Photometric Observations of Exoplanets with Transit Timing Variations

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What is an Exoplanet and how can we observe them?

Our sun is not unique in having a planetary system, most of the stars within our galaxy have planets orbiting them. These planets outside of our solar system are referred to as exoplanets. The field of study regarding exoplanets is relatively new, with the first confirmed exoplanet being discovered in 1992. Building a large database of observations is essential for cataloguing and improving our understanding of exoplanets. There are various methods for detecting exoplanets, but one of the more prominent methods (and the method used during this project) is known as the transit method (See Fig. 1).

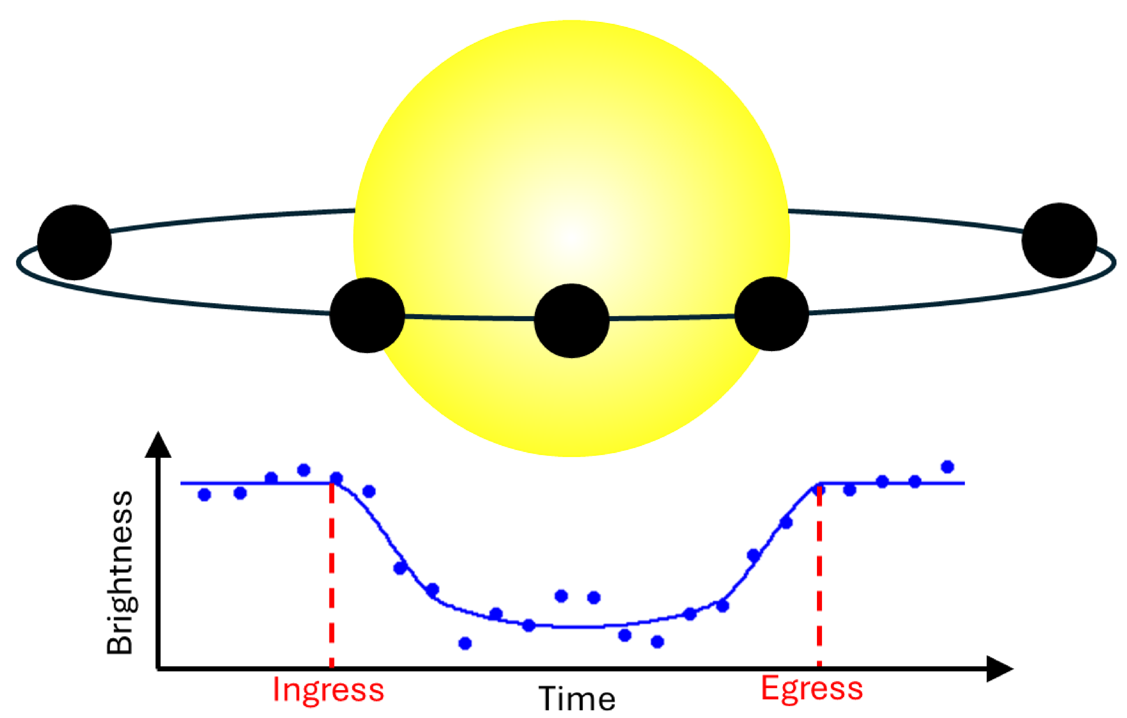


Fig. 1: As an exoplanet passes in front of its host star (in our line of sight) the light we receive from the star will appear to decrease in brightness. By making measurements of the star's apparent brightness over the course of the transit we can observe this dip in brightness. From this data determinations of various planetary parameters can be made for the transiting exoplanet.

Transit Timing Variations

Typically, we expect an exoplanet's orbital period to be constant. However, certain processes can take place that alter the timing of an exoplanets transit. These alterations are referred to as Transit Timing Variations (TTVs). Many of these TTVs can be on the order of minutes or less per year, making multiple observations over a long period of time a necessity in studying them. Possible causes of TTVs could be:

- Gravitational interactions in multi-planet systems
- Apsidal precession
- Tidal orbital decay

Equipment

Observations for this project were made at UNH's observatory which houses a Celestron 14-inch Schmidt-Cassegrain Telescope (SCT) mounted on a Software Bisque MX+robotic German Equatorial Mount (GEM). All images were captured with a SBIG STXL-6303E CCD camera and a Clear Blue-Blocking (CCB) filter to help reduce moonlight. The equipment was run using TheSkyX professional Software and analyzed in AstroImageJ. My knowledge of AstroImageJ comes from a 6-week course run by Dr. Dennis M. Conti, the current Chair of AAVSO's (American Association of Variable Star Observers) Exoplanet Section. This software is widely utilized in the professional community for projects such as TESS (Transiting Exoplanet Survey Satellite).

Process of Observing an Exoplanet

Choose Target Star → Collect Necessary Parameters → Set up Observatory Equipment → Find Target Star → Image Target Star → Calibrate Image → Analyze Data

What to Consider When Choosing a Target Star

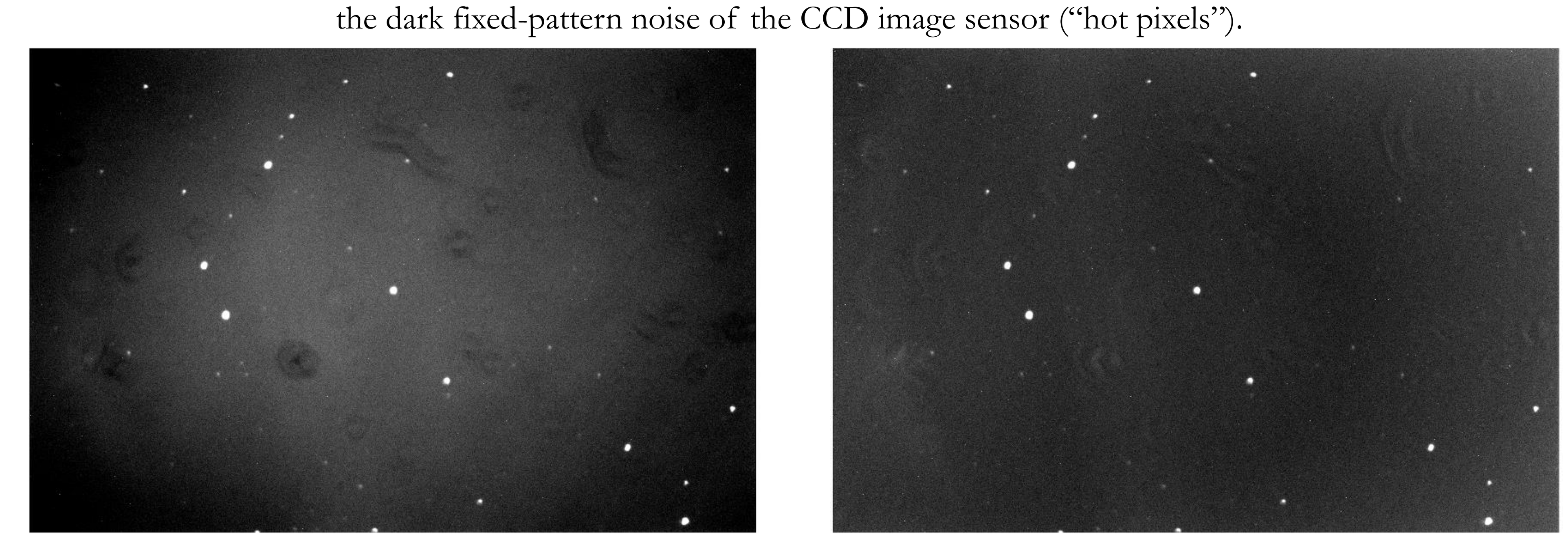
- Sky Location
- Brightness
- Depth of Transit
- Time of Transit
- Weather

Stellar Parameters		
Parameter	**WASP-43**	**QATAR-1b**
Guide Star Catalogue	GSC 05490:00141	GSC 04240:00470
Magnitude	12.4	12.84
Effective Temperature (K)	4500 ± 100	5010 ± 90
Spectral Type	K0V	M0V
Radius ($R_\odot$)	0.651 ± 0.005	0.80 ± 0.04
Mass ($M_\odot$)	0.688 ± 0.037	0.838 ± 0.043
Density (g/cm^3)	2.562 ± 0.080	2.286 ± 0.074
Distance (pc)	87.7 ± 0.3	185.6 ± 0.8

Table 1: This table shows the information needed for observation and analysis.. Magnitude values were taken from the Exoplanet Transit Database and all other stellar parameters were taken from NASA's exoplanet archive (see references).

Image Calibration

Fig. 2: Shown here is an uncalibrated (left) and a calibrated image (right) from an observation of WASP-43b. Calibration requires 3 images: a master flat field, master bias, and master dark (each created from an average of 16+ images). Flat Field frames correct for vignetting, obstructions in the light path, and photo response non-uniformity. Dark frames remove electronic noise introduced by the CCD camera's electronics. Bias frames reduce the dark fixed-pattern noise of the CCD image sensor ("hot pixels").



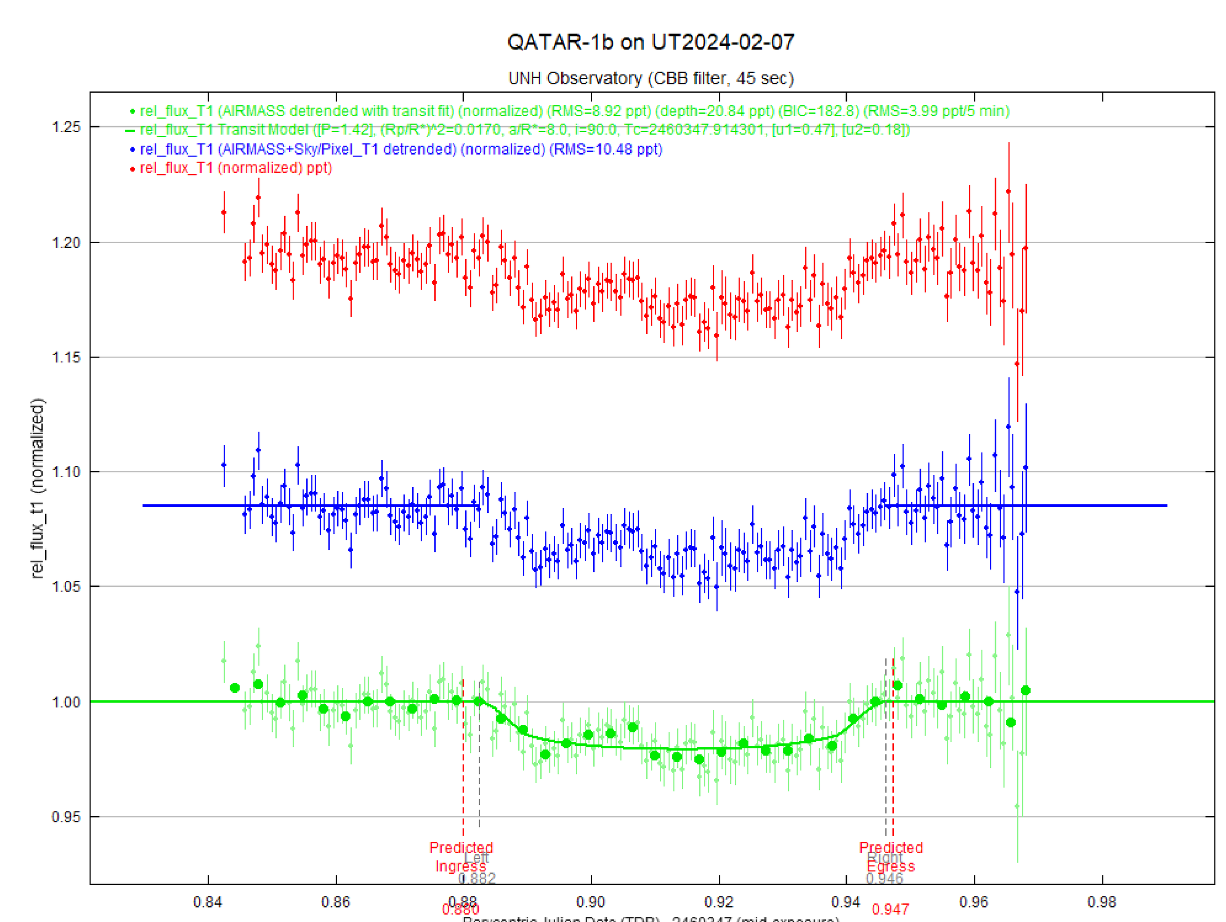


Fig. 3: Transit observation of QATAR-1b taken on February 7, 2024

Results				
	WASP-43b		**QATAR-1b**	
Planetary Parameter	Observed	Predicted	Observed	Predicted
Mid Transit Time (BJD_TDB)	2460401.578799	2460401.579833	2460347.914659	2460347.914791
Transit Depth (mag)	0.02595	0.0289	0.02061	0.0204
Transit Duration (min)	76.15	69.5	91.517	96.7
Radius (R_{Jup})	0.97	0.93	1.02	1.294
Semi-Major Axis (a/R_*)	4.861	4.867	7.893	6.247

Table 2: Observed planetary parameters with their predicted counterparts are displayed. Transit depth, duration, and mid point were taken from ETD. Radius and semi-major axis were taken from data submitted to NASA's exoplanet archive (See References).

Data Analysis

All plotted data has been normalized and arbitrarily shifted for viewability. The red plot is raw data with no detrend parameters applied. Detrend parameters are aspects of observational conditions that can affect data collection. The blue plot is detrended data with air mass as the parameter. Baseline magnitude of the target star was determined by applying a linear fit to the pre-ingress and post-egress portions of the observation. The green plot shows the detrended data with a transit model fit and it's from this model fit that all observed planetary parameters were calculated from (see table 2). Unfortunately, due to poor weather and multiple instances of complete tracking failure, the number of observable transits was greatly reduced.

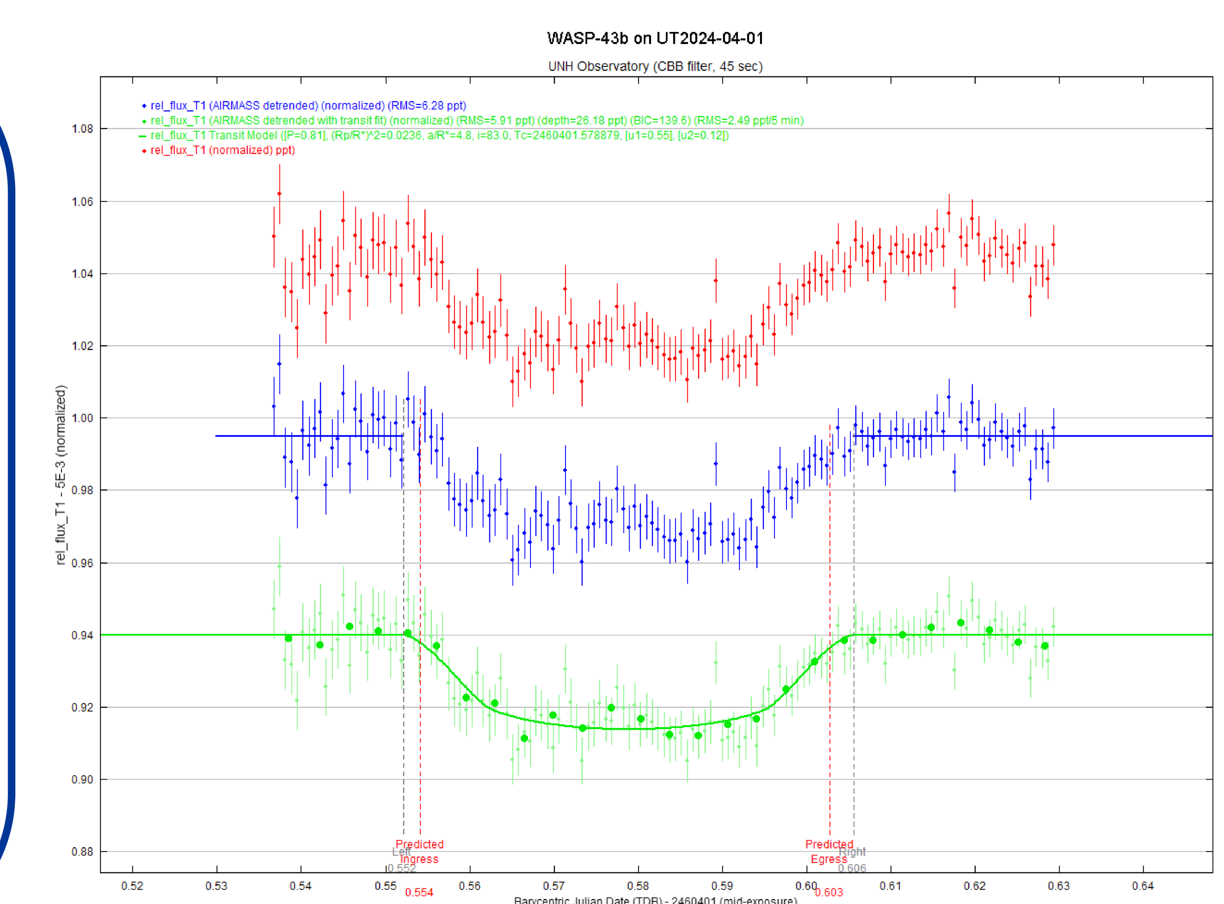


Fig. 3: Transit observation of WASP-43b taken on April 1, 2024

Future Plans

I intend to submit my observations to the AAVSO and ETD databases to allow my data to be used in the professional community. I also intend to further my analysis of these exoplanets by utilizing previous data uploaded to ETD and AAVSO. Having mid transit time measurements that span a long period of time will allow for better detection of TTVs. Models for the different causes of TTVs can then be fit to this data to determine the source of the orbital variations.

References

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