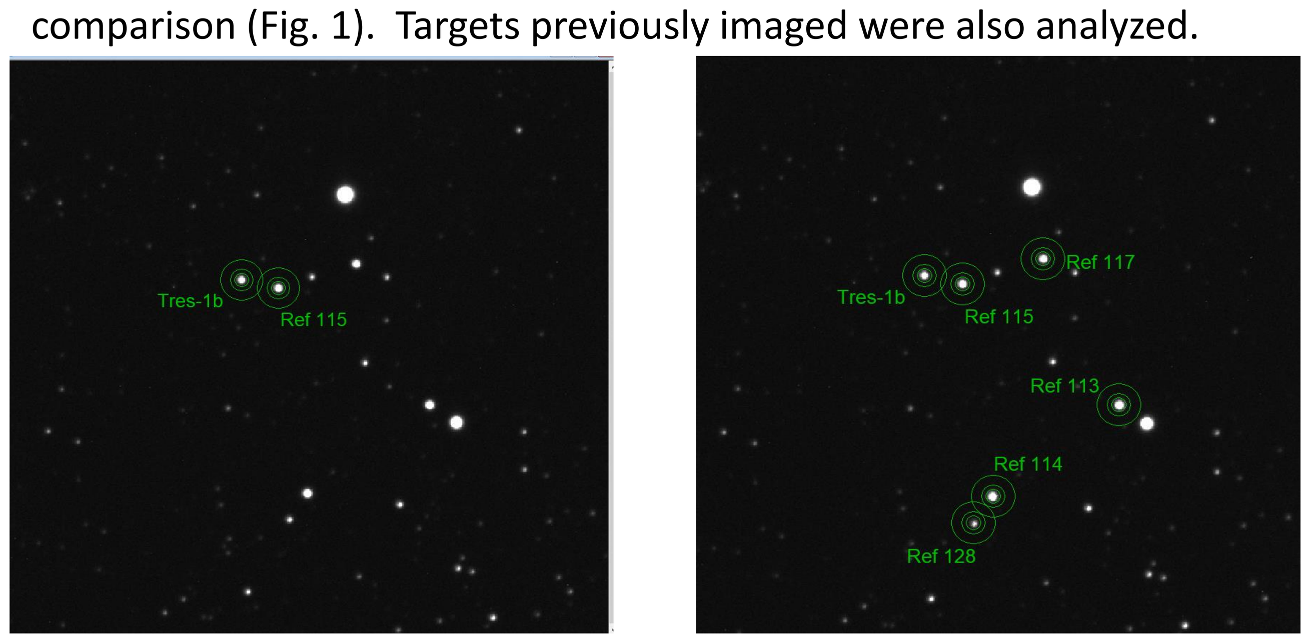

Figure 2: Star field photometry for both the differential method (left) and the Ensemble method (right) for Tres-1b.

Equipment

- Maxim DL 6 - for photometry and image processing
- TheSky6 – for star tracking
- Microsoft Excel - for graphing, calculations and analysis
- 14" Celestron Edge HD
- Apogee Alta U47 and FW50 filter wheel
- Astrodon photometric R filter

Data

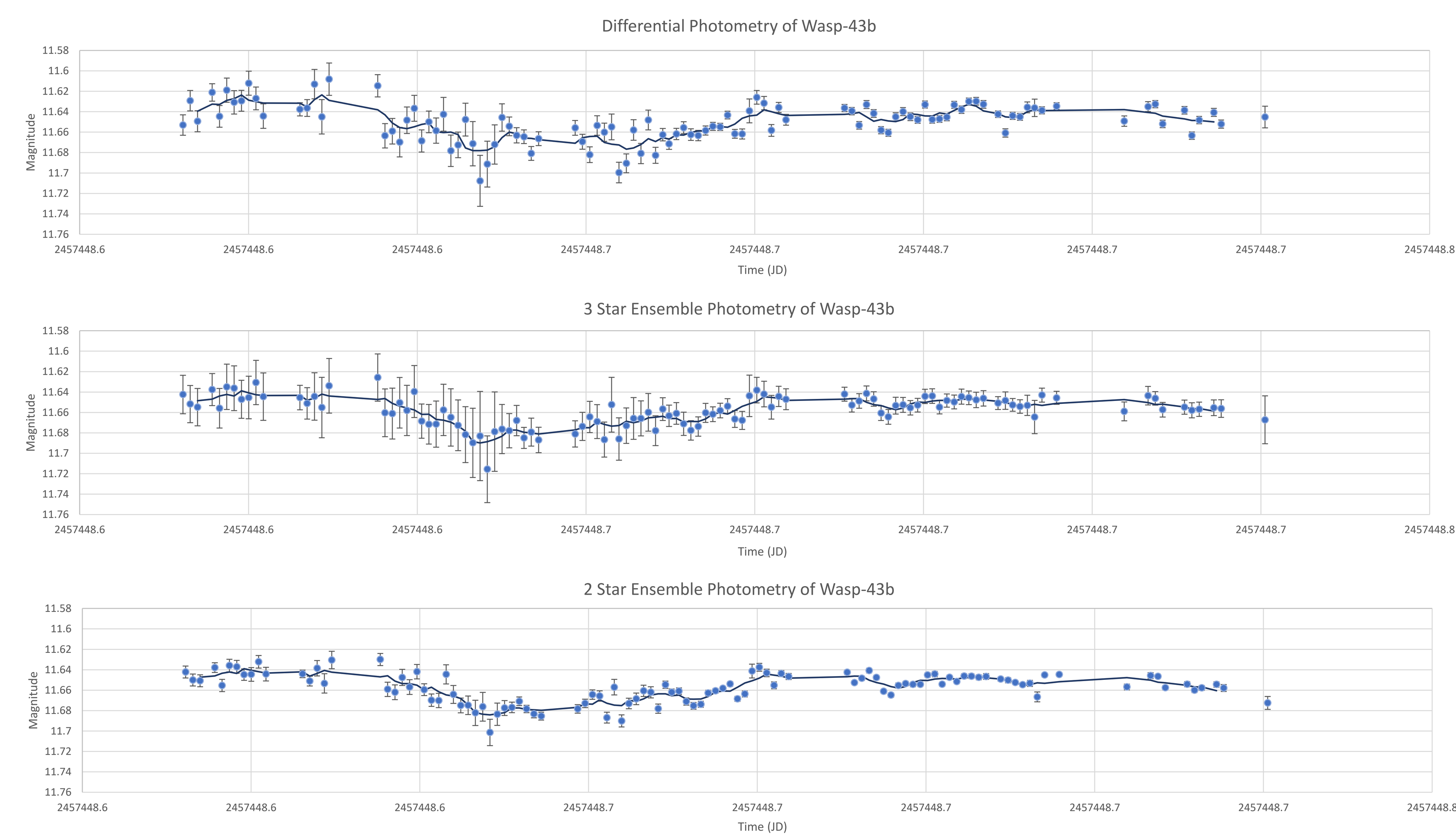

Figure 3: Magnitude vs. time using different methods of photometry on Wasp-43b, differential (top) and ensemble (bottom two). The solid line shows a 5-point moving average. The three star ensemble showed an average error of 0.01 magnitudes and a residual of 0.006 magnitudes. The differential method had an average error of 0.007 magnitudes and an average residual of 0.009 magnitudes. This is because a star with a low SNR was used in the ensemble. Removing that star for only a two star ensemble decreased the error to 0.004 magnitudes and the residual to 0.005 magnitudes.

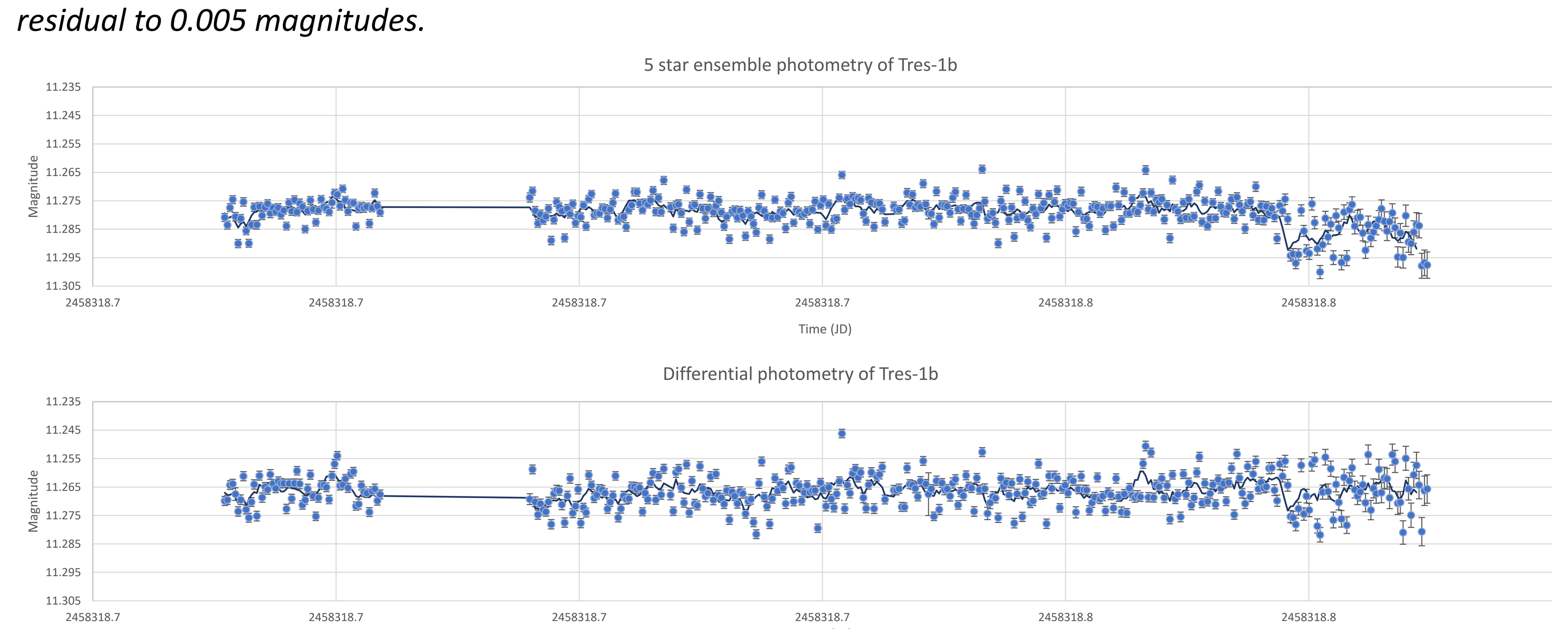

Figure 4: Magnitude vs. time of Tres-1b with the ensemble method (top) and the differential method (bottom). The methods showed little difference in error with both of them having an average error of 0.001 magnitudes. The ensemble method had an average residual value of 0.003 and differential had an average residual value of 0.004. This is because the differential reference star's SNR was higher than others used in the ensemble.

Analysis

The magnitude of the target star for ensemble photometry is calculated relative to an artificial magnitude made from the reference stars' instrumental magnitudes and a real magnitude made from their standard magnitudes. Eq. 1 is an example of the magnitude equation for two reference stars.

$$m_c = -2.5Log(\frac{(10^{-\frac{m_{ref1}}{2.5}}) + (10^{-\frac{m_{ref2}}{2.5}})}{2}) \qquad Eq.\ 1$$

Eq. 1 would be done twice. Once with instrumental magnitudes from photometry for an experimental value (m_{Ci})and once using known magnitudes of the reference stars for a real value (m_{Cr}). Then with these values, and the target's instrumental magnitude, Eq. 2 finds the target's standard magnitude.

$$m_T = m_{Ti} - m_{Ci} + m_{Cr} \qquad Eq.\ 2$$

The solid lines in the all the graphs represent 5 point moving averages (averaging a point and two on either side). The residual of each point was considered that point's difference from the moving average. The error is calculated in quadrature from MaxIm DL's reported errors to account for every star used. Below is a table of average errors and residuals of analyzed targets.

	Tres-1b (Magnitudes)	Wasp-43b (2 star) (Magnitudes)	Wasp-3b (Magnitudes)
Average error (differential)	0.001	0.007	0.002
Average residual (differential)	0.003	0.009	0.003
Average error (ensemble)	0.001	0.004	0.001
Average residual (ensemble)	0.004	0.005	0.003

Conclusions

The Tres-1b target showed a 10% difference in average measurement error and a 20% difference in the residual. The Wasp-43b target showed a 30% improvement in average error and a 40% improvement in the average residual using the 2 star ensemble compared to the differential, and the Wasp-3b target showed a 10% improvement in average error and a 20% improvement in average residual. Results from my Wasp-43b target suggest avoiding reference stars with SNR below a minimum of 100, and those from Tres-1b suggest limiting additional stars in the ensemble only to those with SNRs comparable to the highest quality reference star. Ensemble photometry visibly reduces random noise. However ensemble photometry can be unnecessary if the target has a reference star with high SNR. Ensemble photometry can be applied to all previous photometry work done in the observatory in order to improve results if data are noisy.

Future Work

I am refining a procedure manual on ensemble photometry for the observatory so other students may use it for their own research. A suspected anomaly was also found in Tres-1b's data, requiring further analysis.

Acknowledgments

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