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 error compared to differential photometry if high signal to noise ratios were used. This was because the residual of ensemble photometry is 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.

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.

Data

The solid line 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.

<table>
<thead>
<tr>
<th></th>
<th>Tres-1b (Magnitudes)</th>
<th>WASP-43b (2 star) (Magnitudes)</th>
<th>WASP-3b (Magnitudes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average error</td>
<td>(differential)</td>
<td>0.002</td>
<td>0.007</td>
</tr>
<tr>
<td>Average residual (differential)</td>
<td>0.003</td>
<td>0.009</td>
<td>0.001</td>
</tr>
<tr>
<td>Average error (ensemble)</td>
<td>0.001</td>
<td>0.004</td>
<td>0.001</td>
</tr>
<tr>
<td>Average residual (ensemble)</td>
<td>0.004</td>
<td>0.005</td>
<td>0.003</td>
</tr>
</tbody>
</table>

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

I would like to give a big thanks to my mentor Professor Jamie Kern for guiding me through my research and encouraging me through everything over this summer. I would also like to thank the ATP coordinators for all their hard work to prepare and organize every event that happened and for all the great advice we were given. I would also like to thank the Adrian Tinsley Program for funding my summer research.

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