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FOUR NEW GROUND-BASED OBSERVATIONS OF THE HOT NEPTUNE-LIKE EXOPLANET TOI-1728b

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Abstract

This paper presents results from four recent photometric observations of the hot Neptune-like exoplanet TOI-1728b conducted at the Meshtitsa Observatory, a private citizen science facility near Pernik, Bulgaria, on December 15 and 29, 2025, and January 12 and 19, 2026. Using a 0.25-m telescope, we captured R-band light curves and performed data reduction, airmass detrending, initial modelling, and outliers inspection via *AstroImageJ*. The ground-based observations were combined with historical *TESS* photometric data and radial velocity measurements. Fitting and analysis were executed using the *Exo-Striker* software applying nested sampling. Our results are consistent with the already known parameters of the planet within the uncertainties. We provide fitted values for the orbital period ($P = 3.491402^{+0.000001}_{-0.000001}\,\mathrm{d}$), transit mid-time ($T_0 = 2458839.7833^{+0.0005}_{-0.0005}\,\mathrm{BJD_{TDB}}$), inclination ($i = 87.13^{+1.83}_{-1.28}{}^{\circ}$), scaled semi-major axis ($a/R_\star = 11.59^{+2.09}_{-1.53}$), and planetary radius ratio ($R_p/R_\star = 0.0685^{+0.0044}_{-0.0042}$). The data consistency confirms the stability of the planet's orbit over the extended baseline and agrees with published values. Our results demonstrate the capability of citizen science observatories to contribute scientifically valuable measurements to exoplanetary research when combined with space-based photometry.

Key words: photometry, exoplanet, TOI-1728b, AstroImageJ, Exo-Striker, citizen science

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1. Introduction. Exoplanets are planets outside the Solar System that orbit distant stars. Because of their great distances, the most widely used and accessible way to study exoplanets is the transit method. When a planet transits its star, a slight dip in the star's brightness is observed (typically from hundredths to thousandths of a magnitude). From the depth and duration of the transit, key parameters of the planet's orbit and physical properties can be derived.

TOI-1728b is a Neptune-sized exoplanet orbiting an M0V dwarf. It was first identified as a transiting planet candidate in *TESS* photometry. The object was subsequently confirmed through ground-based follow-up photometry and precise radial velocity measurements, establishing its planetary nature (see KANODIA et al. [1]). According to MALDONADO et al. [2], along with TOI-442b and TOI-3757b, TOI-1728b represents one of only a small number of close-in gas giants around low-mass stars.

Even when a planet has already been confirmed and its orbital parameters are well known, astronomers continue to monitor it from the ground. Periodic observations contribute to detecting changes in the system, keeping the ephemerides up to date, and offer a way to check for possible transit timing variations (TTVs). Citizen scientists with small telescopes at private observatories can also provide precise and repeatable transit photometry (see ZELLEM et al. [3]). The Meshtitsa Observatory (Bulgaria) is an example of such a private citizen science project that regularly conducts transit observations and reports results to international collaborations and databases such as AAVSO[1], ExoFOP[2], ExoClock[3], and VarAstro[4].

2. Observations. From December 2025 to January 2026, four observations of TOI-1728b were conducted from Meshtitsa Observatory, which we report in this article. Meshtitsa Observatory is a private roll-off-roof backyard astronomical facility near Pernik, Bulgaria. We used a 0.25-m Newtonian reflector with a Baader MPCC Mark III coma corrector and Baader Bessel photometric filter R. The imaging detector was a cooled ZWO ASI533MM Pro monochrome CMOS camera (sensor: $11.31 \times 11.31\,\mathrm{mm}$; 3008×3008 native pixels; pixel size $3.76\,\mu\mathrm{m}$). All time series were acquired using 2×2 binning, corresponding to an image scale of 1.28 arcsec/px and an effective field of view of approximately $32' \times 32'$.

All raw science frames were calibrated following the standard reduction workflow. The times were converted to $\mathrm{BJD}_{\mathrm{TDB}}$ during the calibration process. Master calibration frames were constructed as follows:

- Bias frames: 150 frames with 0 s exposure were median-combined.
- Dark frames: Obtained at the same sensor temperature ($-20\,^{\circ}\mathrm{C}$) and exposure times as the science frames, then median-combined.

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[1] `https://www.aavso.org/exoplanet-section`

[2] `https://exofop.ipac.caltech.edu/tess/`

[3] `https://www.exoclock.space/`

[4] `https://var.astro.cz/`

- Flat fields: Twilight sky flats were acquired in the R band, with exposure times adjusted to maintain mean pixel values near 30 000 ADU. At least 25 flat frames were median-combined into a normalized master flat.

3. Methodology. Differential photometry was performed in *AstroImageJ* (see Collins et al. [4]). The target was TOI-1728 (RA = $08^{\mathrm{h}}02^{\mathrm{m}}26.55^{\mathrm{s}}$, Dec = $+64°47'48.93''$, $V = 12.40$; SIMBAD), and the comparison star was TYC 4129-955-1 (RA = $08^{\mathrm{h}}00^{\mathrm{m}}32.23^{\mathrm{s}}$, Dec = $+64°53'10.21''$, $V = 11.81$; SIMBAD). Aperture radii were selected based on the measured FWHM of stellar profiles for each frame (Table 1), typically ranging between 4–8 pixels depending on the seeing conditions and exposure used (1.28 arcsec/pixel scale with 2×2 binning). The sky background was measured using an annulus with inner and outer radii chosen to avoid contamination from nearby sources.

Table 1

Summary of seeing and photometric-aperture parameters for the observing runs

Date	FWHM (px)	Aperture radius (px)	Estimated PSF (arcsec)	Average airmass	Exp. (s)	Duration (min)	Frames
15 Dec 2025	2.58	5	3.3	1.2471	40	235	301
29 Dec 2025	4.09	8	5.2	1.2885	60	252	213
12 Jan 2026	3.05	4	2.5	1.2375	40	224	106
19 Jan 2026	3.99	8	5.1	1.2051	60	233	154

The individual transit light curves were modelled using the built-in fitting routines in *AstroImageJ*. Airmass-based detrending was applied to correct for atmospheric extinction. The light curves were inspected for outliers. The quality of each fit was assessed via the reduced chi-square statistic (χ^2/dof).

To fit all available transit time-series simultaneously, we used the *Exo-Striker* (see Trifonov [5]). In addition to the four transit observations from Meshtitsa, we incorporated *TESS* photometric data from three sectors: Sector 20 (2019-12-24 to 2020-01-21, 28d), Sector 47 (2021-12-30 to 2022-01-28, 29d), and Sector 74 (2024-01-03 to 2024-01-30, 27d), retrieved from the Mikulski Archive for Space Telescopes [6]. Normalized differential photometry from each ground-based observing night, already corrected for airmass in *AstroImageJ*, was used for joint modelling alongside *TESS* long-cadence light curves. In addition to the photometric data, we incorporated 30 radial velocity measurements, as reported by Kanodia et al. [1]. These RV observations span from 2019 to 2020 and were used to constrain the orbital parameters during the joint fit.

The fitted parameters included the orbital period (P), transit mid-time (T_0), planet-to-star radius ratio ($R_p/R_\star$), semi-major axis ($a/R_\star$), and orbital inclination (i). The stellar radius $R_\star = 0.6243\,R_\odot$ (Kanodia et al. [1]) was held fixed throughout the fit and was used to convert the fitted radius ratio into an absolute planetary radius. The RV data provide additional constraints on the orbital parameters and help break degeneracies in the transit-only fit. In *Exo-Striker*, before fitting the transit model, we computed a periodogram on the combined time-series to obtain the orbital period. We then set uniform priors on the fitted parameters. A nested sampling algorithm was employed to explore the parameter space and derive posterior probability distributions.

4. Results. The four light curves of TOI-1728b, shown in Fig. 1, reveal a consistent and well-defined transit profile. By plotting the airmass-detrended, normalized flux against $\mathrm{BJD_{TDB}}$ in *AstroImageJ*, we find that the transit morphology remains stable across all observed events. Here and throughout, photometric scatter is reported in units of parts per thousand (ppt; $1\,\mathrm{ppt} = 10^{-3}$ relative flux). Averaged over the four events (2025 December 15, 29, and 2026 January 12, 19), we obtain a mean transit depth of 5.41 ppt, a mean total transit duration of

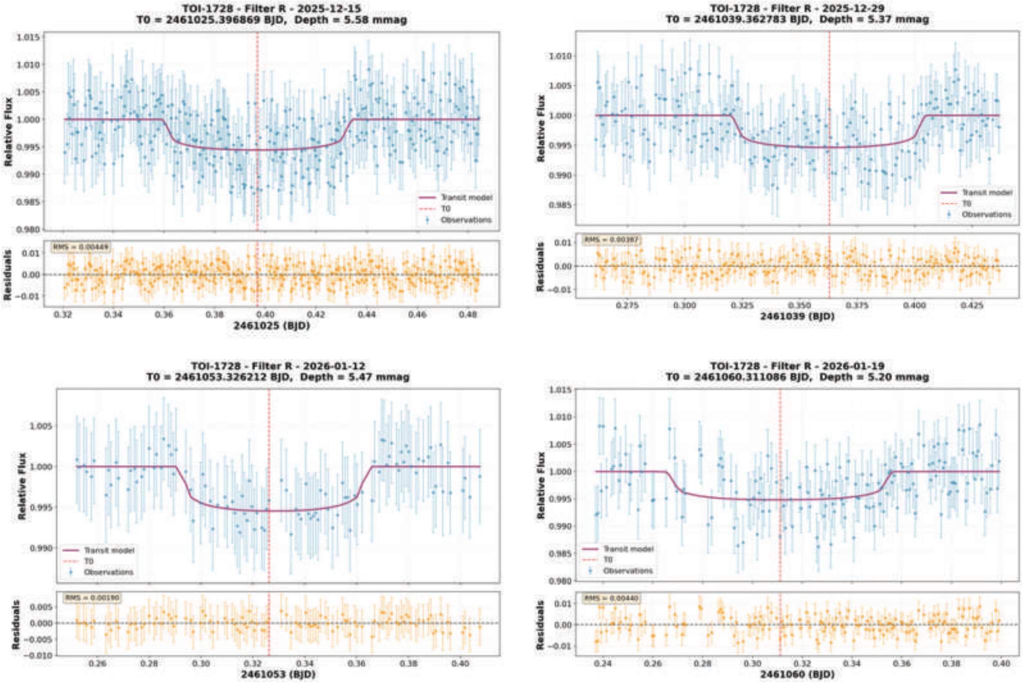

Fig. 1. Individual transit light curves of TOI-1728b from four observing nights at Meshtitsa (2025 December 15, 29, and 2026 January 12, 19) showing normalized relative flux with airmass-detrended best fit from *AstroImageJ*. Blue data points represent individual photometric measurements with error bars, while the solid magenta curve shows the best-fit transit model. Lower subpanels show fit residuals (O-C)

$t_{14} = 0.082\,\text{d}$ (1 h 58 m), and a mean photometric RMS of 3.66 ppt. The statistical quality of these fits is evidenced by a mean reduced chi-square of $\chi^2/\text{dof} = 0.62$. Despite varying observing conditions across the four nights, our results confirm both the internal consistency of our modelling and the stability of the transit geometry over the monitoring baseline.

We performed a simultaneous fit to all available transit observations using nested sampling implemented into the *Exo-Striker* (Trifonov [5]). The dataset combines 774 R-band measurements from four ground-based observing nights (2025 December 15, 29, and 2026 January 12, 19) with *TESS* photometry from Sectors 20, 47, and 74 spanning 2019–2024, along with 30 radial velocity measurements from Kanodia et al. [1]. Figure 2 shows the phase-folded light curve with the best-fit transit model. The residuals show no systematic trends.

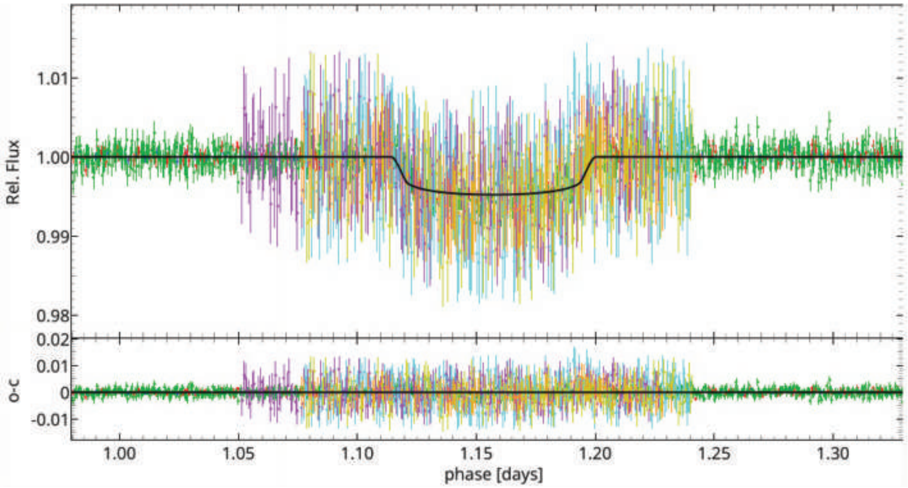

Fig. 2. Phase-folded transit light curve of TOI-1728b combining four R-band observations from Meshtitsa with *TESS* photometric data from Sectors 20, 47, and 74. The black curve shows the best fit derived from nested sampling in *Exo-Striker*. The lower panel displays the fit residuals (O-C). The *TESS* space-based data have noticeably smaller error bars reflecting their high photometric precision. The Meshtitsa ground-based nights are colour-coded: cyan (2025 December 15), purple (2025 December 29), orange (2026 January 12), and yellow (2026 January 19)

Our fitted parameters are summarized in Table 2 in comparison with the literature. The orbital period is $P = 3.491402^{+0.000001}_{-0.000001}$ d, the transit mid-time is $T_0 = 2458839.7833^{+0.0005}_{-0.0005}\,\text{BJD}_{\text{TDB}}$, the orbital inclination is $i = 87.13^{+1.83\circ}_{-1.28}$, the scaled semi-major axis is $a/R_\star = 11.59^{+2.09}_{-1.53}$, and the planet-to-star radius ratio is $R_p/R_\star = 0.0685^{+0.0044}_{-0.0042}$. Our orbital period determination is in excellent agreement with the recent ephemeris update by KOKORI et al. [7], who reported $P = 3.491405 \pm 0.0000035$ d.

5. Conclusion. We present four transit observations of the hot Neptune TOI-1728b obtained with a 0.25-m telescope at Meshtitsa Observatory between

Table 2

Fitted system parameters of TOI-1728b from joint modelling of four ground-based transits (Meshtitsa Observatory, R-band), space-based photometry (*TESS* Sectors 20, 47, 74), and radial velocity measurements compared with literature values

Parameter	This work	Literature	Unit
Period, P	$3.491402^{+0.000001}_{-0.000001}$	3.491405 ± 0.0000035[a]	days
Transit mid-time, T_0	$2458839.7833^{+0.0005}_{-0.0005}$	$2459087.67385 \pm 0.00032$[a]	$\mathrm{BJD_{TDB}}$
Orbital inclination, i	$87.13^{+1.83}_{-1.28}$	$88.31^{+0.58}_{-0.40}$[b]	degrees
Scaled semi-major axis, $a/R_\star$	$11.59^{+2.09}_{-1.53}$	13.48 ± 0.20[b]	—
Radius ratio, $R_p/R_\star$	$0.0685^{+0.0044}_{-0.0042}$	0.074 ± 0.002[b]	—
Planetary radius, R_p	$4.66^{+0.31}_{-0.29}$	$5.05^{+0.17}_{-0.16}$[b]	$R_\oplus$

[a] Kokori et al. [7]; [b] Kanodia et al. [1]

December 2025 and January 2026. These ground-based observations were combined with *TESS* photometric data from three sectors (Sectors 20, 47, and 74) and 30 radial velocity measurements reported by Kanodia et al. [1]. Analysis of the combined dataset using nested sampling in *Exo-Striker* yielded system parameters in excellent agreement with published values, with no significant transit timing variations detected over the 2019–2026 baseline.

Our results demonstrate the effectiveness of the *AstroImageJ* and *Exo-Striker* pipeline for processing and analyzing ground-based transit photometry from small observatories. The combination of data reduction in AIJ with robust statistical fitting via nested sampling in *Exo-Striker*, enhanced by space-based photometry, enables citizen scientists to contribute scientifically valuable measurements to the global exoplanet research effort.

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Data availability. The *TESS* photometric data used in this work were obtained from the Mikulski Archive for Space Telescopes [6] at `https://archive.stsci.edu`. The ground-based photometric data from Meshtitsa Observatory are publicly available through the AAVSO Exoplanet Database (see Appendix A for direct links). The radial velocity measurements used in this work were obtained from Kanodia et al. [1] and are available in the published article.

Appendix A: Meshtitsa observational data. The photometric data from the four transit observations of TOI-1728b conducted at Meshtitsa Observatory between December 2025 and January 2026 are publicly available through the AAVSO Exoplanet Database (ExoSite) at the following links:

1. 2025-12-15 observation (R filter):
   `https://apps.aavso.org/exosite/d/14966`
2. 2025-12-29 observation (R filter):
   `https://apps.aavso.org/exosite/d/14967`
3. 2026-01-12 observation (R filter):
   `https://apps.aavso.org/exosite/d/14968`
4. 2026-01-19 observation (R filter):
   `https://apps.aavso.org/exosite/d/14988`

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