Analyzing Transits of Exoplanet WASP-177b

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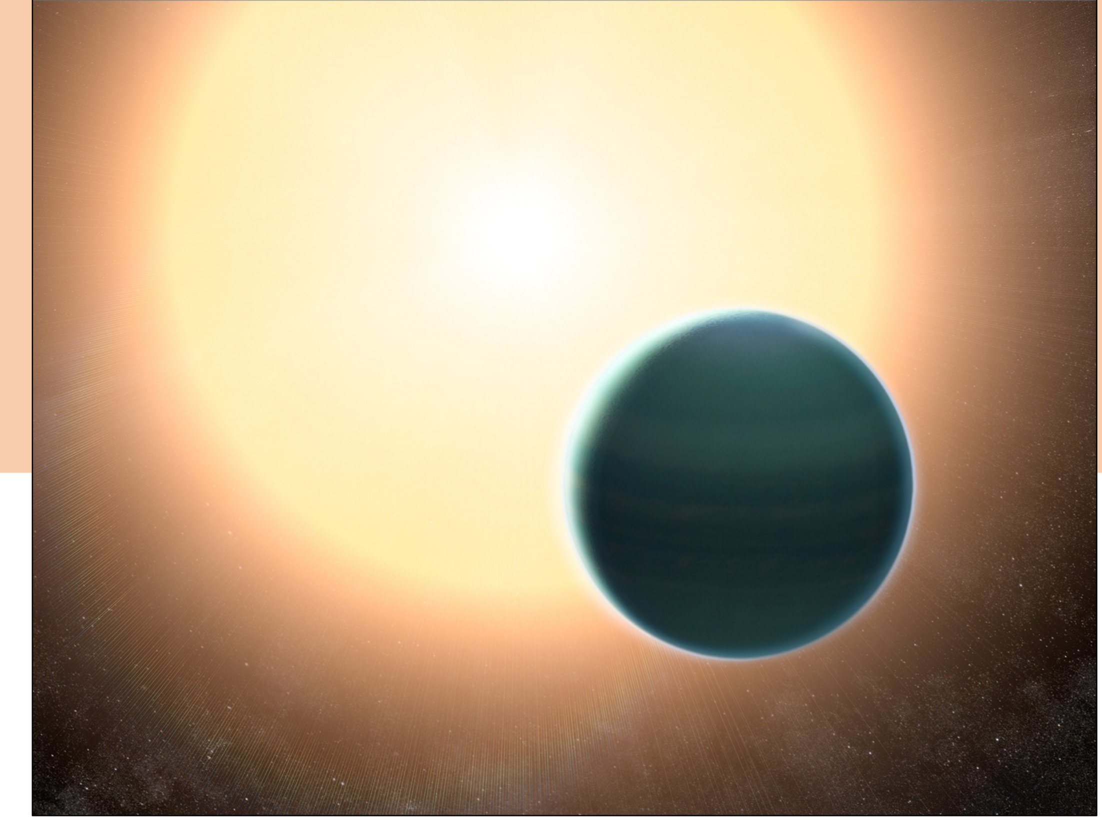

FIG. 1: Illustration of an exoplanet passing in front of, or transiting, its star (Credit: NASA/GSFC)

WASP-177b is an exoplanet discovered by Turner et al. in 2019 through a ”dip” in the star WASP-177’s light curve characteristic of a transit, or an event in which one celestial body passes in front of another, as illustrated in Figure 1. From the shape of the light curve, it was determined that WASP-177b is approximately 1.6 times the size of Jupiter and occupies an orbit roughly one-tenth of Mercury’s. These so-called “Hot Jupiter” exoplanets are relatively easy to detect due their short orbital period and large size. Undetected exoplanets exert a gravitational force on these “Hot Jupiters,” slightly advancing or delaying the time of transit and revealing their presence through these so called “transit-timing variations.” Previous studies suggest only one planet within the WASP-177 system, and this research observed and analyzed transits of WASP-177b for potential transit-timing variations and thus additional planets.

Data Collection & Processing

Transit events of WASP-177b were identified weekly by using the *Tapir* web-interface made publicly available by Swarthmore College, with viability was dependent on weather conditions and observatory availability. Over the research period, two transits were observed:

- September 5 – Using the RIT Observatory, transit was observed through a 12-inch f/10 Meade LX200 telescope using a clear filter and ASI 6200-mm camera; images acquired by MS and MR
- October 15-16 – Transit was observed through a 24-inch f/6.5 Planewave CDK using a V filter and FLI PL16803 camera; images acquired by JD

For both data sets, dark frames and dome flats were taken to account for detector defects affecting the observational data. To remove detector noise,

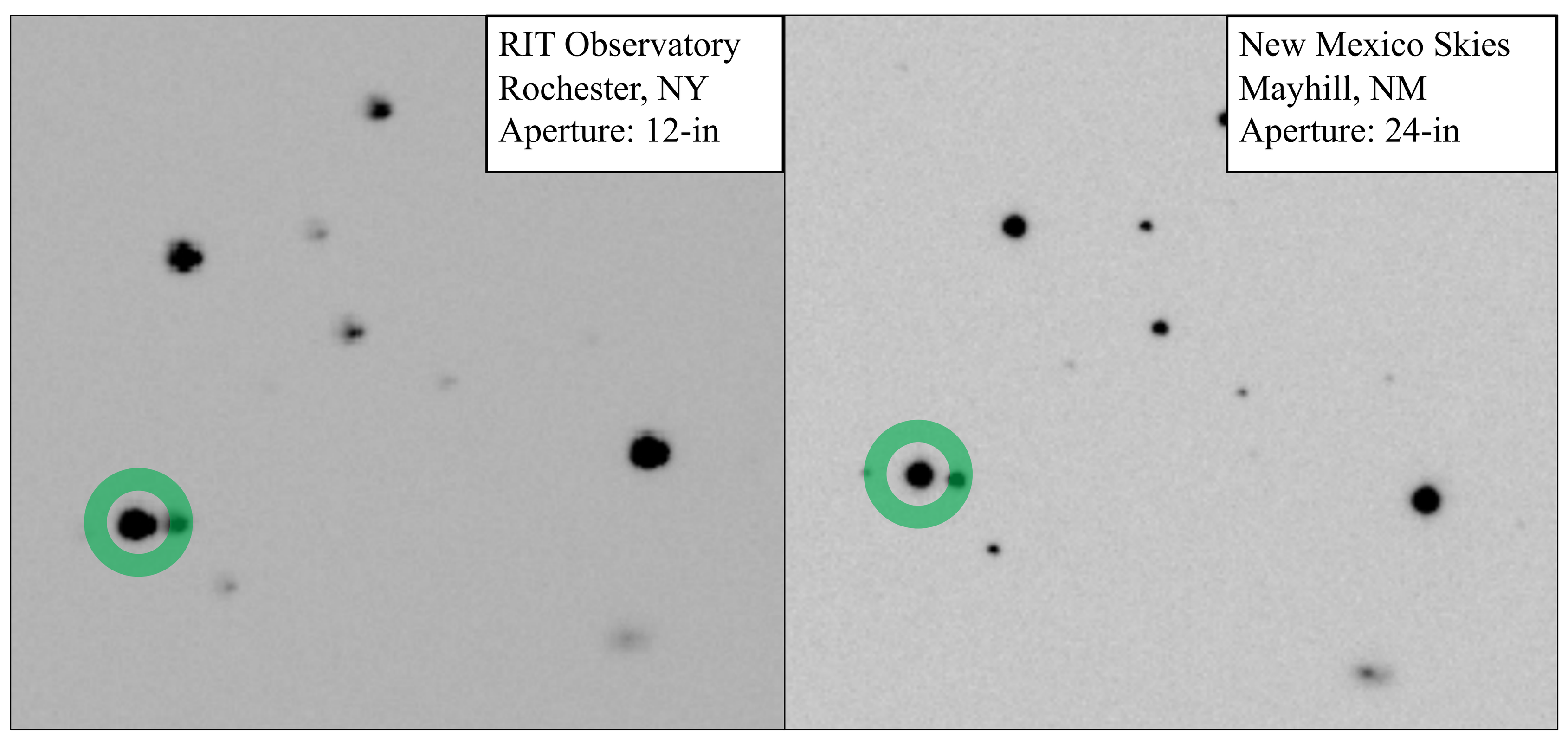

FIG. 2: Composite images of WASP-177 field captured at the RIT Observatory (on the left) and by JD in New Mexico (on the right). The green annulus is centered on the star WASP-177.

the set of images was cleaned by subtracting the dark frames and dividing by the flats in AstroImageJ (for the September transit) or PinPoint Astrometric Engine (for the October transit). Composites of these images are shown in Figure 2.

Fluxes from WASP-177 and 6 comparison stars were measured in AstroImageJ using multi-aperture photometry on all frames collected during an observing session. Aperture sizes were determined by sampling frames through out the night and determining the average radii that best captured the extent of WASP-177’s light emission and sources of emission in the background. The annulus containing these background sources are used to remove noise from the nearby signal of interest – a star. Data are then saved to a tsv file to allow for further analysis in Python.

Analysis

To put WASP-177’s flux in terms of standard astronomical units, it is converted to instrumental magnitudes and detrended by a reference star to produce differential magnitudes – smaller values correspond to brighter sources, and larger to fainter. These magnitudes are binned to reduce noise in data and plotted against the reduced Julian date, as shown in Figure 3 for both transits. Changes of 0.01 magnitudes correspond to brightness changing by 1%. For this transit, a change of approximately 2% is expected.

A Python routine was written to identify the times of ingress (start of transit), conjunction (midpoint of transit), and egress (end of transit).

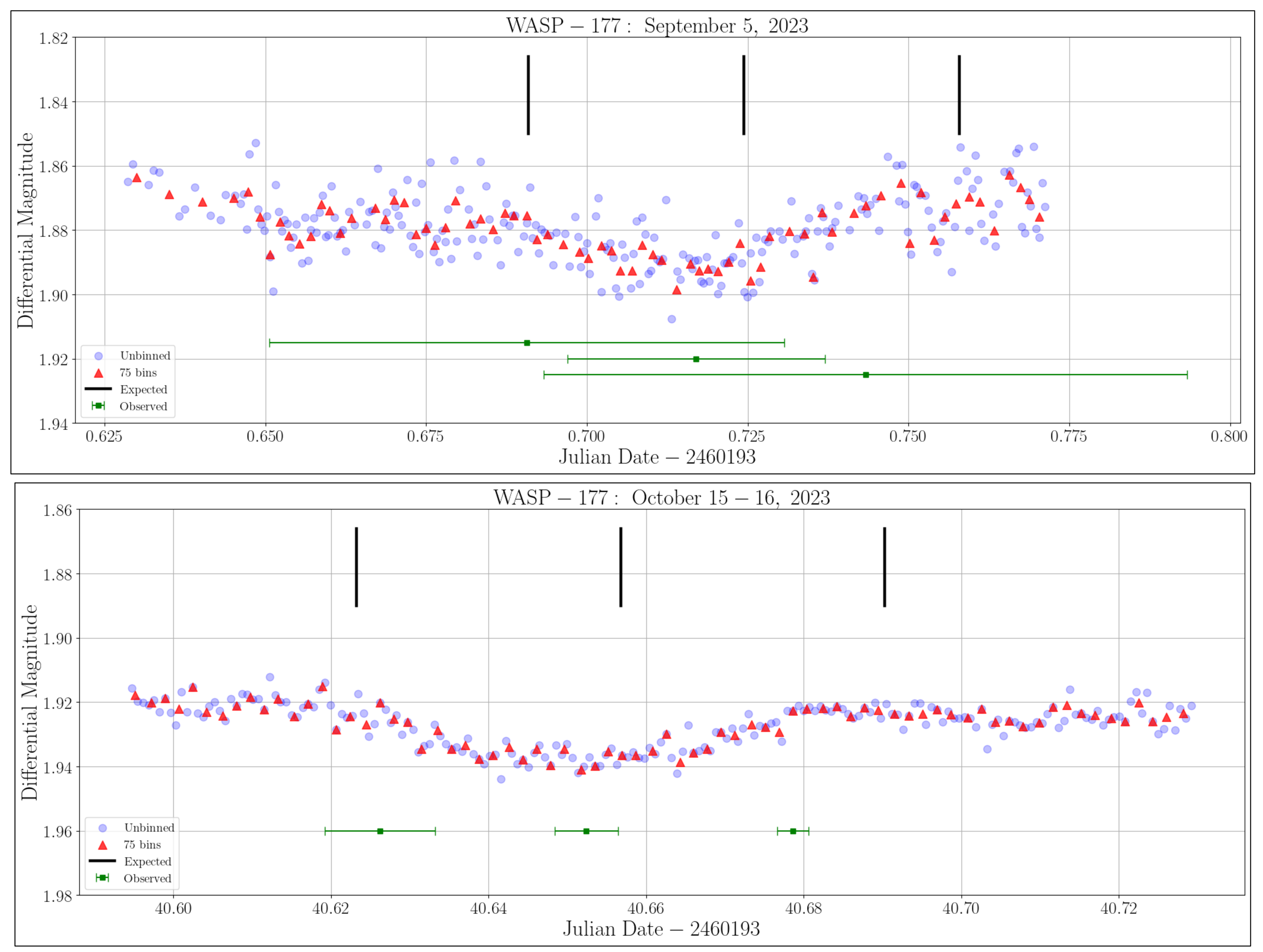

FIG. 3: Light curves of WASP-177 on September 5 (on top) and on October 15-16 (on bottom). Black lines indicate the expected times of ingress, conjunction, and egress based on Turner et al., and green square indicate similar values determined from observational data with error bars to represent uncertainties.

Uncertainty in these values were determined by artificially introducing noise to this routine and identifying the variation in values produced by multiple iterations. For comparison, the anticipated times of ingress, conjunction, and egress were also determined using Turner et al.’s measurements for WASP-177b’s time of conjunction and orbital period. These values are indicated on the plots in Figure 3 (vertical lines for expected, and squares with error bars for observed) and listed in Table I.

	Ingress [JD-2460193]	Conjunction [JD-2460193]	Egress [JD-2460193]
Expected	0.6908	0.7244	0.7579
Observed	0.67 ± 0.04	0.72 ± 0.02	0.75 ± 0.05
Expected	40.6232	40.6567	40.6903
Observed	40.626 ± 0.007	40.652 ± 0.004	40.679 ± 0.002

TABLE I

By finding the time between corresponding parts of the transit and dividing by the number of orbits completed in that time span (approximated from the accepted period value), one can then derive the length of WASP-177b’s orbital period.

These derived values, in addition to their average and the accepted orbital period value for comparison, are recorded in Table II.

	Period [days]
Ingress-Derived	3.074 ± 0.003
Conjunction-Derived	3.072 ± 0.002
Egress-Derived	3.071 ± 0.004
Average	3.072 ± 0.002
Accepted [Ivshina & Winn 2022]	3.071772156

TABLE II

Conclusions

Since all observed periods agree with the accepted value within measured uncertainty, there is no compelling evidence for transit-timing variations in the orbit of WASP-177b. However, the light curve and analysis of the transit on October 15-16 suggests slight changes in the duration of the transit as the observed and expected times of egress do not agree within uncertainty. The exact nature of this apparent change would require additional transit observations and further analysis.

References:

Ivshina E. S., Winn J. N., 2022, *ApJS*, 259, 2, 10.3847/1538-4365/ac545b

Jensen E. L. N. 2013. *Tapir: A Web Interface for Transit/Eclipse Observability*, Astrophysics Source Code Library ascl:1306.007

Turner O. D., et al., 2019, *MNRAS*, 485, 4, 10.1093/mnras/stz742