

TOI-3905 b: Statistical Confirmation and Characterization of a Hot Super-Jupiter with Citizen Scientists

Abstract We report on the confirmation of TOI-3905 b—the first planet in the TOI-3905 system. The analysis of ground-based and TESS data is consistent with a hot super-Jovian exoplanet with a radius of $R_p = 3.176 \pm 0.018 R_J$, and an orbital period of $P = 5.359959 \pm 0.000012$ days with a semi-major axis of $a = 0.060527 \pm 0.000114$ au. Our joint fit analysis, comparing transit data from space-based observations and citizen science contributions, demonstrates that including data from citizen scientists enhances the results compared to using space-based data alone.

1. Introduction

As of September 2025, the NASA Exoplanet Archive (NEA) had a collection of more than 6000 confirmed exoplanets.¹ Of these, nearly 319 of them are characterized as hot Jupiters (NASA Exoplanet Archive 2025) classified as having a typical mass $\geq 0.25 M_J$, and an orbital period of $P \leq 10$ days (Dawson & Johnson 2018). These planets were commonly found through the previous campaigns of *Kepler* (Borucki et al. 2010) and *K2* (Howell et al. 2014), while currently, the most prolific observatory for finding hot Jupiters is the *Transiting Exoplanet Survey Satellite* (TESS; Ricker et al. (2014) with 83 confirmed hot Jupiters.² The MIT Quick-Look Pipeline (QLP; Huang et al. 2020; Kunimoto et al. 2021) first identified the hot Jupiter candidate in Sectors 22 and 23 (Kunimoto et al. 2022).

Confirmation of exoplanets through photometric transit observations has sometimes been made with the help of citizen scientists, as in the cases of HD 17156 b (Barbieri et al. 2007), TOI 6883-Ab (Conzo & Moriconi 2024; Sgro et al. 2024; Conzo et al. 2025), TOI-4465 b (Essack et al. 2025), and many others. Organizations which help citizen scientists contribute to the discovery and confirmation of exoplanets include Exoplanet Watch (Zellem et al. 2020),³ the Unistellar Network (O’Conner Peluso et al. 2023),⁴ and ExoClock (Kokori et al. 2022a, 2022b, 2023).⁵

In this work, we present the statistical confirmation of TOI-3905 b, with a period of $P = 5.359959 \pm 0.000012$ days, $R_p = 3.176 \pm 0.018 R_J$, through a citizen scientist ground-based telescope network and the TESS satellite. We identified additional transit signatures for TOI-3905 b in Sector 49 and 76 of TESS via the *Lightcurve* (Lightcurve Collaboration et al. 2018) package and lastly through the TESS Science Processing Operations Center (TESS-SPOC) with their Data Validation (DV) report (Caldwell et al. 2020). In 2025, follow-up observations from a network of citizen scientists and amateur astronomers confirmed the existence of this planet.

2. Observations

This study uses observations of TOI-3905 taken by *GAIA* DR2 and DR3 releases (Gaia Collaboration et al. 2018, 2022), TESS (Section 2.1), and ground-based telescopes (Section 2.2), some of which included speckle imagery.

2.1 TESS observations

As exoplanet transits consistent with $R_p = 2 R_J$, like TOI-3905 b, the transit could instead be an eclipsing binaries; the SPOC-DV report from Sector 49⁶ was crucial to allow us to utilize the tests and provide evidence to hinder the claim of TOI-3905 b not

being an eclipsing binary (Figure 1).

We employed the odd and even eclipsing binary discrimination test (Twicken et al. 2018), used to determine the depth significance of the odd and even transits around the star, to test for the possibility of an eclipsing binary. This test must occur under the circumstances that the eclipsing binary system is circular, and if there is a single planet, as near-resonance orbital periods will cause the test to be invalid. After this first model fits, the model subsequently fits on the odd and even transits. Additionally, the ASAS-SN database (Shappee et al. 2014; Kochanek et al. 2017) and the Re-normalized Unit Weight Error (RUWE; Castro-Ginnard et al. 2024; Lindegren 2018; Pearce 2022) did not flag this system to include a possible binary. The resulting fits must be statistically distinguishable from the initial model (Figure 2) to confirm an eclipsing binary (see Figure 9; Twicken et al. 2018). While we found no statistically significant deviation in the odd and even test, TOI-3905 is a confirmed rotationally modulated (ROT) variable star (Gaia Collaboration 2022), and such variability could potentially contribute to a false negative.

We completed two false-positive diagnostic tests: the secondary eclipse test and the Multiple Event Statistic (MES) test. The secondary transit from the SPOC-DV report for TOI-3905 b is shown in Figure 3. An important caveat is that secondary transits can be less significant in the optical than in the infrared (Deming et al. 2018). TOI-3905 b has an MES value of 2.9σ consistent with a planetary transit (Twicken et al. 2018).

2.2 Ground-based observations

We conducted eight ground-based observations starting in January of 2025 lasting until May of 2025 (Table 1) with an additional observation for speckle interferometry from the Gemini 8.1m observatory through the Exoplanet Follow-up Observing Program (ExoFop; Akeson & Christiansen 2019).

Since the 1970s (Labeyrie 1970), speckle interferometry has been used for different purposes, and recently this method has been used to confirm eclipsing binaries (Howell et al. 2025). TOI-3905 was viewed via this method with the Gemini North 8.1m Observatory (‘Alopec’ on the 21st of March 2024 at 562nm and the 832nm wavelengths (Figure 4). No companion was evident.

3. Analysis

Analyzing Sector 49 data with the *Lightcurve* script recovered a mid-transit value of $T_0 = 2459642.711865256$ BJD_{TDB}.

¹ <https://exoplanetarchive.ipac.caltech.edu/>

² As of September 13, 2025, at 06:00 UTC

³ <https://exoplanets.nasa.gov/exoplanet-watch>

⁴ <https://science.unistellar.com/>

⁵ <https://www.exoclock.space/>

⁶ [TOI 3905 Sector 49 SPOC Full Data Validation Report](#)

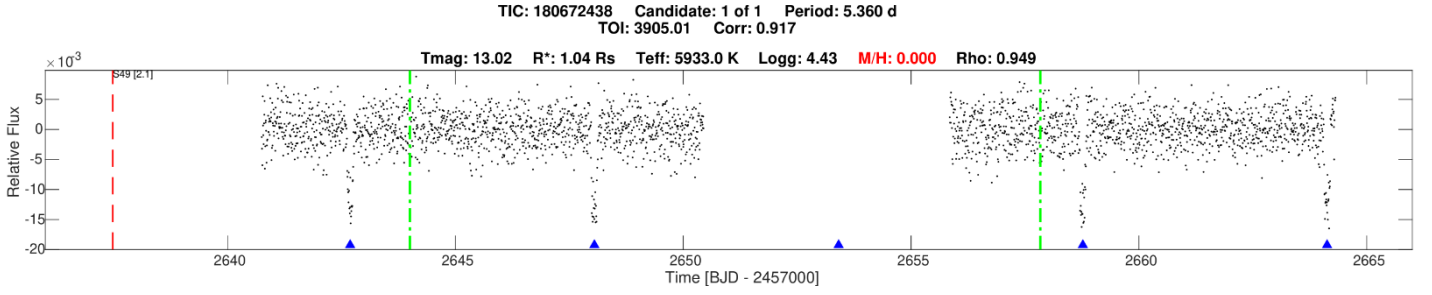


Figure 1. Sector 49 light curve from the TESS-SPOC DV Report. Each black dot is raw data. The vertical red dashed line is the beginning of the sector. Each gap is the satellite downlink. Each blue triangle at the bottom of the figure represents the expected arrival time of the transit. Each vertical green dashed link is where these momentum dumps from TESS occur.

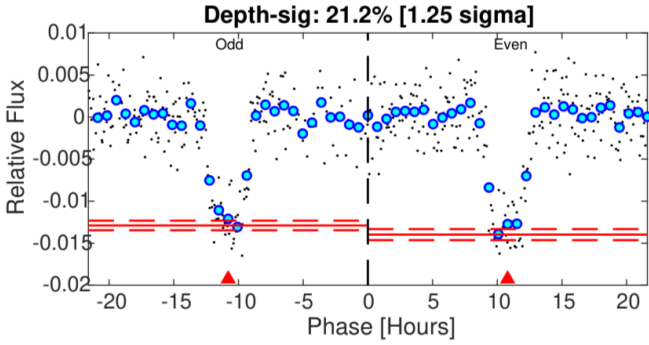


Figure 2. The relative flux versus orbital phase in hours for the odd and even numbered transits of TOI-3905 b. Detrended flux values are plotted in black. Binned and averaged flux values are displayed in cyan. The event depth in each case is marked with a solid red line and the relatively small 1σ uncertainties are marked with dashed red lines.

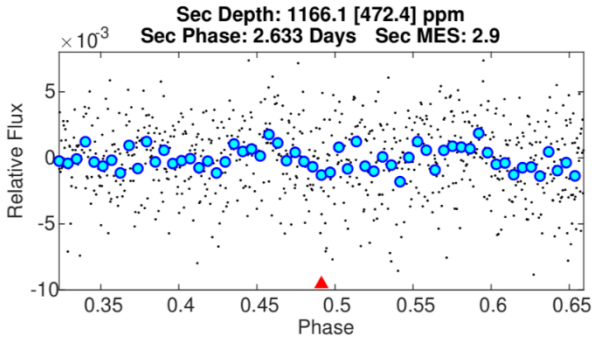


Figure 3. The secondary eclipse of the exoplanet TOI-3905 b through TESS data. Each black dot is the raw data, while each blue dot is a 1/5 binning of the raw data.

This mid-transit value was used to predict subsequent transits but with increasing time elapsed, the ephemeris of a transiting planet can become increasingly outdated (see Section 2.1; Zellem et al. 2020). Due to the uncertainty of the mid-transit value, a “stale” ephemeris was evident in the analysis of our initial photometric campaign on January 18, 2025. Updating the ephemeris after the initial campaign resulted in improved transit timing for the subsequent observations.

Analyzing Sector 49 data with the *Lightkurve* script recovered a mid-transit value of $T_0 = 2459642.711865256$ BJD_{TDB}. This mid-transit value was used to predict subsequent transits but with increasing time elapsed, the ephemeris of a transiting planet can become increasingly outdated (see Section 2.1; Zellem et al. 2020). Due to the uncertainty of the mid-transit value, a “stale” ephemeris was evident in the analysis of our initial photometric campaign on January 18, 2025. Updating the

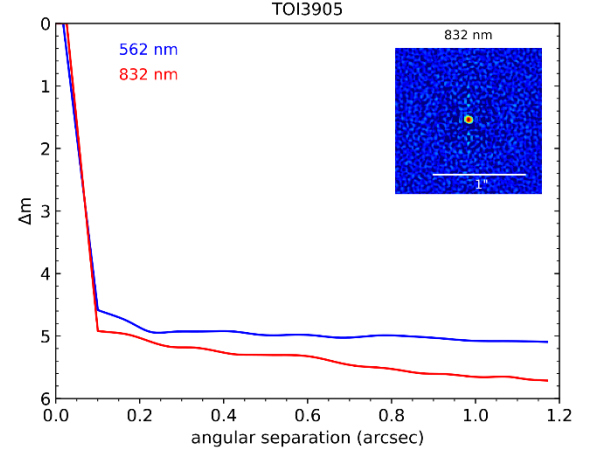


Figure 4. The Alopec 5 σ speckle imaging contrast curves in the 562nm (blue line) and 832nm (red line) filters as a function of the angular separation out to 1.2". The inset figure is the 832 nm reconstructed speckle image.

ephemeris after the initial campaign resulted in improved transit timing for the subsequent observations.

Each observation from Table 1 had a different field of view and limiting magnitude and thus was optimized with a different number of comparison stars (Table 2). The variation was ultimately accounted for with the standard methods in EXOTIC (Zellem et al. 2020) to reduce the combined data from *TESS* and the ground-based campaigns. Figure 5 shows the comparison stars used to produce the individual light curves (Figure 6) and the global light curve (Figure 7).

4. Results

Using space observatories and our ground-based observations, we obtained the parameters reported in Table 3. *TESS* initially estimated TOI-3905 b to be $R_p = 1R_J$ (Kunimoto et al. 2021), substantially smaller than our $R_p = 3.1757 \pm 0.018 R_J$ fit. This result is consistent with T. Han et al. (2025) who indicates that the *TESS* PIPELINE underestimates the measurements of Jovian-sized exoplanets. One cause of this could be the wide field of view of the *TESS* observatory which allows for dilution from other stars, through the dilution depth calculated from *Lightkurve* (Lightkurve Collaboration et al. 2013), *Astropy* (The Astropy Collaboration et al. 2013; Price-Whelan et al. 2018; T. A. Collaboration et al. 2022), and *NumPy* (Harris et al. 2020) is 0.007974% did not meaningfully affect our final parameters.

Forecaster (Chen & Kipping 2017) models this planet to have a mass of $0.975^{+0.121}_{-0.110} M_J$ corresponding to a density of

Table 1. Observations of TOI-3905 b

Observer	Date	Telescope	Filter (nm)	Re-sidual %	SNR
TESS Sector 22	March 2020	Camera 2	-	-	-
TESS Sector 23	April 2020	Camera 2	-	-	-
TESS Sector 49	March 2022	Camera 2	-	-	-
TESS Sector 76	March 2024	Camera 1	-	-	-
A	01/18/25	Celestron EdgeHD 11 5.9"	Johnson R (570-720)	1.39	2.01
B	02/07/25	Newtonian	N/A	1.84	2.34
C	02/23/25	Celestron SCT	N/A	3.41	1.08
D	03/06/25	SkyWatched Evolux 62/ED	UVIR (380-720)	4.69	1.04
E	03/06/25	EvScope 2	N/A	4.36	0.70
F	03/06/25	Celestron Nexstar SE C8 5.9"	R (590-700)	1.68	3.66
B	03/11/25	Newtonian	N/A	2.18	0.59
G	03/22/25	Astrotech AT8IN	Luminance (420-685)	1.11	1.63
H	04/23/25	12.5" CDK AG Optics	Luminance (418-700)	0.72	4.38
C	04/23/25	Celestron C11	N/A	2.11	2.01
H	05/09/25	12.5" CDK AG Optics	Luminance (418-700)	0.67	5.48
C	05/09/25	Celestron SCT	N/A	5.76	0.57
I	05/09/25	Planewave CDK 17"	R (620-680)	1.64	3.18

$40.386^{+4.994}_{-4.573} \text{ kg/m}^3$ indicating a “puffy” exoplanet. Radial velocity measurements are needed to confirm this hypothesis.

We estimated the angular momentum from McNally (1965) and relevant data provided from Pecaute & Mamajek (2013) to back out the likely stellar rotation period of TOI-3905 using Skumanich’s Law (Skumanich 1972).

$$\Omega_e \propto t^{-1/2} \quad (1)$$

Where Ω_e is the angular momentum, and t is the age of the star in billion years. We estimate a stellar rotation period of 44.5 ± 9.7 days which should not cause an alias with the planetary eclipse period.

5. Summary and Discussion

We confirm that TOI-3905 has an orbiting hot super Jupiter, with an orbital period of $P = 5.359959 \pm 0.000012$ days, and a radius of $R_p = 3.176 \pm 0.018 R_J$. This allows us to update the original TESS ephemeris of TOI-3905 b. Furthermore, we provide evidence that this star does not have a companion, and the stellar properties do not affect the planetary parameters fit. Lastly, with the involvement of citizen scientists from around the world, this work provides another example on how such collaborations can advance the science of exoplanets.

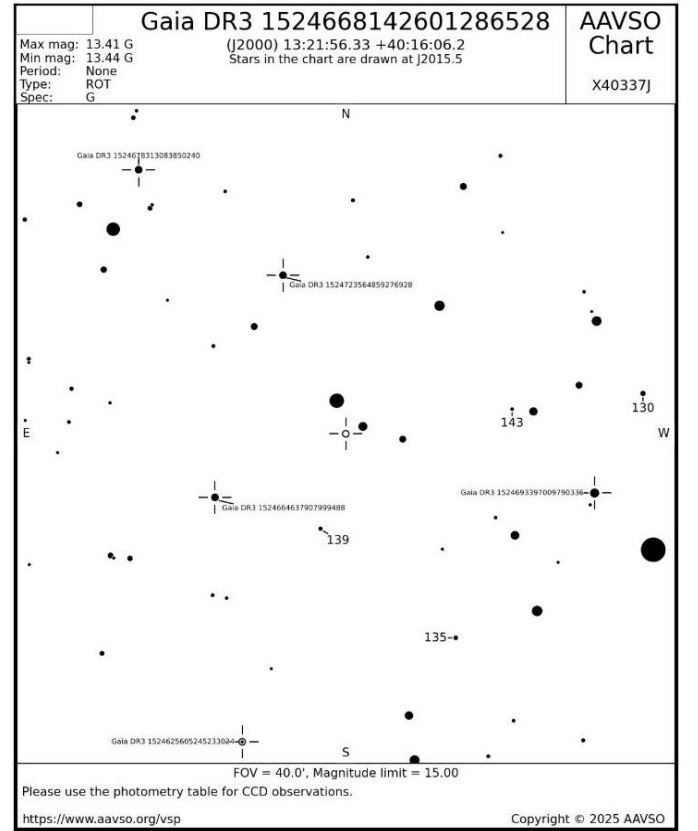


Figure 5. *Gaia* DR3 1524668142601286528-star finder chart from the AAVSO VSX team. The crosshatched circle in the center is the target. Each number (i.e. 130, 135, 139, 143) indicates a viable comparison star. Other marked stars are variable and avoided for use as comparisons.

Table 2. Comparison Star Visibility in the Field of View for TOI-3905 b

Observer	Date	Comp Star(s)	Arcmin*Arcmin	Image Scale (arcsec/pixel)
A	01/18/25	139, 143	33.43' * 22.37'	0.558
B	02/07/25	130, 135, 139, 143	87.69' * 59.72'	1.269
C	02/23/25	139, 143	35.04' * 23.86'	0.507
D	03/06/25	130, 135, 139, 143	95.25' * 54.50'	1.625
E	03/06/25	130, 135, 139, 143	40.11' * 19.74'	1.33
F	03/06/25	139, 143	25.17' * 11.27'	0.558
B	03/11/25	130, 135, 139, 143	76.95' * 52.40'	1.114
G	03/22/25	130, 135, 139, 143	41.53' * 23.36'	1.298
H	04/23/25	135, 139, 143	27.33' * 18.61'	0.396
C	04/23/25	139, 143	30.65' * 20.87'	0.444
H	05/09/25	139, 143	27.32' * 18.61'	0.396
C	05/09/25	139, 143	30.62' * 20.85'	0.443
I	05/09/25	130, 135, 139, 143	77.86' * 62.69'	1.038

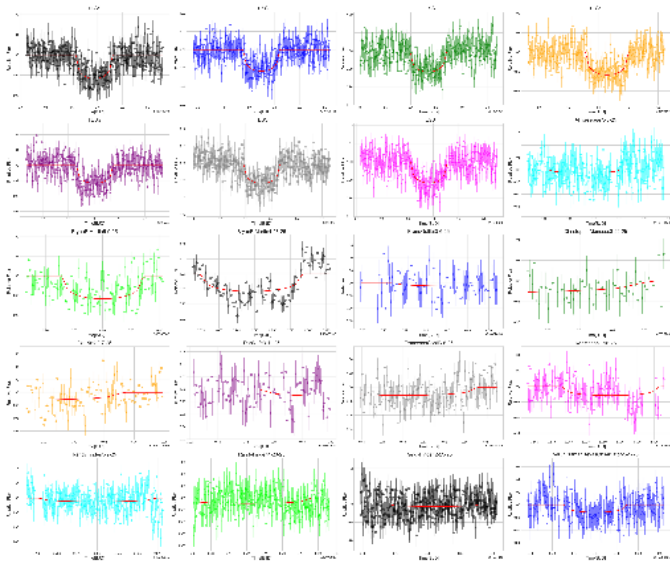


Figure 6. *TESS* and individual light curves were produced via EXOTIC. Citizen science observations span approximately four months from January 2025 to May 2025 with the *TESS* transits consisting of four sectors. Colors correspond to those seen in Figure 7.

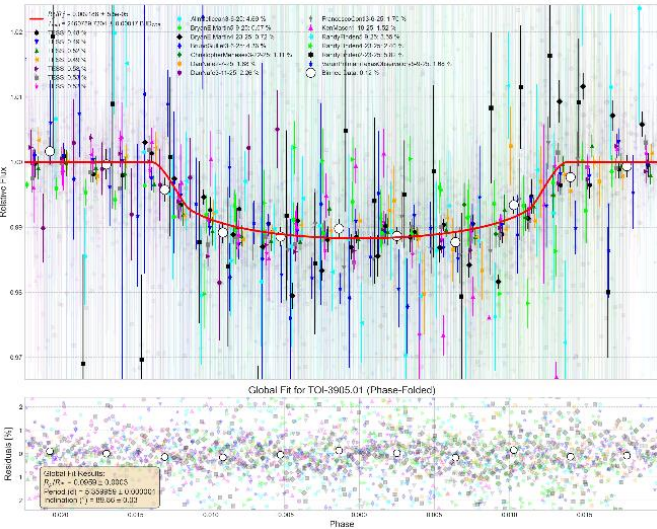


Figure 7. The normalized and phase-folded light curve from EXOTIC. Each marker represents a separate dataset, with each fainter marker being the raw data and each white bold marker representing the binned data. The bottom half of the figure shows the residuals from each dataset, with each representative marker indicated. The bottom left includes the results that were calculated from EXOTIC at the end of the reduction.

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Author Contributions

Author Contributions have been removed for the purpose of blind submission.

Software: Astropy (The Astropy Collaboration 2013; A.M. Price Whelan et al. 2018; T. A. Collaboration et al. 2022), Astroquery (Ginsburg et al. 2019), Lightkurve (Lightkurve Collaboration et al. 2018), Matplotlib (Hunter 2007), NumPy (Harris et al. 2020), SciPy (Virtanen et al. 2020)

Table 3. Median Parameters for TOI-3905 b with a 68.3% Confidence Interval

Parameter	Unit	Value
Stellar Parameters		
RA (J2000)	°	200.484635
Dec (J2000)	°	+40.268462
Proper Motion (RA)	mas/yr	-14.900 ± 0.017
Proper Motion (Dec)	mas/yr	13.077 ± 0.023
Parallax	mas	1.639 ± 0.013
d = distance	pc	644 ± 18
RV = Radial Velocity	km/s	2.5 ± 1.2
T_{eff} = Effective Temperature	K	5742 ± 75
Metallicity (M/H)	Dex	-0.487 ± 0.065
$\log(g)$ = Surface Gravity	-	4.495 ± 0.066
R_* = Solar Radii	$R_{\odot}$	1.0576 ± 0.0087
M_* = Solar Mass	$M_{\odot}$	1.030 ± 0.20
L_* = Solar Luminosity	$L_{\odot}$	1.214 ± 0.048
Age	GYR	5.63 ± 0.49
Rotational Period	Days	44.5 ± 9.7 ^a
Planetary Parameters		
P = Period	Days	5.359959 ± 0.000012
R_p = Jupiter Radii	R_J	3.176 ± 0.018
T_c = Midtransit value	BJD _{TDB}	2460789.72040 ± 0.00018
a = Semimajor axis	au	0.06053 ± 0.000114
i = inclination	°	89.858 ± 0.030
b = impact Parameter	-	0.0001418 ± 0.00003
T_{eq} = Equilibrium Temperature	K	1185.3 ± 0.6 ^b
M_p = Mass	M_J	0.975 ^{+0.121} _{-0.110}
Density	kg/m ³	40.386 ^{+4.994} _{-4.573}
R_p/R_s	-	0.0958 ± 0.0029
A/R_s	-	12.2951 ± 0.0057
$(R_p/R_s)^2$	-	0.009188 ± 0.0055
Total Transit Duration	Days	0.1321 ± 0.0050

^aSee Section 4 for the analysis in deriving this value.

^bCalculated with no albedo and perfect distribution

Facilities: *TESS*, *GAIA*, ‘Alopeke, Numerous Amateur Observatories

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