Ground based light curve follow up observations and false positive testing for TESS Object of Interest 3553.01

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Abstract

The Transiting Exoplanet Survey Satellite (TESS) mission gathers data for thousands of candidate exoplanets and their host stars (Zhang et al., 2022). In this paper we present research of TOI 3553, which is orbited by candidate exoplanet TOI 3553.01. The goal of this paper is to provide a ground based follow up of the planetary nature of TOI 3553.01. We also will confirm if TOI 3553 is a near eclipsing binary (NEB). We took 303 exposures with the GMU 0.8 m telescope and reduced them, then we conducted ground based multi aperture photometry using AstroImageJ to generate a light curve. Lastly, we conducted an NEB analysis on TOI 3553. We determined that TOI 3553.01 is not a near eclipsing binary. Due to the fact that the transit did not happen during the expected time, we did not confirm the planetary nature of TOI 3553.01.

Introduction

Since the discovery of the first exoplanets in the 1990's, the study of exoplanets has skyrocketed (https://www.schoolsobservatory.org). One way exoplanets can be identified is whether or not they transit their host star. The Transiting Exoplanet Survey Satellite (TESS) mission, launched by the Massachusetts Institute of Technology (MIT) and the National Aeronautics and Space Administration (NASA) gathers data from star systems in order to determine if they host candidate exoplanets. This data includes images taken with the four cameras. The candidate exoplanets are called TESS Objects of Interest (TOIs). The goal of ground based follow ups are to confirm the exoplanet status of these TOIs, and rule out any false positives.

Exoplanets must undergo the validation process so we can examine their properties, and how those compare to planets in our solar system. In a study by Cañas et al (2023), researchers conducted a ground and space based follow up of candidate exoplanets TOI-3984 A b and TOI-5293 A b. They conducted ground based photometry in addition to other techniques to determine the exoplanet status in their star systems, eventually confirming two gas giants orbiting M dwarf stars. In another study by Brahm et al (2023), scientists confirmed the planetary nature of three TOIs by using tools that allow them to conduct aperture photometry on TESS light curves.

While follow up studies made their own light curves and conducted many tests, many were unable to conduct any tests for a false positive result. This left unanswered questions about the possibility of being an NEB.

In this paper, we will observe and analyze data to provide a ground base follow up analysis of candidate exoplanet TOI 3553.01. TOI 3553 is an F type star with a period of 1.941 days, and its radius is 1.46336 solar radii. Our goal is to determine whether or not the transit happens during the expected time with the expected depth, and whether or not TOI 3553 is a false positive.

In Section 2 we present our Observations from the GMU 0.8m telescope. In Section 3 we present our data reduction process, our ground based light curve analysis, and our NEB analysis. In Section 4 we present the results of our ground based light curve and NEB analyses. In Section 5 we present our interpretation of our results. In Section 6 we present our conclusion in addition to recommended future work.

Observations

In Section 2.1 we present TOI 3553.01, its properties, and the properties of its host star, from the NASA Exoplanet Archive and the Exoplanet Follow-up Observing Program. In Section 2.2 we present our observing process for TOI 3553 on 2022.08.31.

2.1 Properties of TOI 3553

The right ascension of TOI 3553 is 21h42m24.91s, and the declination is +29d52m09.75s. TOI 3553 is a star with metallicity -0.051 and effective temperature 6497.17 K. The transit depth of TOI 3553.01 is 5.275108 mmag.

2.2 Observational process

We collected a total of 303 exposures using the GMU 0.8m telescope, each of which were 60 seconds. We started collecting exposures at 20:40 on 2022.08.31 and ended at 5:40 on 2022.09.01. In addition to the science exposures, we collected 20 darks and 10 flats. 10 of the darks had the same exposure time as the sciences (60s), and 10 of the darks had the same exposure time as the flats (2.5s). We used the R filter on the telescope.

Analysis

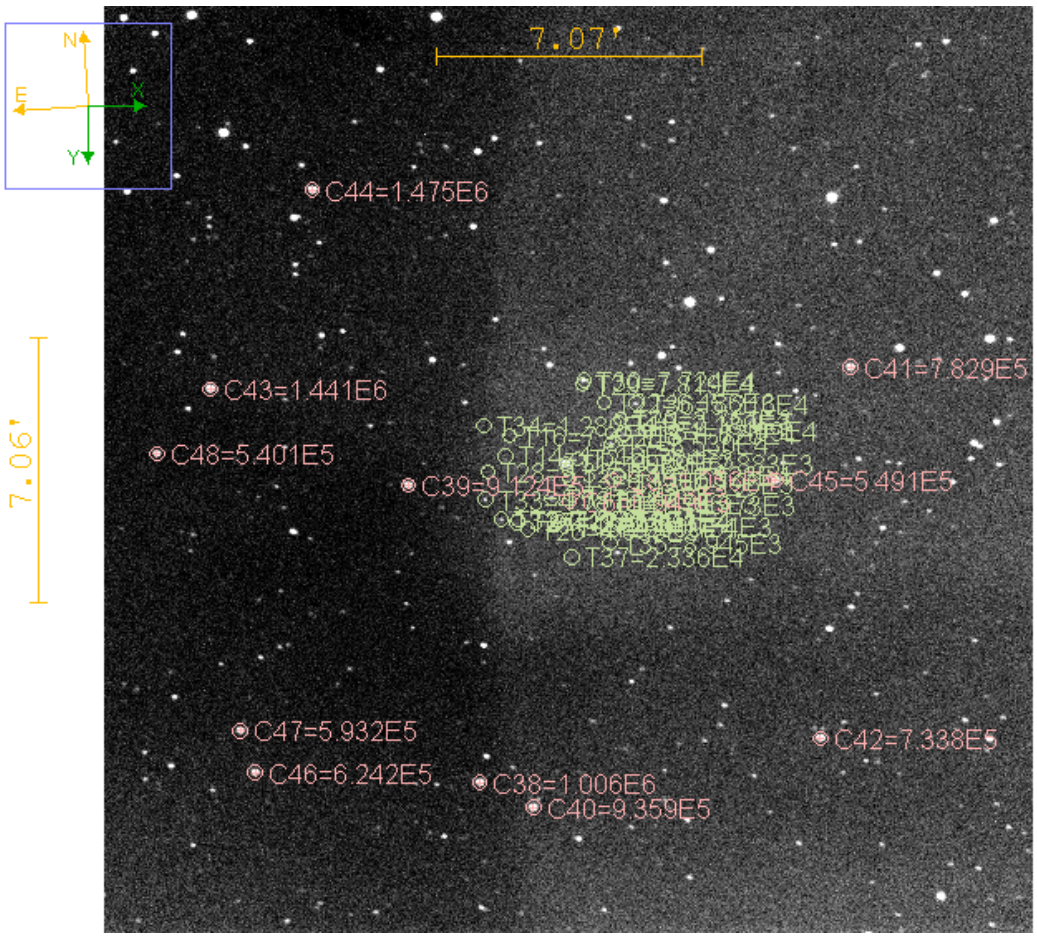
In section 3.1 we present our data reduction process using AstroImageJ to reduce our sciences. In section 3.2 we present our analysis of the ground based light curve.

3.1 Data reducing exposures

After collecting the exposures, we had to reduce them to cancel any distortions in the images. Using the CCD Data Processor and DP Converter features in AstroImageJ, we created a master flat dark and master science dark. Then, we subtracted each raw flat with the master flat dark. Next, we created a master flat from the dark subtracted flats. After, we dark subtracted and flat divided our raw sciences to result in reduced sciences. Lastly, using the plate solve feature of AstroImageJ we plate solved all of the reduced exposures.

3.2 Ground based light curve analysis

We conducted aperture photometry and multi aperture photometry to generate our light curve (Ha & Boyce, 2020; Conti, 2020). Initially, we generated a seeing profile from the plugins dropdown of AstroImageJ. We also created a 2.5' radius around the target using the Annotation Text window in AstroImageJ. Then, we uploaded the Gaia reference star file created using (astro.louisville.edu/gaia_to_aij/#close) on the plate solved sciences. The purpose of this upload was to assess any nearby stars that could be a near eclipsing binary.



We began multi aperture photometry by using the Multi Aperture tool from AstroImageJ (Collins et al., 2017). The radius of object aperture was 31 pixels, and the inner and outer radii of the annuluses were 54 and 81 pixels respectively. These values were obtained from the seeing profile. AstroImageJ automatically placed 11 apertures. Additionally, a measurement table was generated from AstroImageJ after the multi-aperture photometry finished.

Then, we used the multiplot tool from AstroImageJ to analyze the ground based light curve. We initially uploaded the Template plotcfg (astrodennis.com) to the multi plot main window. We changed the default x-data to BJD_TDB. Using a UTC to JD converter (aavso.org/jd-calculator) and a JD to BJD_TDB converter (astroutils.astronomy.osu.edu/time/utc2bjd.html), we input the predicted ingress (UT2:45) and egress (UT4:15) into the V. Marker 1 and V. Marker 2 sections, and selected the auto x range for the plot.

In the Data Set 2 Fit Settings window, we entered TOI 3553's period (1.941 days) and its radius (1.463 solar radii). Since surface gravity wasn't provided, we unlocked Linear LD u1 and locked Quad LD u2. We did not use any detrend parameters, and we showed residuals with error.

We plotted Sky/Pixel_T1, Width_T1, AIRMASS, tot_C_cnts, X(FITS)_T1, Y(FITS)_T1 using recommended scale, shift, and color from the latest TFOP SG1 Guidelines.

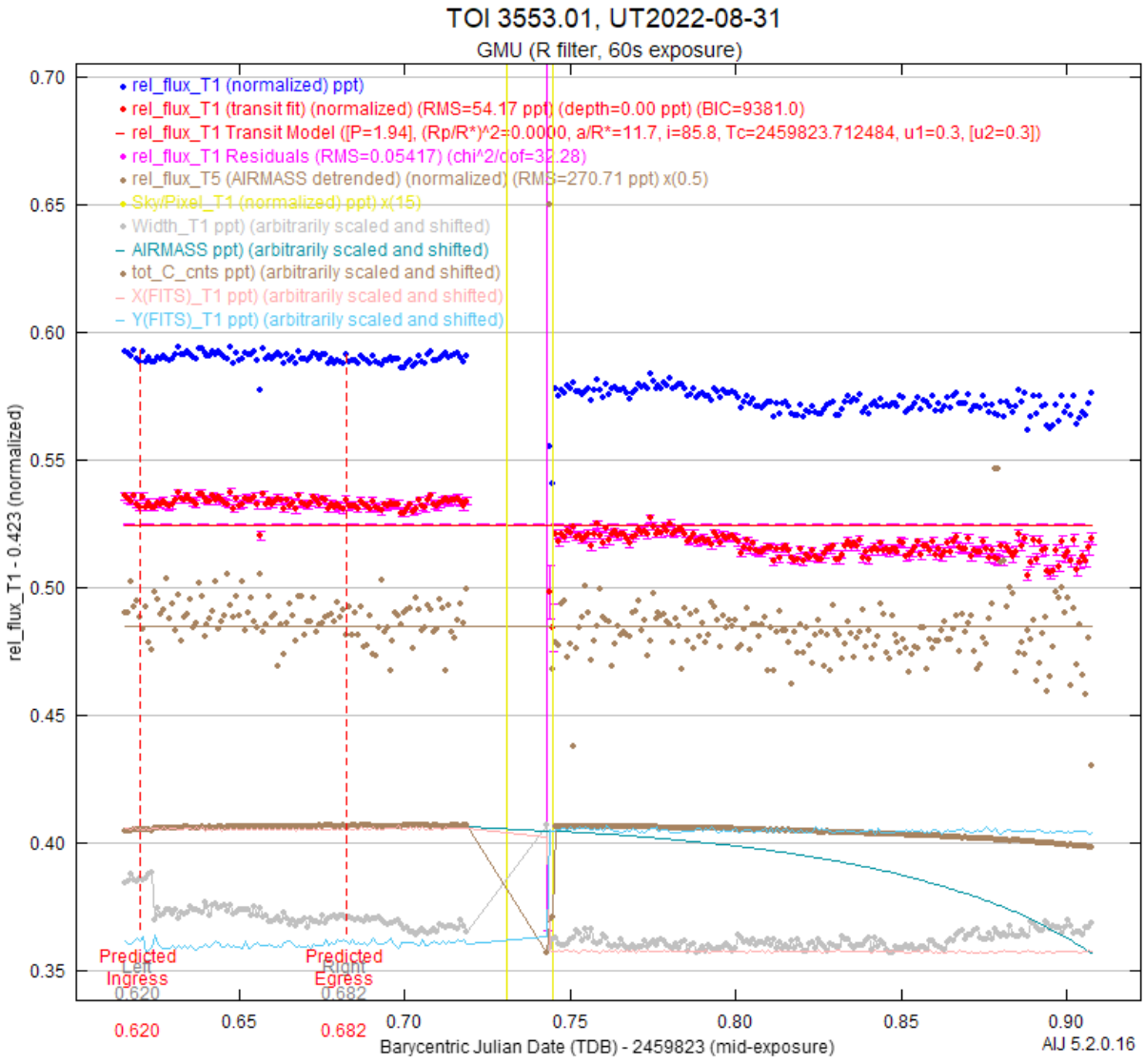
Finally, we used the TFOP SG1 NEB Analysis Macro tool from AstroImageJ to conduct a near eclipsing binary analysis of TOI 3553. We created an NEB analysis measurements table, and a dmag vs RMS plot.

Results

In Section 4.1 we present our ground based light curve and other findings from our data analysis.

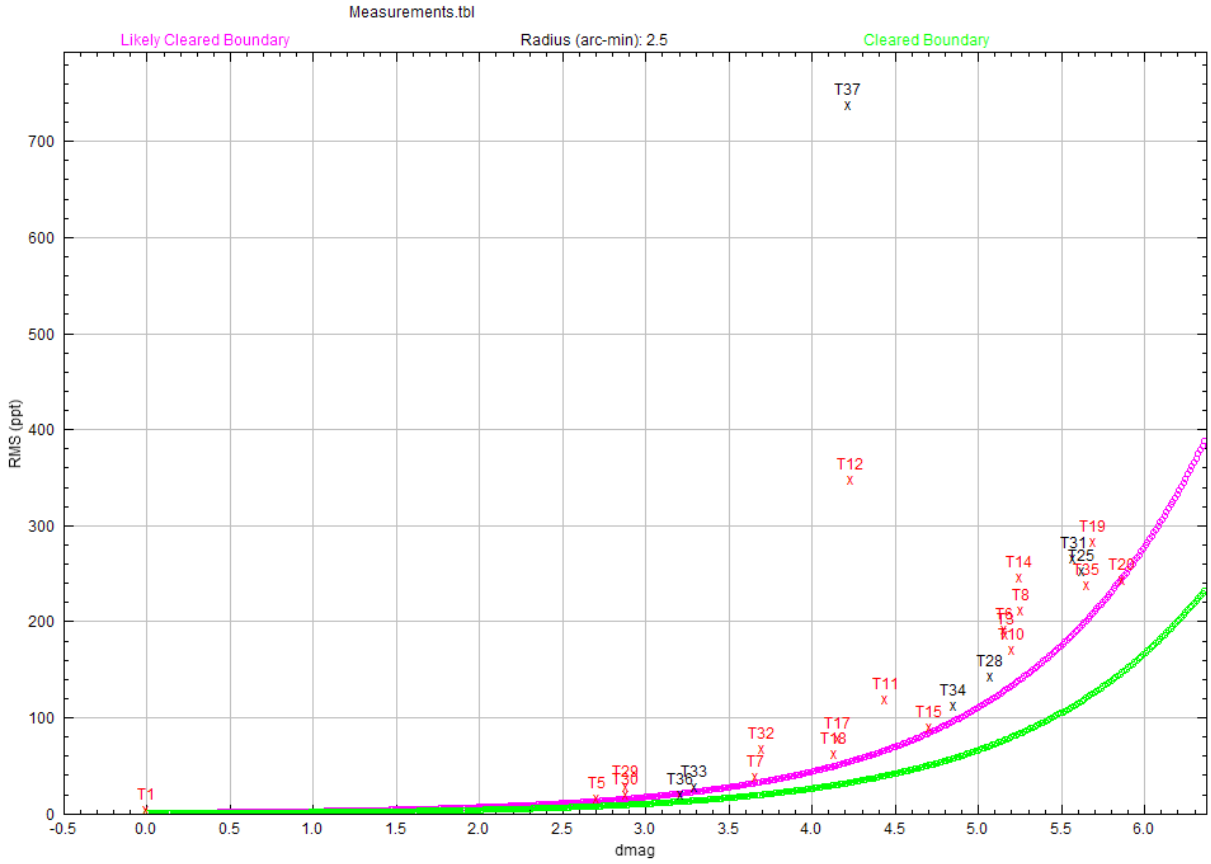
4.1 Figures and tables

Figure 1 Plot of Ground Based Light Curve



The ground based light curve shows no transit between the predicted ingress and egress times. The flux of one of the target stars was also plotted.

Figure 2 dmag vs RMS plot of Gaia reference stars



This plot shows the boundaries for clearing the NEB analysis. All stars are above both lines.

Table 1. NEB analysis measurements table

Star	Separation from target	PA (deg.)	Uncorr. dmag	RMS(ppt)	NEBdepth(ppt)	NEBdepth/RMS	Disposition
T2	0'20"	289	6.77	701.75	N/A	N/A	***Not Cleared-flux too low***
T3	0'25"	189	5.171	192.54	389.4	2	***Not Cleared***
T4	0'50"	187	6.382	393.72	N/A	N/A	***Not Cleared-flux too low***
T5	1'00"	154	2.715	22.06	40.6	1.8	***Not Cleared***
T6	1'01"	181	5.163	196.74	386.8	2	***Not Cleared***
T7	1'19"	290	3.667	43.46	97.6	2.2	***Not Cleared***
T8	1'21"	247	5.262	216.88	423.5	2	***Not Cleared***
T9	1'25"	217	6.131	369.63	N/A	N/A	***Not Cleared-flux too low***

T10	1'26"	253	5.211	175.93	404.3	2.3	***Not Cleared***
T11	1'31"	169	4.441	124.32	199	1.6	***Not Cleared***
T12	1'34"	169	4.241	353.93	165.5	0.5	***Not Cleared***
T13	1'35"	246	6.248	411.08	N/A	N/A	***Not Cleared-flux too low***
T14	1'38"	80	5.251	250.91	419.4	1.7	***Not Cleared***
T15	1'40"	175	4.708	95.83	254.4	2.7	***Not Cleared***
T16	1'40"	60	5.976	338.08	N/A	N/A	***Not Cleared-flux too low***
T17	1'43"	293	4.163	83.04	153.9	1.9	***Not Cleared***
T18	1'44"	294	4.142	67.9	151.1	2.2	***Not Cleared***
T19	1'45"	304	5.696	288.36	632.2	2.2	***Not Cleared***
T20	1'53"	306	5.872	249.09	743.4	3	***Not Cleared***
T21	1'54"	231	6.601	448	N/A	N/A	***Not Cleared-flux too low***
T22	1'54"	325	6.194	374.85	N/A	N/A	***Not Cleared-flux too low***
T23	1'54"	205	6.404	347.79	N/A	N/A	***Not Cleared-flux too low***
T24	1'59"	136	5.923	353.18	N/A	N/A	***Not Cleared-flux too low***
T25	2'00"	267	5.626	258.03	592.4	2.3	***Not Cleared***
T26	2'02"	147	6.925	632.56	N/A	N/A	***Not Cleared-flux too low***
T27	2'03"	137	6.086	444.22	N/A	N/A	***Not Cleared-flux too low***
T28	2'05"	93	5.077	148.48	357.5	2.4	***Not Cleared***
T29	2'09"	345	2.884	32.77	47.4	1.4	***Not Cleared***
T30	2'16"	345	2.887	24.78	47.5	1.9	***Not Cleared***
T31	2'17"	289	5.574	271.5	564.9	2.1	***Not Cleared***
T32	2'16"	128	3.702	73.14	100.7	1.4	***Not Cleared***
T33	2'21"	111	3.302	32.88	69.7	2.1	***Not Cleared***
T34	2'25"	62	4.857	117.47	291.8	2.5	***Not Cleared***
T35	2'26"	206	5.658	243.44	610.3	2.5	***Not Cleared***
T36	2'27"	307	3.214	25.38	64.2	2.5	***Not Cleared***
T37	2'30"	180	4.225	742.84	163	0.2	***Not Cleared***

All reference stars did not clear the NEB analysis.

Discussion

In section 5.1 we discuss our interpretation of our results. In section 5.2 we discuss our results in context of the greater field of follow up research for the NASA TESS mission.

5.1 Interpretation of results

The ground based light curve does not show a transit detection. Between the predicted ingress and egress there is a flat line, it lacks the characteristic dip of a transit (see Figure 1). We determined that the transit did not happen during the expected time. Due to the lack of transit, we were unable to conduct further tests using software like ExoFASTv1, which requires a visible transit on the light curve. We also determined that the candidate exoplanet TOI 3553.01 is not in a near

eclipsing binary system, given that none of the Gaia stars in a 2.5 arcmin radius successfully cleared the NEB analysis (see Figure 2, Table 1). One reason we missed the detection could have been because of clouds, as our initial exposures had some cloud coverage in the background.

5.2 Results in context of the greater field

Other works were able to classify their candidate exoplanets as gas giants (Cañas et al., 2023; Brahm et al., 2023). While we used similar methods like ground based photometry, we were unable to classify TOI 3553.01 due to lack of transit in the plot. Although our results about the planetary nature were inconclusive, we were able to eliminate the possibility of being an NEB, shedding some light on the traits of this TOI.

Conclusions and Future Work

Our goal was to confirm the planetary nature of TOI 3553.01 using data reduction and multi aperture photometry to generate a light curve and conduct NEB analysis. We did not confirm the planetary nature of TOI 3553.01. We created a ground based light curve, a dmag vs RMS plot, and an NEB table. The light curve did not show any transit during the expected time, and TOI 3553 did not clear the NEB analysis. We determined that the star is not part of a near eclipsing binary system.

In the future we hope to find the right time of transit for TOI 3553. The ground based light curve analysis can be performed again to create a plot with a visible transit on it. With a transit, further light curve analysis can be performed using ExoFASTv1 to learn more properties about the planet.

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