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Analyzing Variability in Exoplanetary Eclipses

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I. Abstract

A transit occurs when a planet passes in front of its star as seen from Earth, which causes the amount of light we observe from the star to drop while the planet is crossing the face of the star. A secondary eclipse occurs when the planet passes behind the star, during which time the star blocks out light from the planet. Studying observations from NASA's Kepler Mission of exoplanetary transits and eclipses allows us to study the variability of an eclipse from one transit to another. Variability in an eclipse could result from variations of atmospheric condensates or volcanic activity on the planet. The Kepler Science Team has provided a Python package called lightkurve. This package allows data from the Kepler, K2, and TESS missions to be easily analyzed and plotted. The lightkurve package can be used to plot the data for the exoplanets that we are targeting in our study. In this presentation, we discuss our work looking for variability in the eclipses of two short period planets: HAT-P-7b, a hot Jupiter orbiting an F8 star.

I. Introduction

The Kepler telescope surveyed a portion of the Milky Way to detect earth-sized planets in the habitable zone of their host stars. The photometer stares at a region of space to monitor the brightness of over 100,000 stars using the transit method.

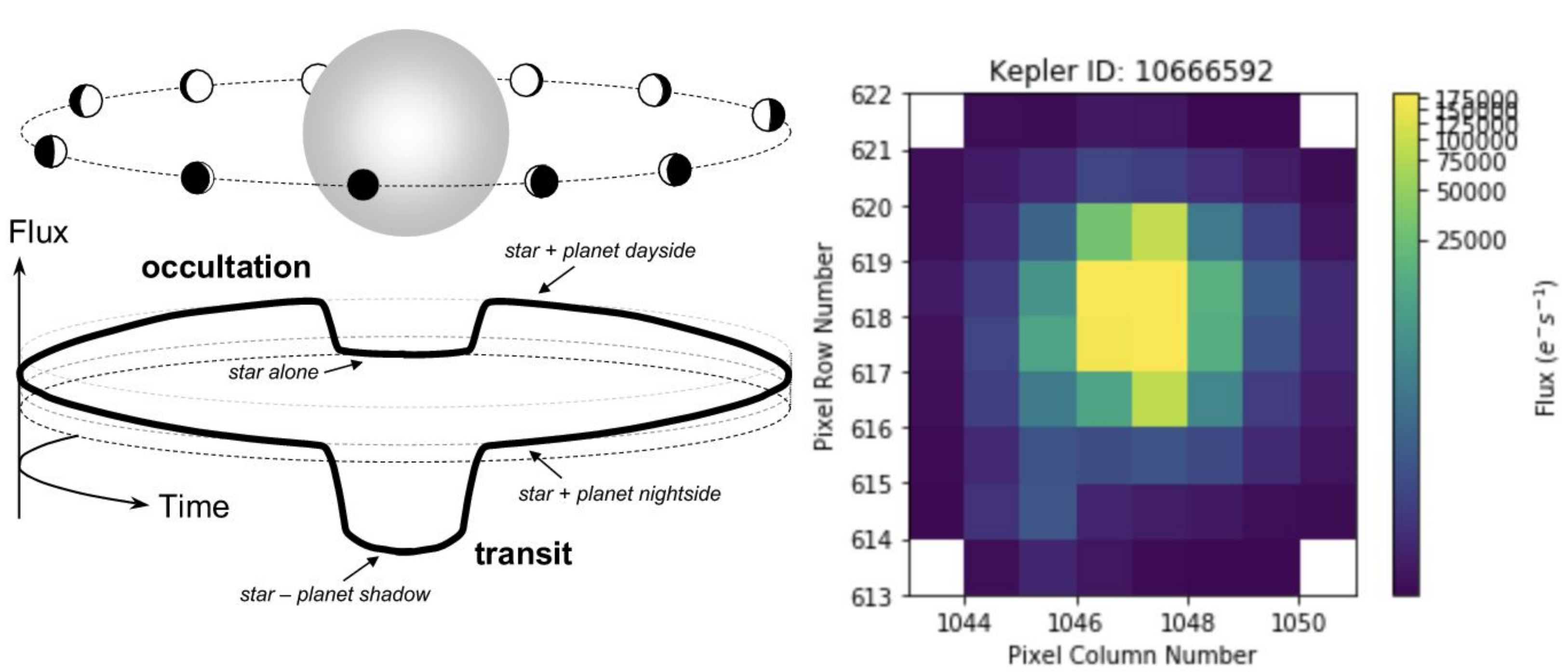

Figure 1: An illustration of a planetary transit and eclipse. As the planet passes in front of its host star, a small portion of the star's flux is blocked. Similarly, as the planet passes behind its host star, the reflected or emitted light from the planet is blocked by the star. *From Seager et al. (2010).* The image on the right is from the Kepler space telescope of HAT-P-7b.

HAT-P-7b is a hot Jupiter, a gas giant planet resembling Jupiter but much closer to its F8 host star. It has an orbital period of 2.2 days and is very bright, producing a prominent transit curve. The eclipse is much shallower than the transit light curve due to less flux being blocked out during occultation.

II. Methods

The depth of an eclipse depends on the atmospheric and/or surface conditions of the planet, in addition to other system properties. In order to look for variability in the eclipse of HAT-P-7b, the lightcurve data collected from Kepler needed to be filtered. We used the Python coding language to filter the Kepler data using the lightkurve package, seen in Figure 2 below.

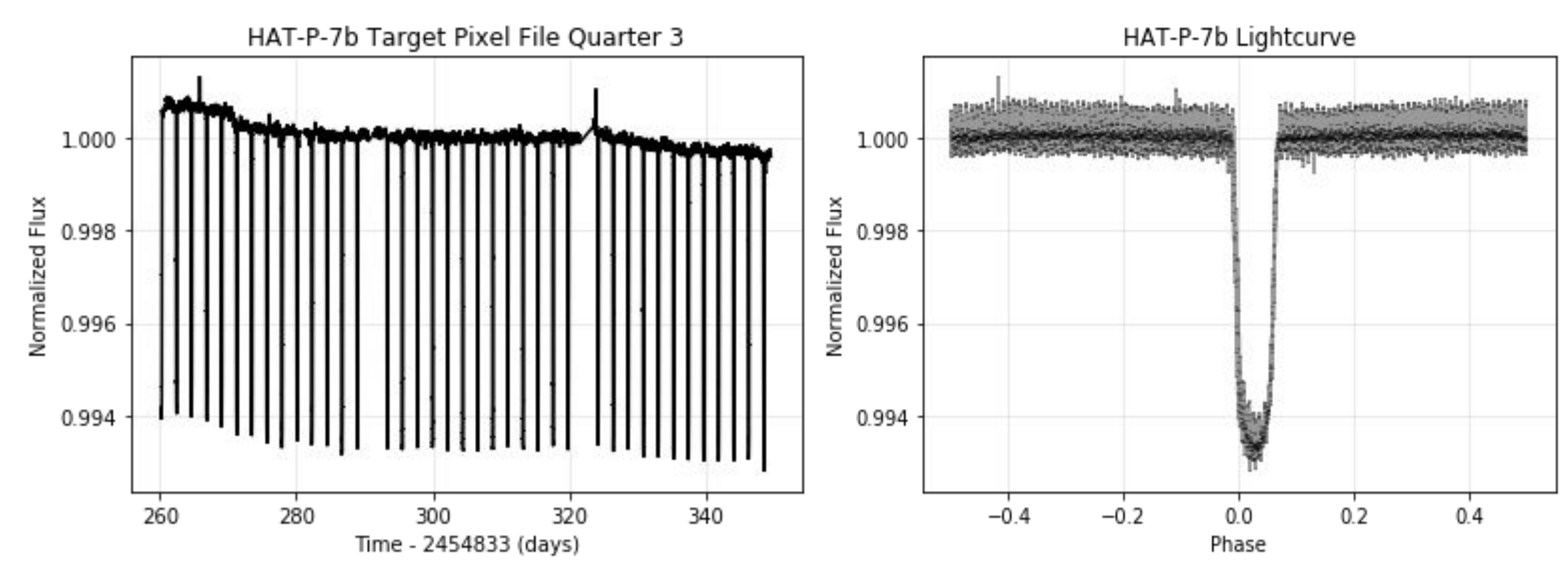

Figure 2: The transit lightcurve of HAT-P-7b. The graph on the left are the data collected by Kepler for one quarter (90 days) of data. The lightcurves from each orbit have been folded on the planet's orbital period, enhancing the planet's signal and averaging the noise by creating a single lightcurve for the entire dataset.

III. Modeling

In order to examine the eclipse data in the lightcurve of HAT-P-7b, a model of the planetary phase curve was constructed based on the equations from Jackson et al. (2012). This system includes three factors that contribute to the planet's flux: reflected light from its surface, tidal forces distorting the planet's shape, and a Doppler beaming effect that arises from reflex motion of the star. We also included an eclipse with Python code written by Jason Eastman based on the quadratic limb-darkening routine from Mandel & Agol (2002). This combination of models is shown in Figure 3.

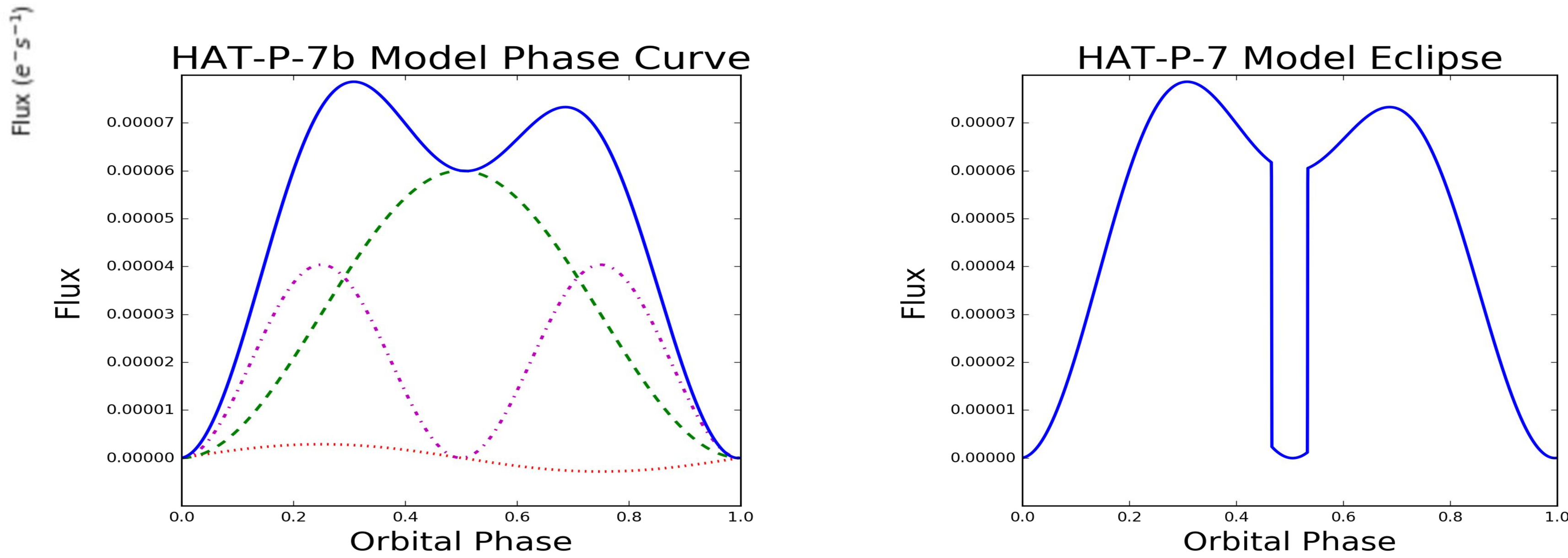

Figure 3: The model phase curve is shown to the left, where the contributing components include reflected as green dashed, ellipsoidal as magenta dot dashed, and doppler beaming as red dotted. To the right is the resultant phase curve with the eclipse included at the orbital phase of 0.5.

IV. Data Fitting

The working model allows the eclipse data to be fit using a least squares approach. To ensure that our model works properly, the results of the fit were compared to those from Jackson et al. (2012), which had previously determined accurate values for the parameters. The initial fit as seen in Figure 4 was poor, so we again applied a fit after binning and shifting the data to minimize noise, and maintain consistency with the model. The transit portion of the lightcurve was masked out at the orbital phase near zero and one for both fits.

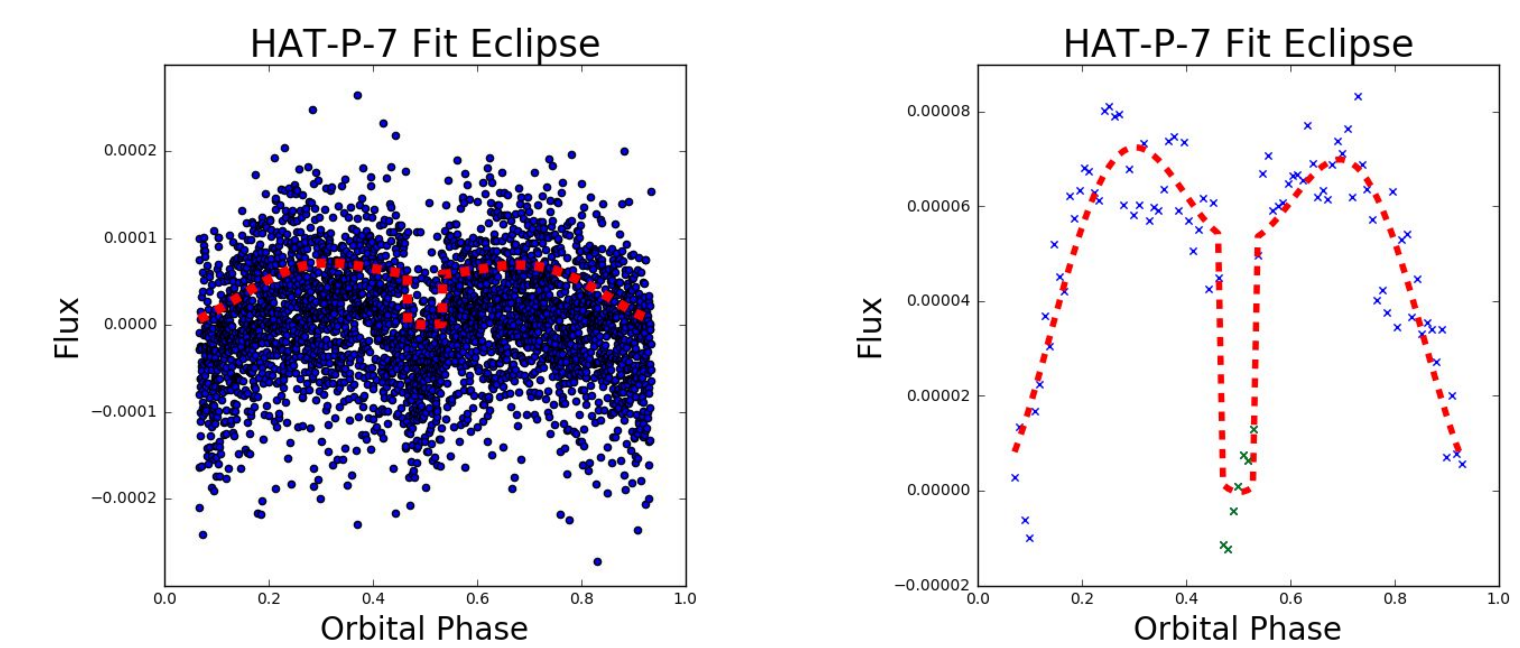

Figure 4: The fit eclipse data of HAT-P-7b. Following the initial fit, the data was binned into small time increments as a means to average out the noise. The green markings indicate the indexed eclipse that was used to shift the data to have a miniumum at zero, consistent with the model.

V. Continuing Plans

The results of the most recent fit of the eclipse are satisfactory, although there is still work to be done. The transit must be modeled and fit in order to subtract it from the data, avoiding the need to mask portions of the lightcurve, thus yielding a more accurate fit of the eclipse. We can then apply our fit to each orbit to look for variability in the eclipse, which can provide information on the atmosphere of HAT-P-7b. A paper by Parmentier et al. (2013) investigated a particularly interesting source of variability in the eclipses of gas giants. They described that a meteorological effect involving global atmospheric circulation of tiny particles could be driven by extreme differences in the planet's dayside and nightside temperatures, leading to notable variation from eclipse to eclipse. Further analysis of the eclipses of our planet HAT-P-7b may reveal how the planet may be changing over time.

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