Class Project: Exploring WASP-18 b via the Transit Method

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I. Transit Method Background

Commencing as an observational method, the first scientific study of transits in the solar system was that of Mercury transiting the sun, observed by Pierre Gassendi in 1631 [1]. Since the discovery of HD 209458 b in 1999 as the first exoplanet to be discovered via the transit method, the method has soared to large popularity within the astrophysical community, leading to more than four thousand exoplanet discoveries via the transit method as of 2024. The idea of detecting planets via their shadows dates back centuries, but it became scientifically feasible in the late 20th century with advancements in photometry. Over time, space-based telescopes like Kepler and later TESS revolutionized the method, providing continuous and highly precise observations free from Earth's atmospheric interference, with the JWST mission providing a bright future for the detection of extrasolar planets via their transits.

II. Methodology of the Exoplanet Study

A. Data Acquisition Reference [2], known as the Mikulski Archive for Space Telescopes, sources all relevant data in this project. 1), referring to the code assigned to step 1 of the class project (which will be a notation used for the code file signed to each respective part of the project), downloads all 2-minute cadence data on WASP-18 b from TESS, including all sectors of the relevant observation periods. The download comes in the form of multiple `.fits` files, which will allow the use of `astropy` features that will simplify 2) and onward.

B. Data Preprocessing: 2) processes the relevant data fields, masking unuseful data, concatenating the desired data, and plotting such data into a light curve, as shown in Figure 1.

Since data of poor quality is removed, an uncertainty is implemented in 2) on the concatenated data's flux only. Due to the time disparities in each observation period on WASP-18 b, the light curve appears compressed.

C. Rediscovering WASP-18 b: Through the box-least squares (BLS) `astropy` implementation, the following periodogram is generated in 3) (Figure 2).

Calculations of the periods of WASP-18 b's transits, along with their depths, are calculated via a "best-fit" period, or the most resonant peak from the generated periodogram. This best-fit period is calculated to be 0.94 days. Binning is used to remove noise and identify the flux of the transit period, with the transit depth calculated using the flux to be around 0.0067. With the given radius of WASP-18 as 1.319 solar radii, WASP-18 b's radius is calculated to be 0.11 solar radii, and the impact parameter of its transits is around 0.37 using the following equations, where R_s is the radius of WASP-18, R_p is the radius of WASP-18 b, T is the transit depth, a is the semi-major axis of WASP-18 b's orbit, i is its inclination, and b is the impact parameter:

$$R_p = R_s\sqrt{T}, \quad b = \cos(i)\frac{a}{R_s}$$

Uncertainty (flux error) is accounted for as the stan-

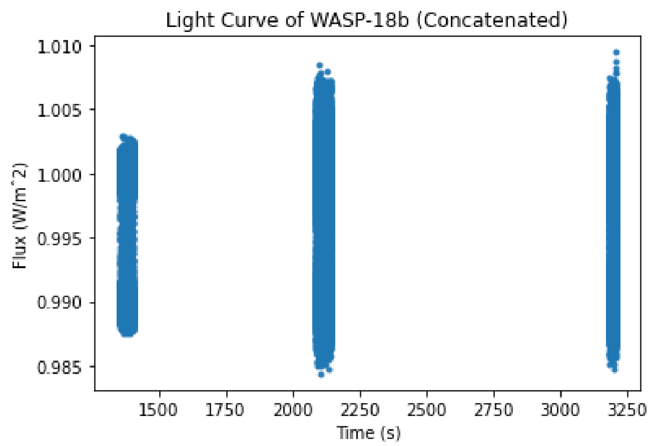

Figure 1:

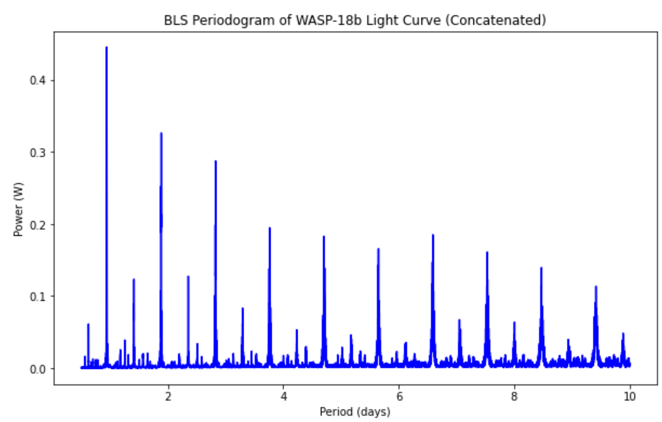

Figure 2:

dard deviation of flux. This is also implemented in 4) to account for uncertainty.

D. The Primary Transits of WASP-18 b: The light curve of the best-fit period is folded in 4), which obtains the phase curve of the period. This is then plotted across three transits of WASP-18 b on its host star, as shown below, where the primary transit is highlighted.

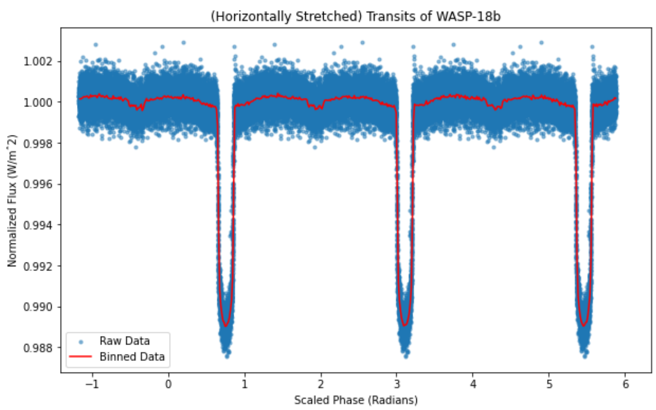

Figure 3:

Binning is applied to the graph, and the phase is scaled for clarity.

E. The Secondary Eclipse of WASP-18 b: The applied binning in 4) already shows distinct "secondary" transits in the light curve of WASP-18 b, but nonetheless 5) follows the desired instructions. Two of the three transits from 4) are highlighted, where the primary (most distinct) transits are removed from the light curve via masking. BLS is rerun, generating the following graph (Figure 4).

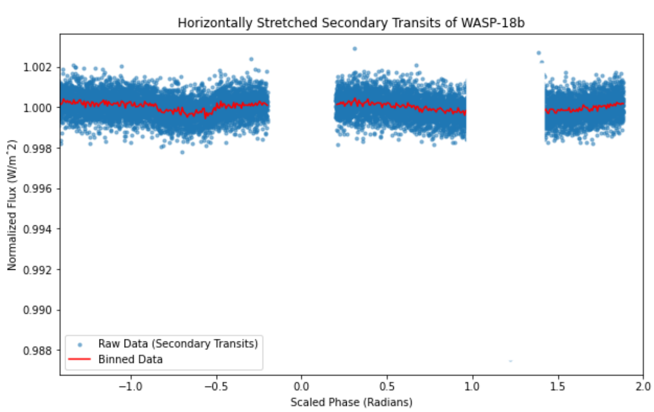

Figure 4:

5) also bins the data to identify the secondary eclipse of WASP-18 b, which is most clear in the dip just before the leftmost "primary" transit in the light curve. By the scaled phase, this occurs between -1.0 radians and -0.5 radians, with a calculated depth of 0.0011. Through this given value, the dayside temperature of WASP-18 b can be calculated via the mathematical implementation in 5) to be around 3084 K.

F. Full Phase Curve of WASP-18 b: Via the phase curve generated by the periodogram data in 3), the full phase curve is plotted below with distinctions made to label the primary and secondary transits/eclipses. The phase is scaled to highlight the transits and focus on the landmarks of the phase curve. Primary transits are distinguished as purple regions, while secondary transits are distinguished as green regions, as shown below (Figure 5).

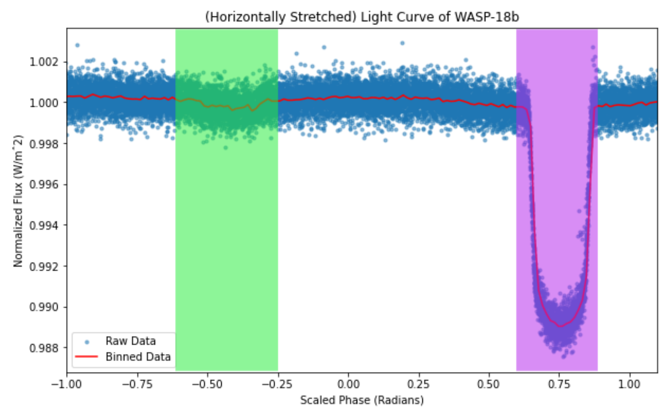

Figure 5:

III. Results and Conclusion

Via the data presented, the following quantities were inferred about WASP-18 b:

- **WASP-18 b's radius:** 0.11 solar radii.
- **WASP-18 b's dayside surface temperature:** 3084 K.

These results are approximately (within a small margin of error) what is considered today as the accurate qualities of WASP-18 b in the astrophysical community. Through the photometric data from the Transiting Exoplanet Survey Satellite (TESS), the project utilized common software methods to make observations on a paradigm exoplanet, allowing us to make inferences on other details of the exoplanet through statistical analysis.

Furthermore, this methodology can be implemented to analyze other photometric data to make claims about other exoplanets, and serves as a strong example of how modern technologies continue to do so for the increasing discovery of new extrasolar planets in the cosmos.

References

1. D. Briot and J. Schneider, "Prehistory of Transit Searches," https://arxiv.org/abs/1803.06896.
2. Space Telescope Science Institute, Barbara A. Mikulski Archive for Space Telescopes, https://mast.stsci.edu/portal/Mashup/Clients/Mast/Portal.html