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Research Article

The Transiting Exoplanet HAT-P-37b from the Magnificent Parallel

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Abstract

We present new transit photometry of the exoplanet HAT-P-37b, a hot Jupiter orbiting a G-type star 410 pc away, to obtain the planet's radius, orbital semi-major axis and orbital inclination. The data, collected at the ParMagnus Observatory in the El Paso (USA)-Juárez (México) Magnificent Parallel region, are part of the first differential photometry study by this recently founded suburban astronomical observatory, which in this work provides evidence of the technical capability and photometric resolution possible with medium-sized telescopes and CCD/CMOS cameras, through follow-up observations, to confirm and characterize exoplanets via the photometric transit method. Using AstroImageJ (AIJ), our results for the radius of the exoplanet HAT-P-37b (R_p= 1.02 R_{Jup}), its orbital semi-major axis (a/Rs=10.55) and orbital inclination (89.99°) are consistent with those in the literature.

Keywords: Extrasolar planets; hot jupiters; HAT-P-37b; transit photometry

Introduction

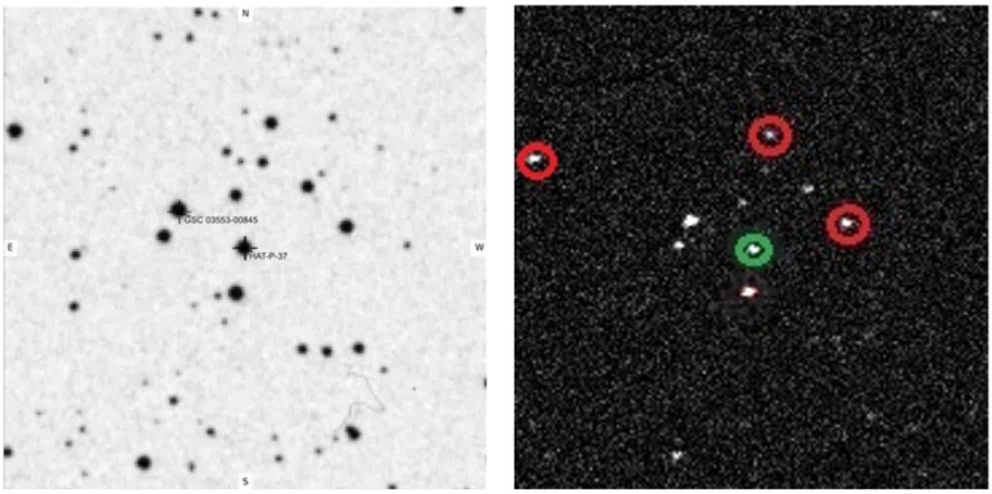
Given the natural observational limitations for detecting planets beyond our solar system, remote, unresolved, outshined by the stars they orbit even through the eyes of our best ground-based and space telescopes, the transit photometry method is the most successful observational approach to date to indirectly discover planets orbiting stars other than the Sun. It is the observed dip in the light curve of the host star that reveals a transiting planet in front of it, as the inclination of the planet's orbit makes it cross our line of sight to its star. The transit method was first applied by Charbonneau et al. [1] to successfully confirm the known planet HD 209458 b's passage in front of its star, in the same lustrum when the radial velocity (Doppler) technique had been the standard approach to discover the very first extrasolar worlds known orbiting normal, main sequence stars such as 51 Peg b [2] and 70 Vir b [3]. But it was in the 2010's when the transit method reached its climax as a robust tool of discovery with NASA's Kepler and K2 missions, whose confirmed number of new exoplanets discovered from photometric transit events is now greater than 3300 [4]. Nowadays, the Transiting Exoplanet Survey Satellite (TESS) picks up Kepler's baton searching the galaxy for new exoplanets by means of the transit method. In this work we present transit photometry of the HAT-P-37 extrasolar system, the first differential photometry study performed by the ParMagnus Observatory, which provided us with an excellent opportunity to test the technical capabilities and photometric resolution of our 12-inch telescope/CMOS camera setup, especially with the goal of confirming and characterizing new exoplanets by means of the transit method. Our follow-up observations of HAT-P-37 confirmed the presence of a planet in orbit about this star, originally discovered in 2012 from the dip in the resulting light curve, being AstroImageJ (AIJ) [5] the image reduction and analysis software package we used for processing, calibrating and analyzing the new photometric data of this work. Based on AIJ's model fit, our results for the radius, the orbital semi-major axis and orbital inclination of the exoplanet around HAT-P-37 are consistent with those in the literature.

Observatory and Photometry Setup

The ParMagnus Observatory is a privately-owned, privately-funded, small suburban astronomical observatory in the USA-México (El Paso-Juárez) Borderplex region (the *Magnificent Parallel*). ParMagnus is an acronym for *Parallelus Magnificus*, the author's astronomy project at the University of Texas at El Paso (UTEP) Physics Department. Our observatory currently includes a fork-mounted Meade LX-600 ACF 12-inch telescope, a QHY183M CMOS camera (with a Sony IMX183 back illuminated sensor) and two SLOAN photometric filters (g' and i'), although we clarify that the photometry of the HAT-P-37 system presented here was performed without a filter. Also, due to initial technical difficulties with the telescope's off-axis guider (OAG) for precise tracking (that becomes crucial in transit photometry), it was LX600's own guider instead, Starlock, that efficiently tracked the target star during the first round of observations and photometric data presented here. Starlock's performance was so good at guiding the telescope that only small adjustments were necessary to align, with the AIJ tools, the final stack of FITS images obtained.

Photometry of the HAT-P-37 System

HAT-P-37 is a G-type star 410 parsecs away in constellation Draco (RA_{2000} 18:57:11, Dec_{2000} +51:16:09) with an apparent magnitude of V=13.2 and a mass of 0.93 MSun (Figure 1). Using the transit method [6] discovered a planet with a mass equivalent to 1.17 M_{Jup} completing an orbit about this star in P=2.79 days, a hot Jupiter. This astronomical source became the 37th star of the Hungarian Automated Telescope Network (HATNet) survey discovered to have a planetary companion. Follow-up observations [7] have contributed to a better characterization of the basic physical parameters of the hot Jupiter HAT-P-37b.



a b

Figure 1: a) Star map (5' x 5') showing HAT-P-37's location in constellation Draco (RA2000 18:57:11, Dec2000 +51:16:09). Next to it, in the same star field of interest for this work, the source GSC 03553-00845, a W Uma variable. Courtesy of the AAVSO. b) FITS image from our data showing the same 5' x 5' star field including our target star, HAT-P-37 (green circle), and the three comparison stars (red circles) used to perform the differential photometry.

On Aug. 5, 2023, based on Swarthmore's Exoplanet Transit Finder [8], we found an open time window to observe HAT-P-37 and apply the transit photometry method to indirectly confirm its hot Jupiter. The experience would also allow us to test the photometric capabilities of the equipment in our recently founded astronomical observatory. HAT-P-37 was tracked for five hours that night by the LX-600 telescope with the CMOS camera at -10°C, a long-enough time interval to be able to capture, in that single observing session, the full transit of the hot Jupiter across its host star; i.e., our goal was to determine, as accurately as possible, the precise timing of the planet's ingress and egress on the star's light curve, the two points defining the beginning and end of the transit, respectively. This would allow us to calculate the (a/R_s) ratio, from which the semi-major axis of the planet's orbit is determined. Short-exposure, unfiltered 9-second images were continuously taken of the star field including the target star HAT-P-37 and the three comparison stars selected to perform the differential photometry. Figure 2 shows the original, calibrated, unphased light curve obtained from our photometric data of the HAT-P-37 star, after the corresponding image reduction/calibration process with AstroImageJ. A full transit of the hot Jupiter was captured, and the observed ingress/egress times were compared to those predicted after the light curve fitting process. Most importantly in this work, we could estimate the planet's radius from the transit's depth on the curve by means of the transit analysis routines and model fit in AstroImageJ.

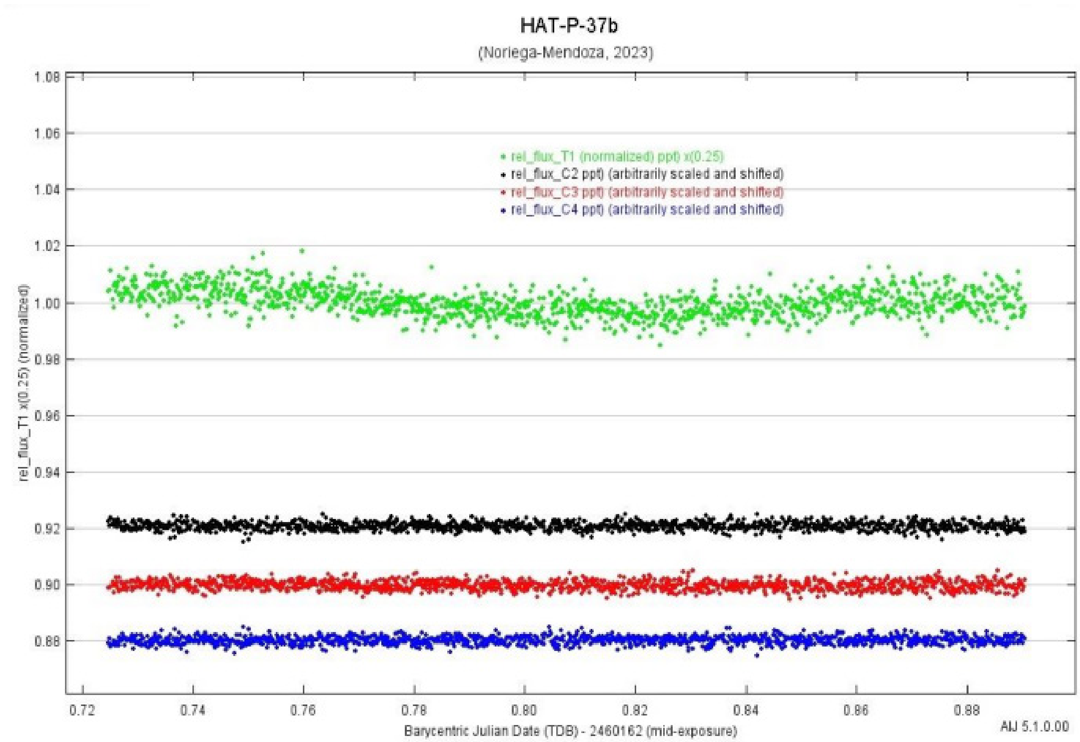


Figure 2: Calibrated, unphased light curve of HAT-P-37 obtained from photometric data collected on Aug. 5 2023 at the ParMagnus Observatory, revealing the transit of a hot Jupiter (dotted green band). Relative flux (T1, vertical axis) is plotted versus Barycenter Julian Date (TDB, horizontal axis). As a reference, flat light curves corresponding to three comparison stars in the field are displayed as well.

A Planet Slightly Bigger than Jupiter

In order to estimate the size of the orbiting world about HAT-P-37, we used the AstroImageJ (AIJ) software package. AIJ was introduced by Collins et al. in 2017 [5] as a powerful, resourceful tool to calibrate and analyze astronomical images and photometric data. It has also been the natural choice for data reduction and analysis in transit method-based exoplanet surveys such as that of the Transiting Exoplanet Survey Satellite (TESS), as well as the one by its follow-up initiative with ground-based telescopes, the TESS Followup Observing Program (TFOP). Table 1 shows the physical parameters that, together with the calibrated photometry and the observed light curve of the host star, are required to get a reliable model fit to our data in AIJ, resulting in a good estimate of the planet's radius (size) from the transit's depth. Among such parameters are the star's spectral type (to estimate in turn the star's size) and the linear and quadratic limb darkening coefficients, obtained from the literature [9] and from the EXOFAST quadratic limb darkening calculator [10].

Table 1: HAT-P-37 parameters adopted from the literature and EXOFAST to perform a model fit to the photometric data and the star's light curve with AstroImageJ.

HAT-P-37 parameter	Adopted value in the AstroImageJ model fit
Surface temperature (spectral type)	5429 K [9]
Radius	0.88 RSun [9]
Linear limb darkening coefficient (u1)	0.5242636 [10]
Quadratic limb darkening coefficient (u2)	0.2181136 [10]

Fundamentally, the transit method allows us to calculate the radius of a transiting planet from the fact that the light flux (ΔF) being blocked by the planet, as it crosses in front of its host star, scales with the square of the ratio of the planet's radius (Rp) over the star's radius (Rs). ΔF is the measurable dip in light obtained directly from the star's light curve, such that

$$\Delta F = \left(\frac{Rp}{Rs}\right)^2$$

One of the key elements in the analysis of the photometric data and the star's light curve, is an accurate determination of the ingress and egress times of the transiting planet in front of its host star. Based on the Exoplanet Transit Finder [8] for the night of Aug 5, 2023, the HAT-P-37b hot Jupiter would be transiting its star during the time interval defined by [2060162.7623, 2060162.8593] BJD (Barycentric Julian Day). We used these ingress and egress times in AstroImageJ's transit model fit, as well as a series of parameters shown in Figure 3 - AIJ's Data Set Fittings Screen-, particularly the specific AIRMASS determined by AIJ for our observing location, to estimate the system's (a/R_s), the inclination of the planet's orbit and $(Rp/R_s)^2$. AIRMASS is the most relevant detrend parameter recommended by Conti [11] to minimize the Bayesian Information Criterion (BIC) statistical value in AIJ. BIC is a measure of the goodness of our transit model fit.

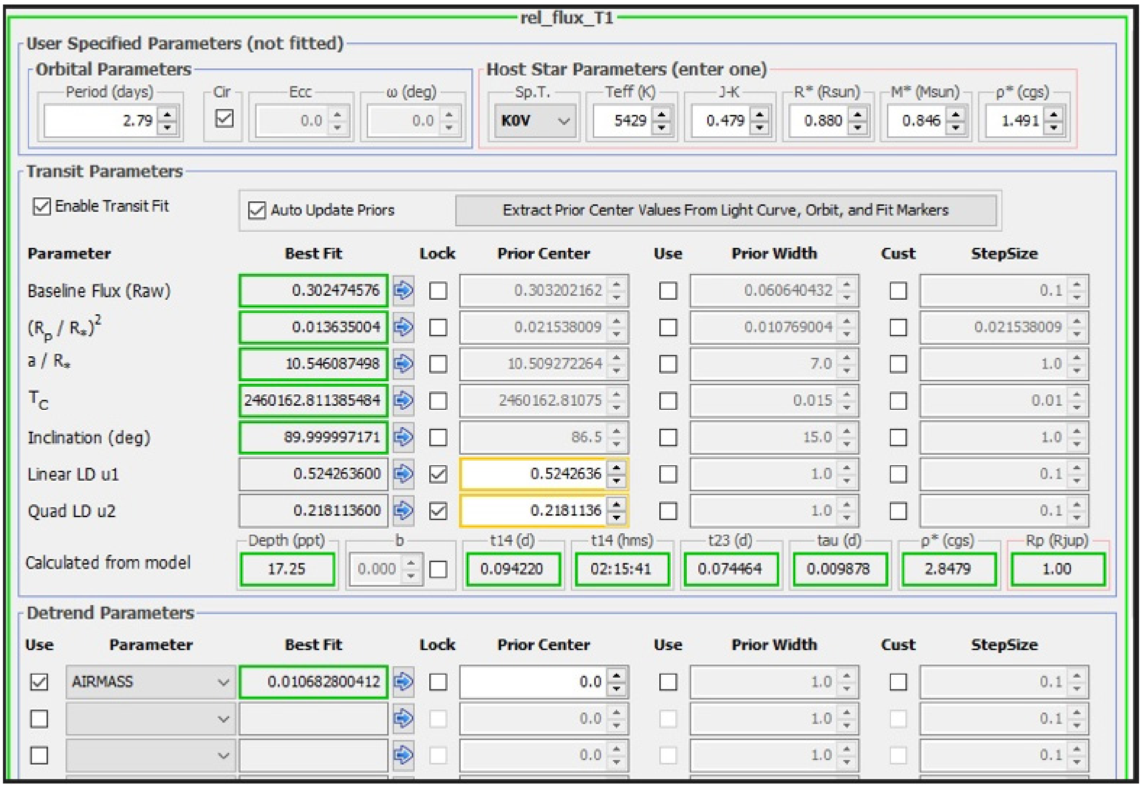


Figure 3: AstroImageJ's Data Set Fittings Screen, showing the parameters employed to perform a statistical model fit to our photometric data of HAT-P-37b's transit: orbital period, the star's surface temperature and radius, and linear and quadratic limb darkening coefficients. The model fit to the observed light curve of HAT-P-37 provides the numerical values of (Rp /Rs)2, (a/Rs) and orbital inclination of the transiting planet.

In Figure 4 the input-averaged, unphased light curve of HAT-P-37 is displayed with a model fit onto the calibrated photometric data. At the bottom, also included, are the (flat) light curves of the three comparison stars used in this work. The transit's depth, clearly shown by the curve fitting to our data with AIJ, in combination with the parameters included in (Table 1) and the above relationship between the planet and the star's radii, provided us with an estimate of $(Rp/R_s)2=0.0136$, which implies that $R_p=1.02\ R_{Jup}$. From Kepler's 3rd law and a reported orbital period of only P=2.79 days [9], this planet 1.02 times bigger than Jupiter is a fast-orbiting body in a close-in trajectory about its host star, in other words, a hot Jupiter.

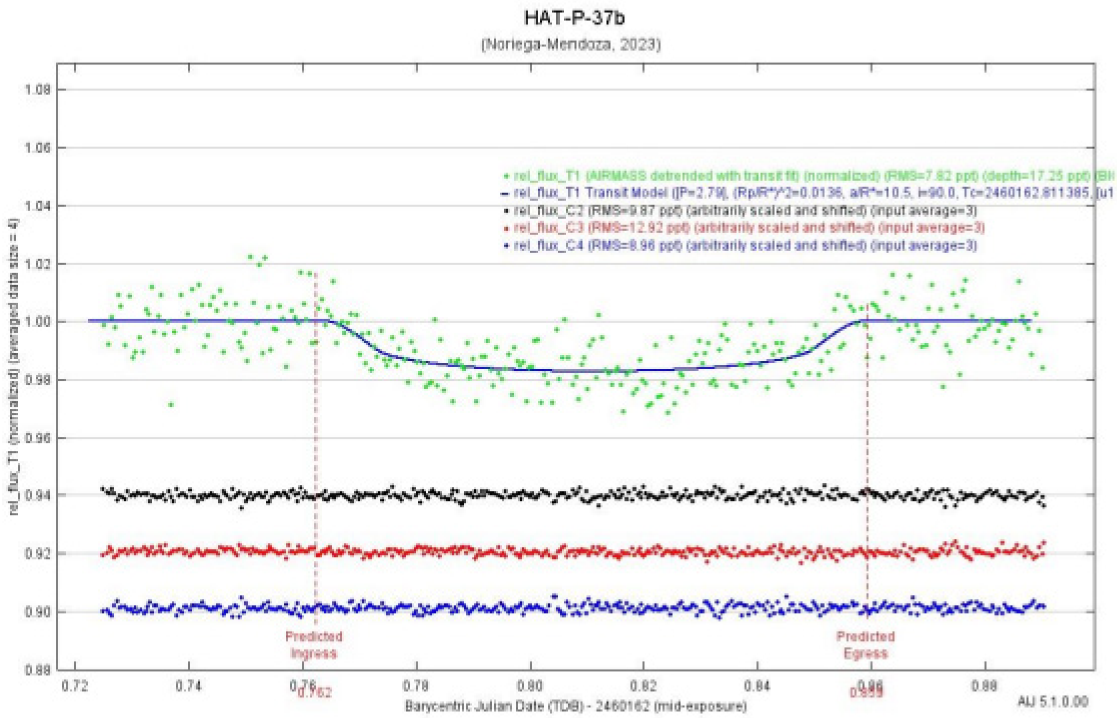


Figure 4: Unphased, input-averaged, calibrated light curve of HAT-P-37 and the corresponding transit model fit with AIJ to the photometric data. Relative flux (T1, vertical axis) is plotted versus Barycenter Julian Date (TDB, horizontal axis). The transit's depth, the star's size and spectral type and the linear and quadratic limb darkening parameters were used to calculate the transiting planet's radius, R_p=1.02 RJup.

The transit photometry data analysis we performed on the HAT-P-37 star with AIJ provided us with specific information on three basic physical parameters of the hot Jupiter HAT-P-37b in orbit about this star: radius (R_p=1.02 R_{Jup}), orbital semi-major axis (a/R_s) =10.55 and orbital inclination (89.99°). Our result for the radius of HAT-P-37b is in better agreement with the one by Bakos et al. [6], who reported Rp=1.178 ±0.077 R_{Jup}., than that by Maciejewski et al. [7], where according to these authors R_p=1.231±0.048 R_{Jup}. Given the fact that this photometric study was based on data collected from the ParMagnus Observatory's suburban location under limited seeing conditions, our results are still consistent with those in the literature. This work provides evidence of the technical capability and photometric resolution possible with medium- sized telescopes and CCD/CMOS cameras, through follow-up observations under limited-seeing conditions from suburban locations, to confirm and characterize exoplanets via the photometric transit method.

Conclusion

Differential photometry was performed of the HAT-P-37 star from data collected with a medium-sized telescope and a CMOS camera at the recently founded, suburban ParMagnus Observatory in the USA- México Borderplex region. The transit method allowed us to confirm the presence of the hot Jupiter HAT- P-37b orbiting this star, first reported by Bakos et al. [6]. Using AstroImageJ (AIJ) to calibrate our data and perform a transit model fit, the radius of this exoplanet was calculated from the star's corresponding light curve, as well as the ratio (a/R_s) that yields the semi-major axis of the planet's orbit. Likewise, we obtained an inclination of the planet's orbit. Our results are consistent with those in the literature.

Acknowledgment

None

Conflicts of interest

No

Data Availability

Data are freely available upon request.

References

1) D Charbonneau, TM Brown, DW Latham, M Mayor (2000) Detection of Planetary Transits Across a Sun-like Star. The Astrophys J 529(1): L45-L48.

2) M Mayor, D Queloz (1995) A Jupiter-mass companion to a solar-type star. Nature 378(6555): 355.

3) GW Marcy & RP Butler (1996) A Planetary Companion to 70 Virginis. Astrophys J 464(2): L147.

4) NASA Exoplanet Archive.

5) KA Collins, JF Kielkopf, KG Stassun, FV Hessman (2017) AstroImageJ: Image Processing and Photometric Extraction for Ultra-precise Astronomical Light Curves. The Astronomical Journal 153(2): 77.

6) GA Bakos, JD Hartman, G Torres, B Béky, DW Latham, et al. (2012) HAT-P-34b-HAT-P-37b: Four Transiting Planets More Massive than Jupiter

Orbiting Moderately Bright Stars. The Astronomical Journal 144(1): 19.

7) G Maciejewski, D Dimitrov, L Mancini, J Southworth, S Ciceri, et al. (2016) New Transit Observations for HAT-P-30b, HAT-P-37b, TrEs-5b, WASP-28b, WASP-36b and WASP-39b. Acta Astronomica 66(1): pp. 55-74.

8) ELN Jensen (2013), Tapir: A web interface for transit/eclipse observability, Astrophysics Source Code Library, record ascl: 1306.007.

9) NASA Exoplanet Archive, NASA Exoplanet Science institute.

10) EXOFAST quadratic limb darkening calculator.

11) DM Conti (2022) A Practical Guide to Exoplanet Observing, Revision 5.2, pp. 48-50.