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# Photometric Observations and Refined System Parameters of the High-Density Gas Giant Hat-P-20 b

## Yüksek Yoğunluklu Gaz Devi HAT-P-20 b'nin Fotometrik Gözlemleri ve İyileştirilmiş Sistem Parametreleri

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**Abstract**

HAT-P-20 b is a dense, hot Jupiter discovered by the HATNet project, orbiting a K-type main-sequence star with high stellar activity. It exhibits an unusually high density (~13.8 g/cm³), a short orbital period (~2.9 days), and a close-in orbit (~0.0361 AU), making it a notable case among similar gas giants. With a mass of ~7.25 $M_J$ and a radius of 0.867 $R_J$, the planet presents key challenges in understanding planetary structure and composition. This study presents a photometric analysis of HAT-P-20 b based on transit observations conducted on January 15, 2017, using the ground-based ADYU60 telescope. Data reduction was performed with AstroImageJ (AIJ), and transit modeling was carried out using EXOFAST. The derived light curve yielded refined system parameters: $M_P = 7.09^{+0.26}_{-0.24}$ $M_J$, $R_P = 0.84 \pm 0.2$ $R_J$, $a = 0.0357 \pm 0.0006\ AU$. These results are in agreement with previous studies within the expected uncertainties. Transit timing analysis was also performed to explore potential variations, yielding a refined minimum transit time of $T_0 = 2457769.357408^{+0.001403}_{-0.001476}$ $BJD_{TDB}$.These findings enhance the structural and dynamical understanding of the HAT-P-20 system and offer valuable input for future investigations of possible additional bodies.

**Keywords:** Stars: planetary systems, Exoplanets, Individual: HAT-P-20, Transit Observations

**Öz**

HAT-P-20 b, HATNet projesi kapsamında keşfedilen ve yüksek yıldız aktivitesine sahip bir K tipi ana kol yıldızının etrafında dolanan yoğun bir sıcak Jüpiter gezegendir. Yaklaşık 13,8 g/cm³ gibi sıra dışı yüksek bir yoğunluğa, kısa bir yörünge periyoduna (~2,9 gün) ve yıldızına yakın (~0,0361 AU) bir yörüngeye sahiptir; bu özellikleriyle benzer gaz devleri arasında dikkat çekmektedir. Yaklaşık 7,25 Jüpiter kütlesinde ve 0,867 Jüpiter yarıçapında olan gezegen, iç yapısına ilişkin önemli soruları gündeme getirmektedir. Bu çalışmada, 15 Ocak 2017 tarihinde yer tabanlı ADYU60 teleskobuyla gerçekleştirilen geçiş gözlemlerine dayalı fotometrik analiz sunulmaktadır. Veri indirgeme işlemleri AstroImageJ (AIJ) yazılımı ile yapılmış, geçiş modellemeleri ise EXOFAST yazılımı kullanılarak gerçekleştirilmiştir. Elde edilen ışık eğrisinden sistemin güncellenmiş parametreleri hesaplanmıştır: $M_P = 7.09^{+0.26}_{-0.24}$ $M_J$, $R_P = 0.84 \pm 0.2$ $R_J$, $a = 0.0357 \pm 0.0006\ AU$. Bu sonuçlar, beklenen belirsizlikler dahilinde önceki çalışmalarla uyumludur. Ayrıca, geçiş zamanlaması analizi yapılarak potansiyel varyasyonlar araştırılmış ve minimum geçiş zamanı $T_0 = 2457769.357408^{+0.001403}_{-0.001476}\ BJD_{TDB}$ olarak belirlenmiştir. Bu bulgular, HAT-P-20 sisteminin yapısal ve dinamik özelliklerinin daha iyi anlaşılmasına katkı sağlamaktadır ve sistemde olası ek cisimlerin araştırılması için değerli veriler sunmaktadır.

**Anahtar Kelimeler:** Yıldızlar: Gezegen Sistemleri, Ötegezegenler, HAT-P-20 sistemi, Geçiş Gözlemi

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## Introduction

Exoplanets are defined as planetary systems orbiting stars outside the Solar System. The first exoplanet was discovered in 1992 around the pulsar PSR B1257+12 (Wolszczan & Frail, 1992), but the real breakthrough in this field occurred with the discovery of 51 Pegasi b in 1995 (Mayor & Queloz, 1995). Since that time, thousands of exoplanets have been discovered, and many of their various physical properties have been studied in detail. The investigation of exoplanets is significant not only for understanding the structure and dynamics of planets but also for identifying potentially habitable environments beyond the Solar System. Various methods have been developed for the discovery of exoplanets. Among these methods, the transit method is one of the most common and successful techniques for exoplanet detection. This method relies on observing how much a planet obscures or dims the light of its host star as it passes in front of it. During the transit event, when a planet passes in front of the star, there is a small yet measurable decrease in the star's brightness. This decrease varies depending on the size of the planet, with larger planets blocking more starlight. Recently, there has been a rapid increase in the discovery rate of exoplanets using the transit method (Huang et al., 2015). The transit method typically consists of several basic stages. First, the star's brightness is continuously monitored. If a repetitive and regular decrease in the star's light is observed, this may indicate that a planet is passing in front of the star. The duration and depth of the light reduction provide information about the planet's size and its distance from the star (Seager, 2010). For example, by analyzing the changes in light during a planet's transit in front of a star, it is possible to calculate the planet's diameter and orbital period. The transit method has achieved significant success, particularly through space-based observation projects such as the Kepler Space Telescope (Borucki et al., 2009). Kepler has proven the efficiency of this method by discovering numerous exoplanets. However, the transit method also has some limitations (Fischer, ExoDetectTech). In particular, planets can only be detected when they transit at specific angles; therefore, if planets are not in the correct plane of the system, they may go undetected. Additionally, the light changes observed during the transit event can be affected by other factors (such as star spots or other astronomical events), complicating detection and analysis processes.

The TTV (Transit Timing Variation) method is a type of transit method used to discover and characterize exoplanets (Agol et al., 2005). This method aims to gather information about the presence of other planets by examining variations in a planet's transit timing, and it is especially effective in multi-planet systems. The TTV method begins with careful documentation of the transits of a planet as it passes in front of its star. These transits are expected to occur within a certain time interval. However, if there are multiple planets in the system, the gravitational interactions between their masses and orbits cause small but measurable changes in the timings of the planets' transits. This phenomenon is known as TTV. For instance, if one planet approaches another, its transit timing may shift forward or backward. Detailed examination of the changes in transit timings can provide insights into the presence of other planets in the system. According to Veras et al. (2011), it is suggested that at least 50 consecutive transit observations are necessary to precisely detect a third body (planet) and its orbit if it is thought to exist in the system. Therefore, precise determination of mid-transit times across numerous events is crucial for detecting both the system's orbital parameters and the presence of additional bodies. The TTV method provides information by evaluating the relationship between the gravitational effects of planets and geometry. Changes in transit timings result from the gravitational influences of planets, and this data can help us learn more about the mass and orbital characteristics of these planets (Agol et al., 2005). The advantages of the TTV method include the ability to detect the presence of other planets in multi-planet systems and to estimate the masses of these planets. Additionally, it offers opportunities to study orbital dynamics, aiding our understanding of the structure of the system. The TTV method has led to the discovery of a large number of exoplanets using data obtained from missions such as the Kepler Space Telescope, and it continues to be an important tool in future exoplanet research with the potential to contribute to the discovery of hidden planets within systems. HAT-P-20 b stands out as an interesting planet discovered in 2010.

This gas giant orbits the K-type main-sequence star HAT-P-20. Recent studies have contributed to our better understanding of its physical and orbital characteristics. HAT-P-20 b has a mass of approximately 7.25 MJ and a radius of 0.867 RJ, making it one of the densest known exoplanets (average density: ~13.8 g/cm$^3$). It orbits very close to its star (0.0361 AU) and completes a revolution in about 2.9 days (Bakos et al., 2010). This study shares the results obtained from transit observation data of the HAT-P-20 exoplanet taken on January 15, 2017, using the ADYU60 telescope. Section 2 provides the characteristics of these observations, as well as the processes of data reduction and modeling for the light curves. In Section 3, the newly obtained system parameters from the modeling results are presented and discussed.

## Observation

The transit observation of HAT-P-20 b was conducted using the ADYU60 telescope, which has a 60 cm diameter primary mirror and is equipped with a high-speed and high-sensitivity 1K x 1K Andor iKon-M 934 CCD camera, at the Adıyaman University Astrophysics Application and Research Center. The details of the observations are given in Table 1. The observation was made on January 15, 2017, using the Johnson R filter with an exposure time of 60 s. The scheduling of the observation times for exoplanet transit was facilitated by the Exoplanet Transit Database (ETD; April 24, 2025). The times listed on the ETD site indicate the start and end times of the transit. Therefore, the observations were made starting earlier and ending later than the durations specified on the ETD to ensure better results for the light curves. Additionally, nights with stable atmospheric conditions and low sky background were selected to maximize data quality.

**Table 1.** Observation Details for HAT-P-20 b Transit on January 15, 2017

| Obs. Date | Obs. Start→End (UT) | Predicted TT (UT) | Filter | Exposure | $N_{obs}$ (Total Frame) | Airmass |
|---|---|---|---|---|---|---|
| **15.01.2017** | 19:00→21:45 | 21:18→23:04 | R | 60 | 156 | 1.19→1.06→1.03 |

*Obs: Observation, TT: Transit Time, UT: Universal Time

## Data Reduction

Calibration, photometry, and detrending were performed using AstroImageJ (AIJ; Collins et al., 2017a). During the data reduction process, bias subtraction and flat field corrections were applied. Three reference stars were used during the data reduction (see Table 2). All selected reference stars were analyzed in the same order for each analysis. During these analyses, the aperture and annulus radii of the target star and the reference stars were determined using the Radial Profile feature of the AIJ program. To minimize modeling residuals during differential photometry (Collins et al., 2017a), a variation of the aperture sizes was allowed, changing by a factor of 1.2 times the FWHM (full-width-half-maximum) value for each image. Detrending was applied to achieve the best modeling for the light curves. The determination of the detrending parameters that yielded the best modeling results was based on changes in the BIC (Bayesian Information Criterion) values from the “Fitting” module of AIJ (Collins et al., 2017b). Among the tested detrending parameters, only "airmass" yielded statistically significant improvements; therefore, it was the sole detrending factor applied in the light curve modeling. Additionally, the time conversions from $JD_{UTC}$ to $BJD_{TDB}$ were performed using AIJ. The light curve and its model with the EXOFAST software (Eastmann et al., 2013) obtained as detailed in the next section are presented in Figure 1.

**Table 2.** Some properties of target and comparison stars for the HAT-P 20 b system

| Source Name | Source type | RAJ2000 | DEJ2000 | K (mag) |
|---|---|---|---|---|
| HAT-P 20 | Target | 111.916469 | +24.336630 | 8.601 |
| TYC 1910-871-1 | Comparison | 111.961697 | +24.318037 | 10.225 |
| 2MASS 07274451+2418097 | Comparison | 111.935496 | +24.302706 | 10.938 |
| 2MASS 07272798+2419213 | Comparison | 111.866586 | +24.322594 | 11.925 |

## Light Curve Analysis

To model the transit light curves of the star-planet system, the EXOFAST program (Eastman et al., 2013) was utilized, which allows the calculation of certain physical parameters of the system and the estimation of their uncertainties. The EXOFAST program **uses** the Markov Chain Monte Carlo (MCMC) method for parameter estimation. The Monte Carlo algorithm generates random values for the parameters iteratively, ensuring that the newly generated values are independent of the previous ones. EXOFAST constructs probabilities that indicate how likely these randomly produced independent parameters are within the data (Eastman et al., 2013).

The radial velocity (RV) data needed to model the HAT-P-20 system were obtained from the work of Bakos et al. (2010). Additionally, some initial values (logg*, Teff, and [Fe/H]) were provided during the EXOFAST modeling. Some of these initial values were used from the literature (Bakos et al., 2010). In modeling with EXOFAST, the orbit of the system was assumed to be circular. The updated system parameters resulting from the modeling and their comparison with literature values are given in Table 3.

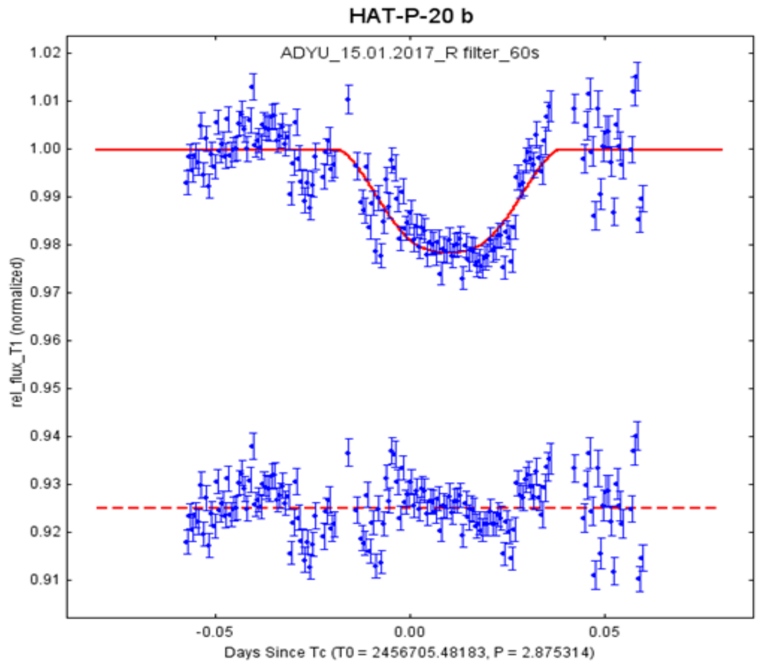


**Figure 1.** Transit light curve of HAT-P-20 b from ADYU60 (top, blue points with error bars) and residuals from the EXOFAST model (bottom, red line).

The mid-transit times required for TTV (Transit Timing Variation) analyses used to detect the presence of a third body in the system and to enhance the precision of the orbital parameters were also determined for the transit light curve obtained in this study. The mid-transit time obtained is given in Table 3.

**Table 3.** HAT-P-20 system parameters from this study compared with Bakos et al. (2010) and Esposito et al. (2017).

| Parameters | Units | This work | Bakos et al. (2011) | Esposito et al. (2017) |
|---|---|---|---|---|
| Stellar Parameters | | | | |
| $M_*$ | Mass ($M_\odot$) | $0.728^{+0.041}_{-0.036}$ | $0.756 \pm 0.028$ | $0.742 \pm 0.042$ |
| $R_*$ | Radius ($R_\odot$) | $0.665^{+0.019}_{-0.018}$ | $0.694 \pm 0.021$ | $0.6796 \pm 0.0054$ |
| $\log g_*$ | Surface gravity (cgs) | $4.655^{+0.015}_{-0.014}$ | $4.450 \pm 0.200$ | $4.643 \pm 0.020$ |
| $\rho_*$ | Density (cgs) | $3.501^{+0.19}_{-0.17}$ | ... | $2.36 \pm 0.16$ |
| Planetary Parameters | | | | |
| $M_P$ | Mass ($M_J$) | $7.095^{+0.266}_{-0.243}$ | $7.246 \pm 0.187$ | $7.22 \pm 0.36$ |
| $R_P$ | Radius ($R_J$) | $0.843^{+0.026}_{-0.025}$ | $0.867 \pm 0.033$ | $1.025 \pm 0.053$ |
| $\log g_P$ | Surface gravity (cgs) | $4.393 \pm 0.018$ | $4.38 \pm 0.03$ | $4.231 \pm 0.019$ |
| $\rho_P$ | Density (cgs) | $14.69^{+1.03}_{-0.98}$ | $13.78 \pm 1.50$ | $8.31 \pm 0.38$ |
| $T_{eq}$ | Equilibrium temperature (K) | $950 \pm 18$ | $970 \pm 23$ | $964 \pm 10$ |
| Orbital Parameters | | | | |
| $P$ | Period (days) | $2.875314 \pm 0.000003$ | $2.875317 \pm 0.000004$ | $2.875316938 \pm 0.00000019$ |
| $a$ | Semi-major axis (AU) | $0.0357^{+0.0007}_{-0.0006}$ | $0.0361 \pm 0.0005$ | $0.03593 \pm 0.00029$ |
| Transit Parameters | | | | |
| $R_P/R_*$ | | $0.1304 \pm 0.0016$ | $0.1284 \pm 0.0016$ | $0.155 \pm 0.010$ |
| $a/R_*$ | | $11.56^{+0.20}_{-0.19}$ | $11.17 \pm 0.29$ | $11.36 \pm 0.25$ |
| $i$ | Inclination (deg) | $86.4^{+0.2}_{-0.1}$ | $86.8 \pm 0.2$ | $86.88 \pm 0.31$ |
| $b$ | Impact parameter | $0.725^{+0.029}_{-0.031}$ | $0.631^{+0.025}_{-0.028}$ | $0.622 \pm 0.059$ |
| $T_{14}$ | Transit duration (days) | $0.0688^{+0.0025}_{-0.0024}$ | $0.0770 \pm 0.0008$ | $0.07900 \pm 0.00052$ |
| $T_0$ | Mid-Transit Time ($BJD_{TDB}$) | $2457769.357408^{+0.001403}_{-0.001476}$ | | |

## Results and Conclusion

The discovery of exoplanets plays a critical role in understanding the structure of the universe and the potential for extraterrestrial life; therefore, detailed studies of planets such as HAT-P-20 b present significant opportunities for the scientific community. In this context, the light curve obtained from ADYU60 was processed using the AIJ program for reduction and differential photometry. It is modeled with the EXOFAST program to update the system parameters of the HAT-P-20 system. The obtained reduced and modeled light curve is given in Figure 1.

The scatter observed in the light curve is may be attributed to the high stellar activity reported by Bakos et al. (2011) and the atmospheric conditions on the nights of observation. Furthermore, it can be seen that the light curve modeling results obtained from EXOFAST are in agreement with the literature.

The updated physical parameters of the system, compared with data from the literature, are presented in Table 3. For HAT-P-20 b, some of these system parameters include $M_P = 7.095^{+0.266}_{-0.243}$, $R_P = 0.843^{+0.026}_{-0.025} R_J$, $a = 0.0357^{+0.0007}_{-0.0006} AU$. A review of these values indicates compatibility within the range of uncertainties when compared with literature values.

The minimum values of the transit times required for TTV (Transit Timing Variation) analysis are shared in Table 3. Further observations will continue in the coming periods with various projects to achieve more precise analyses of the physical and system parameters for this system and to facilitate TTV analyses.

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