Observation and Model Fitting of Exoplanets and Kepler Objects of Interest

Maria Patrone, Department of Physics (Mentor: Professor Jamie Kern)
Bridgewater State University, Bridgewater MA 02325

Abstract

As part of an ongoing effort to conduct exoplanet research using the BSU Observatory, we prepared and submitted data on exoplanet Qatar 1b to the Exoplanet Transit Database (ETD), collected, processed and analyzed supplementary data on Kepler Object of Interest (KOI) K03810.01, and studied methods of fitting exoplanet light curves. The ETD fit to our Qatar 1b light curve produced a transit depth of 0.0236 ± 0.0015 magnitudes and duration of 97.5 ± 3.4 minutes. The data collected on K03810.01 revealed an issue with our Apogee Alta U47 CCD camera's shutter, which caused the supplementary data to be unusable. We present the components of a fit to an exoplanet transit light curve.

Introduction

Exoplanets orbit stars other than the Sun in our galaxy. Of the many ways to observe and analyze them, the transit method is the most favorable for us at BSU. The transit method involves observing the star when a planet passes in front of it, blocking some of the light the star emits. When the planet transits the star, it creates dip in the light curve (time vs. magnitude) resembling a "U" shape consisting of an ingress, egress, and transit floor.

Last summer, we observed Kepler Objects of Interest (KOIs) to confirm Kepler Object K07525.01 as an exoplanet. When we plotted the light curve for the object, it had an unexpected "V" shape.

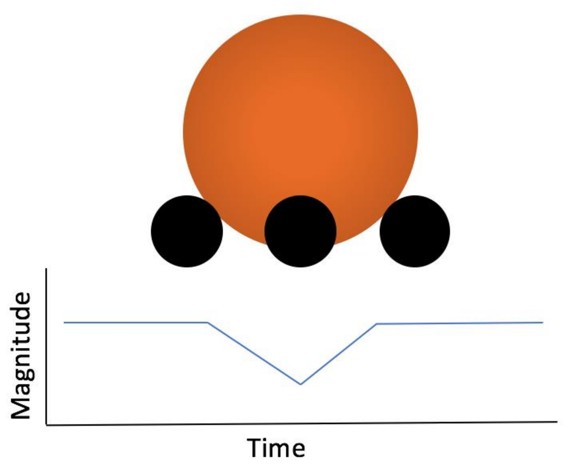

Figure 1: A hypothetical exoplanet forming a "V" shape.

We have two hypotheses to explain this:

1. The exoplanet is not fully passing in front of its host star, so its entire shadow is never apparent.
2. K07525.01 is not an exoplanet at all, but rather a binary star system. In this case, the object Is fairly large compared to its host star and is more likely to be in the egress by the time it reaches maximum depth.

A fit to the light curve can determine attributes of the object, such as size and orbital period. Last year, when we observed well-documented exoplanets, we used the Exoplanet Transit Database (ETD) fitter [1]. This program applied pre-determined parameters to its model-fitting function and then applied it to the data. This means it is only applicable to known exoplanets and unusable for our KOI. The ETD fitter also assumes the transiting object is much smaller than its host star. This is not necessarily the case for K07525.01, which requires a more malleable fit.

Due to the possibility that K07525.01 was a binary star rather than an exoplanet, we also chose to observe a new object, K03810.01, this spring. This KOI was chosen due to the object's relatively small mass (about 14 Jupiter masses). This would make it a more viable candidate for an exoplanet rather than a binary star. This object was chosen as it was the only one transiting at a time that would put it higher than 35 degrees altitude during dark sky this semester.

Transit Fitting

Qatar 1b – ETD Fitter

Submission of our data for Qatar 1b from October 11th, 2016 to the ETD fitter produced the fit below, with transit depth 0.0236 ± 0.0015 magnitude and transit duration 97.6 ± 3.4 minutes. The transit duration is consistent with the ETD's average value. The transit depth differs by 0.0032 magnitudes. However, the submitted data range from 0.0204 to over 0.03 magnitude, making our measurement consistent with others.

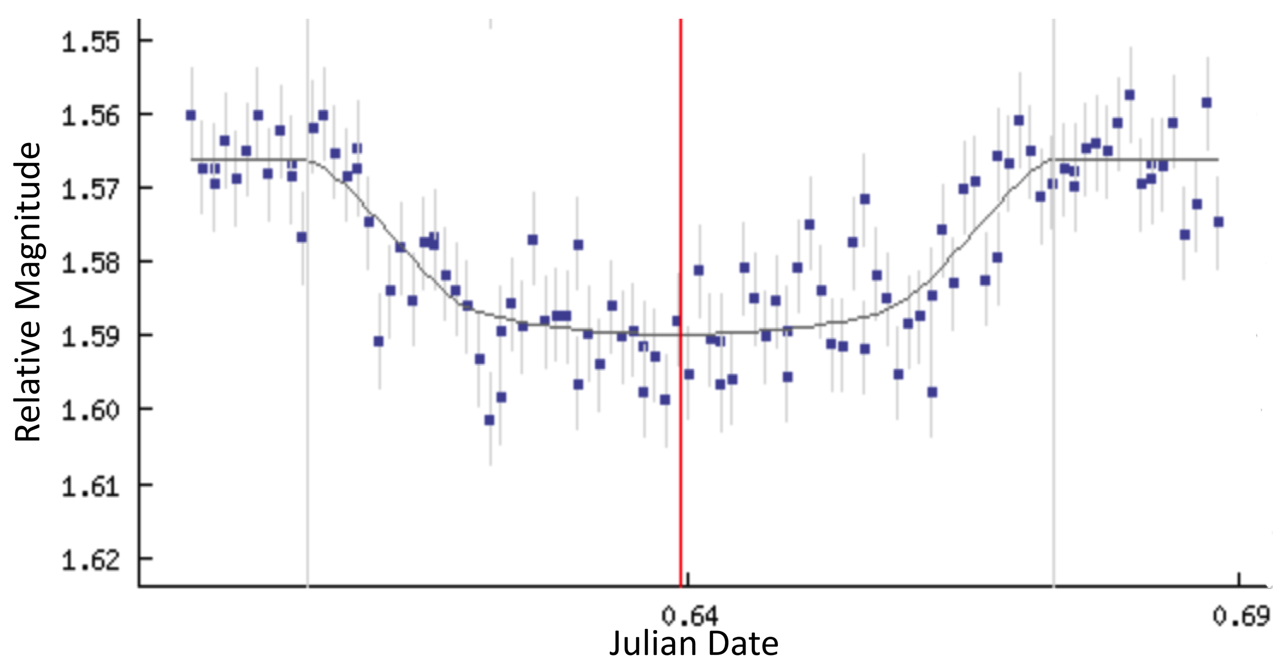

Figure 2: Light curve of Qatar 1b. Data were fit using the Exoplanet Transit Database (ETD), which can model fit data from known exoplanets [1].

K07525.01 – NASA Exoplanet Archive

The NASA Exoplanet Archive model-fits data using a relatively simple fitting program created by Bruce Gary [2]. To create the fit, the program divides the transit into 5 separate parts: The flat magnitude of the star, the ingress, egress, and the transit floor.

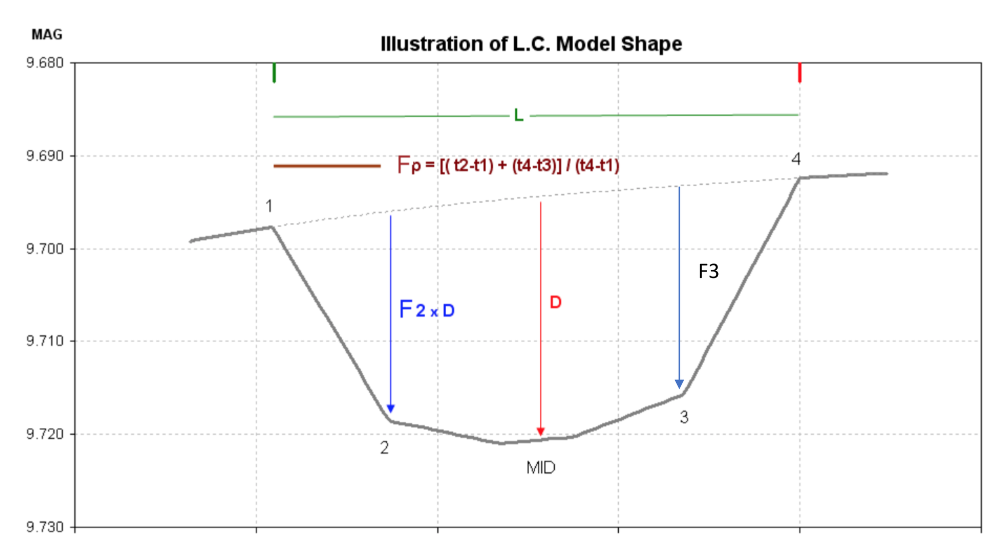

Figure 3: The figure Bruce Gary uses to show the different parts of the transit [3].

In the figure above, eight parameters define the curve [3]:

- D: The Depth at mid transit.
- F_2: Depth at the end of the ingress divided by D
- F_3: Depth at the beginning of the egress divided by D
- F_P: The section of the transit in which light is blocked
- t_1: The time at which ingress begins
- t_4: The time at which egress ends
- Air mass curvature (due to changes in sky conditions as target rises/sets)
- Linear temporal trend (caused by image rotation)

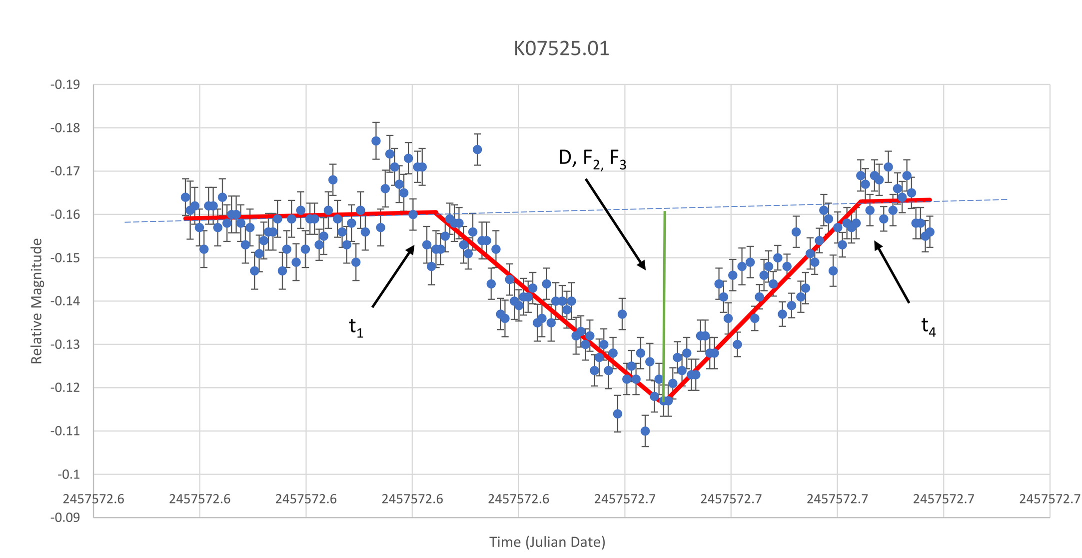

Figure 4: Our light curve for K07525.01 with a simple piecewise linear function to demonstrate the "V" shaped fit.

For K07525.01, $F_2 = F_3 = 1$, as the maximum transit depth occurs at both of these points, which, in turn, are the transit depth D. This eliminates the transit floor section and produces the "V" shape. Next we make $F_P = 1$ as the entire transit is a partial transit. We intend to implement a fit with these constraints over the Summer.

Data

We imaged the only fully observable transit of K03810.01 this spring, on March 12th 2017: the only night that the KOI transited in front of its host star while being above 35 degrees altitude. Though the transit was high enough in the sky, it was not optimal. The beginning of the transit happened low enough that the atmosphere added significant noise to the image.

After image calibration, we discovered an issue with the camera shutter. In figures 3 and 4, there is a "starfish-shaped" pattern. This is normally created during flat-calibration exposures that are too short, when the time the shutter spends opening and closing is significant compared to the exposure length. However, flat calibration images for K03810.01 were long enough that the maximum shutter time should have been <0.3% of exposure time. The appearance of the shutter pattern therefore indicates a blockage or slowdown of the shutter. The starfish pattern artificially changes the signal and background count across an image, rendering photometry incorrect with even slight changes in star positions. Examination of additional recent datasets also reveals this issue, and image ghosting which may be related. K03810.01 must be re-imaged when the CCD is fully operational.

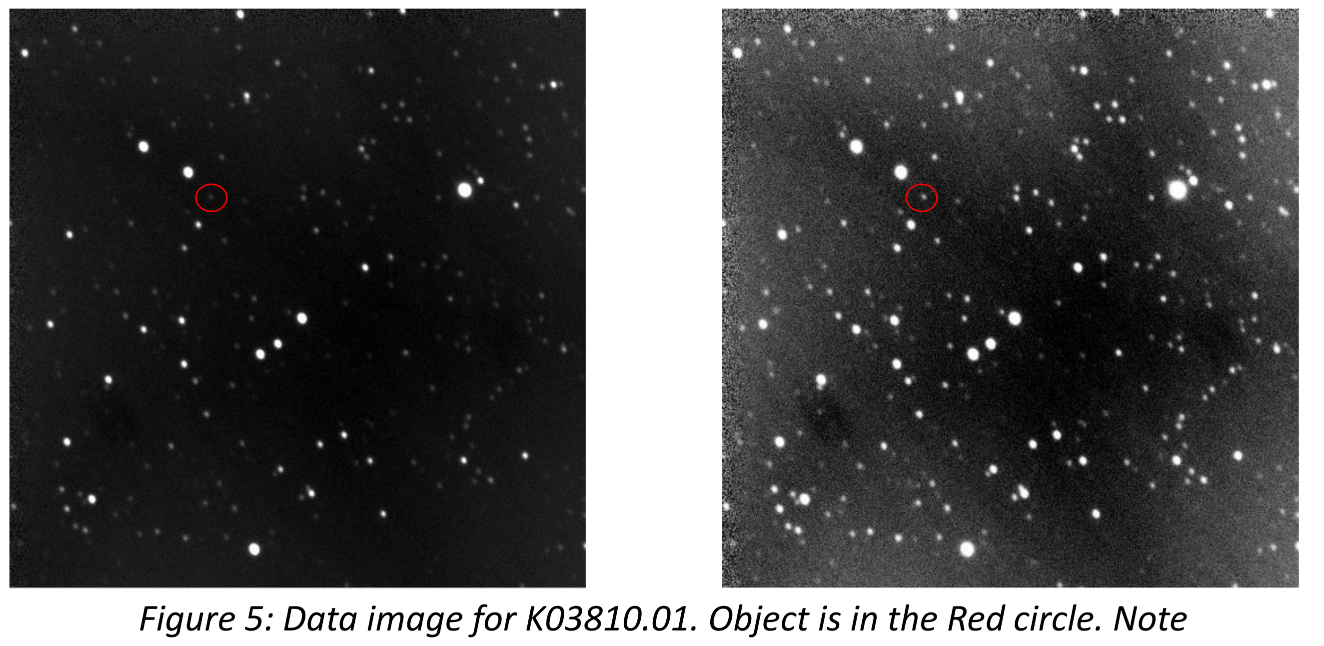

Figure 5: Data image for K03810.01. Object is in the Red circle. Note how the image looks usable on the left, but when contrast is increased, the starfish pattern appears.

Acknowledgments

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References

[1] "ETD - Exoplanet Transit Database." *Variable Star and Exoplanet Section*. Czech Astronomical Society, n.d. Web. Mar. 2017.

[2] "NASA Exoplanet Archive." Infrared Processing and Analysis Center, n.d. Web. Mar. 2017.

[3] Bruce Gary. "Exoplanet Observing For Amateurs: Second Edition." brucegary.net, n.d. Web. Apr. 2017.