Ground based light curve follow up observations and false positive testing for TESS Object of Interest 3772.01

Authors
Aiden Guan, Dr. Peter Plavchan

Affiliations

Peter Plavchan, Department of Physics and Astronomy, 4400 University Drive MS 3F3, George Mason University, Fairfax, VA 22030, USA

Aiden Guan, Yorba Linda High School, 19900 Bastanchury Rd, Yorba Linda, CA 92886, USA

Abstract

The Transiting Exoplanet Survey Satellite (TESS), which uses transit photometry to detect possible exoplanet candidates, has greatly enhanced the hunt for exoplanets. The results of ground-based follow-up observations of TOI 3772.01 are presented in this study. Our objective was to validate the expected transit characteristics in order to verify the correctness of TOI 3772.01. We determined the transit event by analyzing the light curves using information obtained with the GMU 0.8m telescope. Using the GMU 0.8 telescope, we obtained a total of 182 exposures. We then reduced the exposures and performed multi aperture photometry with AstroImageJ to produce a light curve. Our findings suggest that the transit parameters are somewhat consistent with expectations, which is in line with the designation of TOI 3772.01 as having inconclusive evidence for being a real exoplanet.

Introduction

Exoplanet research has blossomed in the nearly 30 years since scientists discovered planets that orbit stars other than our sun. These stars provide a window into how planets form and the possibility for life beyond our solar system. NASA along with MIT developed the TESS mission, which looks for any variability in star systems that could be caused by exoplanets. These stars that are picked are identified as TOIs (TESS Objects of Interest) and have ground based analysis performed on them to validate whether they belong as an exoplanet.

Operated by NASA, the Transiting Exoplanet Survey Satellite (TESS) mission plays a crucial role in this search, where it scans wide areas of the sky to identify hundreds of thousands of potential exoplanets. All of these so-called TESS Objects of Interest (TOIs) need to be observed in much greater detail to ensure that they're real planets rather than false positives. There have been many stars that have been identified as exoplanets but many still haven't been analyzed. In this paper we contribute further to exoplanet research and verification with TOI 3772.01.

Ground-based telescopes play a vital role in these follow-up observations, providing the necessary precision to validate the transits observed by TESS. In this paper, we focus on the candidate exoplanet TOI 3772.01, conducting observations to determine if the transit occurs at the expected time and with the predicted depth and duration. These observations were performed using the George Mason University 0.8m telescope, which allowed us to gather high-quality data for our analysis.

In this paper, we present the follow up observations of TOI 3772.01. The objectives of our study include confirming the predicted transit parameters of TOI 3772.01 and confirming its classification as an exoplanet. The characteristics of TOI 3772.01 include a radius of 7.8 solar radii, an orbital period of 4.169 days, and a transit duration of 2.19 hours.

In Section 2, we describe our observational setup and methodology. Section 3 includes the data reduction process along with the light curves and data returned. The results of our analysis along with our data is presented in Section 4, followed by a discussion in Section 5. Lastly, Section 6 displays our conclusions and suggests directions for future research.

Observations

2.1 Properties of TOI 3772

In this section, we provide information on TOI 3772.01 and its host star, obtained from the NASA Exoplanet Archive and the Exoplanet Follow-up Observing Program (ExoFOP). TOI 3772 has a right ascension of 05h44m10.43s and a declination of +36d04m50.62s. The star has an equilibrium temperature of 961.39 K with a radius of 7.8 solar radii. The transit depth for TOI 3772.01 is recorded at 7.716 mmag.

2.2 Observation Procedure

On 2023.12.12, we conducted observations of TOI 3772.01 using the George Mason University 0.8m telescope. We collected a total of 182 exposures, each lasting 85.00 seconds. The observation period began at 18:35 and concluded at 6:15**.** Alongside the science exposures, we captured 20 dark frames and 10 flat frames. Of these, 10 dark frames matched the exposure time of the science frames (85.00 seconds), and 10 dark frames matched the exposure time of the flat frames (3.00 seconds). The telescope was equipped with the R filter for this session.

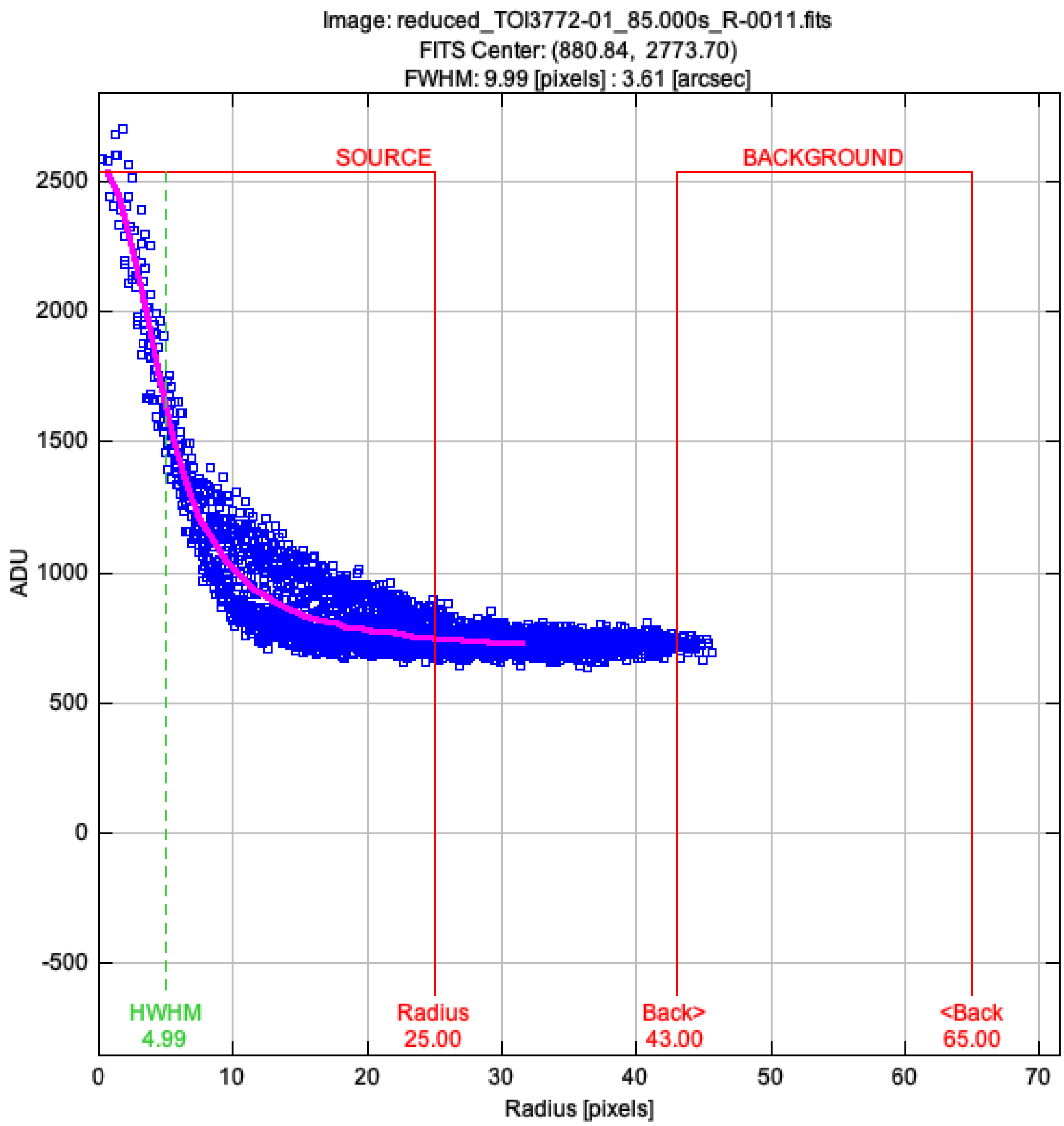
Analysis

3.1 Data Reduction Process

Post-observation, the collected exposures required reduction to mitigate any image distortions. Utilizing AstroImageJ, we employed the CCD Data Processor and DP Converter tools to generate a master flat dark and master science dark. Each raw flat was then subtracted from the master flat dark. We subsequently created a master flat from these dark-subtracted flats. Following this, we dark-subtracted and flat-divided our raw science frames to produce reduced science images. Finally, we used (https://github.com/oalfaro2/alnitak) to plate solve our sciences.

3.2 Light Curve Analysis

For the light curve generation, we performed aperture photometry and multi-aperture photometry (Plavchan et al. 2022). First, we generated a seeing profile using AstroImageJ's plugins dropdown menu. We then created a 2.5' radius annotation around the target star in AstroImageJ. The Gaia reference star file was uploaded to the plate-solved science images to identify any nearby stars that might indicate a near-eclipsing binary scenario.



We conducted multi-aperture photometry using the Multi-Aperture tool in AstroImageJ (Collins et al., 2017). The object aperture radius was set to 25 pixels, with inner and outer annulus radii of 43 and 65 pixels, respectively, as determined by the seeing profile. Upon the completion of multi-aperture photometry a measurement table was created by AstroImageJ.

Next, we analyzed the ground-based light curve using the multiplot tool in AstroImageJ. We began by uploading the Template plotcfg file from astrodennis.com to the multiplot main window and changed the default x-data to BJD_TDB. Then we used the predicted ingress and egress times from the Transit Info png as the “V. Marker 1” and “V. Marker 2” boxes. We then set the x-axis scaling to auto, and renamed the title to the target's name and UT date of observation.

In the Data Set 2 Fit Settings window, we entered TOI 3772’s period (4.17 days) and radius (7.8 solar radii). We utilize our target’s effective temperature and surface gravity parameters to find the “Linear LD u1” and “Quad LD u2” values using (https://astroutils.astronomy.osu.edu/exofast/limbdark.shtml). We applied the AIRMASS detrend parameter with residuals containing low error.

We plotted each parameter using the recommended scale, shift and color settings from the TFOP SG1 Guidelines.

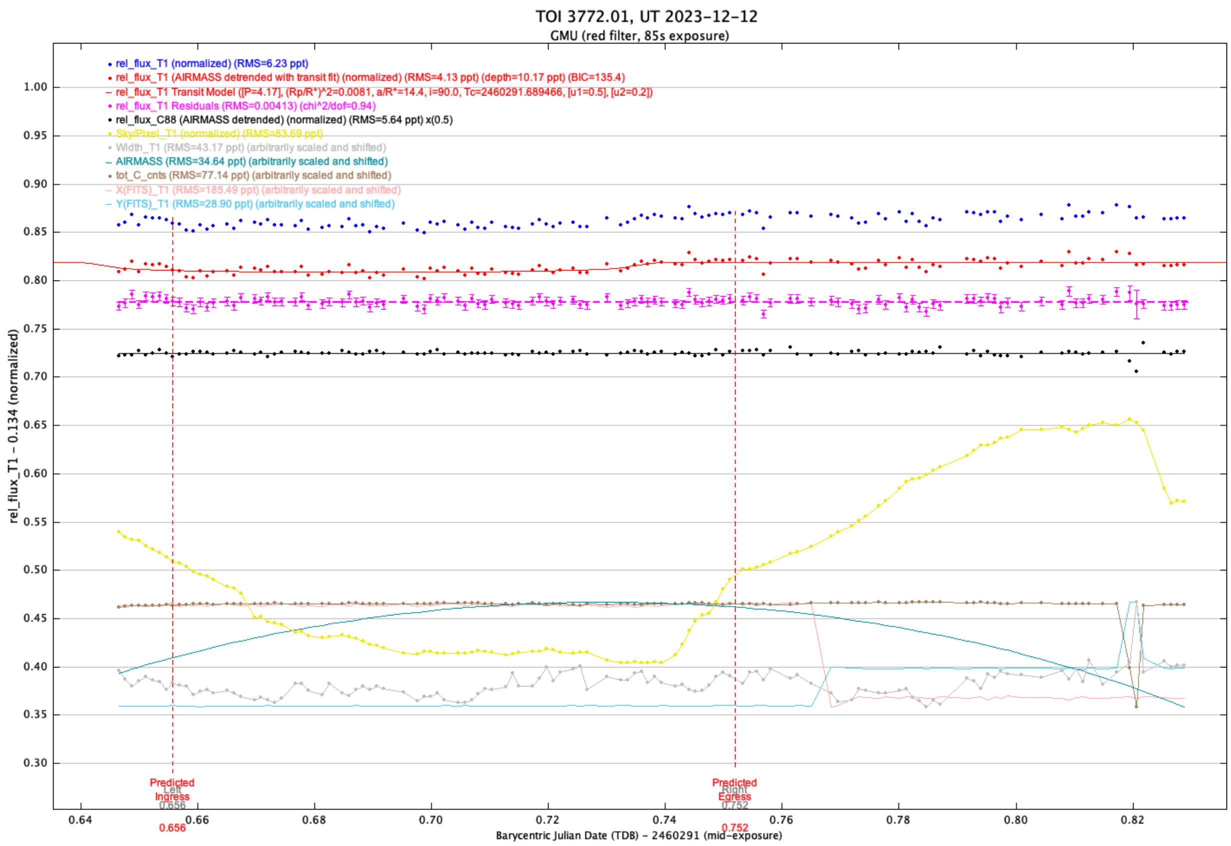
Finally, we used the TFOP SG1 NEB Analysis Macro tool from AstroImageJ to conduct a near eclipsing binary analysis of TOI 3772.01. We created an NEB analysis measurements table, and a dmag vs RMS plot.

Results

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

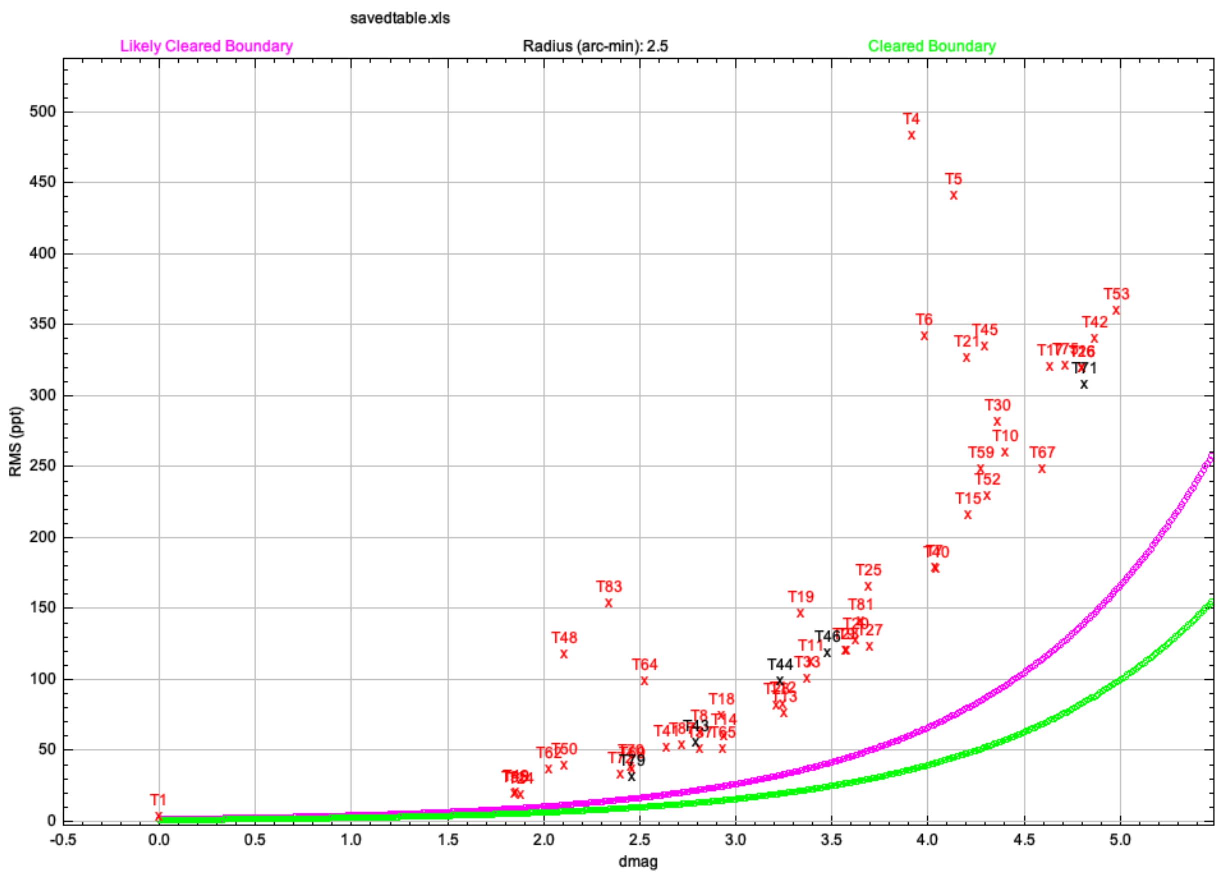
4.1 Data Figures

Figure 1 Plot of Ground Based Light Curve



The ground based light curve shows the ingress and egress covering much of the transit.

Figure 2 dmag vs RMS plot



All stars are above the lines representing the boundaries for clearing the NEB analysis.

Table 1. NEB analysis measurements table

Star	from target	PA (deg.)	dmag	RMS(ppt)	NEBdepth(ppt)	NEBdepth/RMS	Disposition
T2***	0'18"	262	15.000	352.35	N/A	N/A	***Not Cleared-flux too low***
T3***	0'20"	331	12.905	5470.42	N/A	N/A	***Not Cleared-flux too low***
T4	0'24"	3	3.918	487.66	184.0	0.4	***Not Cleared***
T5	0'27"	356	4.143	444.94	226.4	0.5	***Not Cleared***
T6	0'28"	4	3.990	346.66	196.6	0.6	***Not Cleared***
T7	0'31"	300	4.041	183.12	206.0	1.1	***Not Cleared***
T8	0'30"	92	2.819	67.46	66.9	1.0	***Not Cleared***
T9	0'37"	278	3.585	125.04	135.4	1.1	***Not Cleared***
T10	0'46"	337	4.407	264.38	288.8	1.1	***Not Cleared***

T11	0'48"	116	3.393	116.87	113.4	1.0	***Not Cleared***
T12	0'52"	76	3.247	86.83	99.2	1.1	***Not Cleared***
T13	0'53"	79	3.258	80.60	100.2	1.2	***Not Cleared***
T14	0'54"	265	2.945	64.72	75.1	1.2	***Not Cleared***
T15	0'54"	211	4.215	220.31	242.0	1.1	***Not Cleared***
T16	0'55"	355	4.807	323.65	417.1	1.3	***Not Cleared***
T17	0'56"	89	4.642	324.32	358.5	1.1	***Not Cleared***
T18	0'56"	265	2.929	79.16	74.0	0.9	***Not Cleared***
T19	0'58"	72	3.344	150.99	108.4	0.7	***Not Cleared***
T20	0'59"	331	3.631	132.09	141.2	1.1	***Not Cleared***
T21	1'01"	68	4.208	330.80	240.3	0.7	***Not Cleared***
T22	1'02"	61	8.540	2200.69	N/A	N/A	***Not Cleared-flux too low***
T23	1'01"	172	3.578	124.50	134.5	1.1	***Not Cleared***
T24	1'04"	306	1.884	22.92	28.3	1.2	***Not Cleared***
T25	1'03"	166	3.694	169.88	149.7	0.9	***Not Cleared***
T26	1'04"	85	4.807	324.13	417.4	1.3	***Not Cleared***
T27	1'06"	182	3.699	127.68	150.4	1.2	***Not Cleared***
T28	1'08"	205	3.216	85.96	96.4	1.1	***Not Cleared***
T29	1'09"	342	6.996	826.18	N/A	N/A	***Not Cleared-flux too low***
T30	1'11"	234	4.365	286.11	277.7	1.0	***Not Cleared***
T31	1'12"	24	5.643	458.40	N/A	N/A	***Not Cleared-flux too low***
T32	1'20"	296	8.318	36337.16	N/A	N/A	***Not Cleared-flux too low***
T33	1'23"	342	3.377	104.80	111.8	1.1	***Not Cleared***
T34	1'24"	319	4.979	377.65	N/A	N/A	***Not Cleared-flux too low***
T35	1'24"	277	7.178	1141.78	N/A	N/A	***Not Cleared-flux too low***
T36	1'25"	171	14.858	2451.87	N/A	N/A	***Not Cleared-flux too low***
T37	1'26"	224	2.819	55.29	66.9	1.2	***Not Cleared***
T38	1'30"	318	5.246	382.87	N/A	N/A	***Not Cleared-flux too low***
T39	1'30"	233	14.994	891.35	N/A	N/A	***Not Cleared-flux too low***
T40	1'32"	299	4.046	182.72	207.0	1.1	***Not Cleared***
T41	1'33"	293	2.646	56.08	57.0	1.0	***Not Cleared***
T42	1'35"	171	4.872	344.10	443.1	1.3	***Not Cleared***
T43	1'36"	38	2.799	60.18	65.7	1.1	***Not Cleared***
T44	1'37"	59	3.238	103.12	98.3	1.0	***Not Cleared***
T45	1'46"	327	4.300	339.44	261.5	0.8	***Not Cleared***
T46	1'46"	145	3.479	122.59	122.8	1.0	***Not Cleared***
T47	1'50"	318	9.828	4963.44	N/A	N/A	***Not Cleared-flux too low***
T48	1'50"	202	2.111	122.03	34.8	0.3	***Not Cleared***
T49	1'53"	205	1.859	24.54	27.6	1.1	***Not Cleared***

T50	1'53"	234	2.108	43.93	34.7	0.8	***Not Cleared***
T51***	1'54"	285	10.239	4301.59	N/A	N/A	***Not Cleared-flux too low
T52	1'56"	114	4.314	233.37	264.9	1.1	***Not Cleared***
T53	1'58"	326	4.988	364.47	492.9	1.4	***Not Cleared***
T54***	2'00"	98	7.584	1490.63	N/A	N/A	***Not Cleared-flux too low
T55	2'00"	232	1.855	23.68	27.5	1.2	***Not Cleared***
T56***	2'02"	331	9.129	3656.00	N/A	N/A	***Not Cleared-flux too low
T57***	2'02"	50	5.309	443.87	N/A	N/A	***Not Cleared-flux too low
T58***	2'03"	321	6.006	571.08	N/A	N/A	***Not Cleared-flux too low
T59	2'02"	115	4.280	252.74	256.9	1.0	***Not Cleared***
T60***	2'03"	30	6.213	672.75	N/A	N/A	***Not Cleared-flux too low
T61***	2'05"	286	11.178	12928.89	N/A	N/A	***Not Cleared-flux too low
T62	2'04"	231	2.034	40.76	32.5	0.8	***Not Cleared***
T63***	2'09"	288	11.093	6989.12	N/A	N/A	***Not Cleared-flux too low
T64	2'10"	295	2.530	103.55	51.2	0.5	***Not Cleared***
T65	2'11"	306	2.936	55.46	74.5	1.3	***Not Cleared***
T66***	2'11"	67	5.374	631.09	N/A	N/A	***Not Cleared-flux too low
T67	2'11"	130	4.597	252.21	344.0	1.4	***Not Cleared***
T68***	2'12"	195	10.730	4152.93	N/A	N/A	***Not Cleared-flux too low
T69	2'17"	295	2.464	41.13	48.2	1.2	***Not Cleared***
T70	2'17"	295	2.460	42.80	48.0	1.1	***Not Cleared***
T71	2'17"	266	4.817	311.91	421.3	1.4	***Not Cleared***
T72	2'18"	47	2.401	37.32	45.5	1.2	***Not Cleared***
T73***	2'18"	322	7.366	1228.82	N/A	N/A	***Not Cleared-flux too low
T74***	2'19"	229	10.064	3121.47	N/A	N/A	***Not Cleared-flux too low
T75	2'25"	281	4.718	325.23	384.4	1.2	***Not Cleared***
T76***	2'24"	196	12.490	18750.20	N/A	N/A	***Not Cleared-flux too low
T77***	2'24"	152	9.450	3067.52	N/A	N/A	***Not Cleared-flux too low
T78***	2'25"	286	11.568	2236.56	N/A	N/A	***Not Cleared-flux too low
T79	2'26"	348	2.465	35.97	48.3	1.3	***Not Cleared***
T80***	2'25"	144	6.325	756.37	N/A	N/A	***Not Cleared-flux too low
T81	2'25"	190	3.655	145.56	144.4	1.0	***Not Cleared***
T82***	2'26"	66	5.938	642.89	N/A	N/A	***Not Cleared-flux too low
T83	2'29"	310	2.347	158.28	43.3	0.3	***Not Cleared***
T84***	2'28"	149	10.298	3913.21	N/A	N/A	***Not Cleared-flux too low
T85***	2'29"	135	14.960	1883.28	N/A	N/A	***Not Cleared-flux too low
T86***	2'30"	250	6.911	1164.89	N/A	N/A	***Not Cleared-flux too low
T87	2'30"	277	2.721	58.40	61.1	1.0	***Not Cleared***

No reference stars cleared 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 show some transit detection between the ingress and egress lines. The RMS values are fairly low, especially after detrending, which suggests that the data is good quality. The residuals show some scatter but no significant deviation from zero, indicating that the transit event has been captured accurately.

5.2 Results in context of the greater field

TOI 3772.01 likely fits the profile of either a Hot Jupiter, a Hot Neptune, or a Super-Earth, depending on the exact size of the host star. Its short orbital period suggests that it experiences high surface temperatures, which could lead to fluctuating atmospheric conditions. Further observations would need to be confirmed to authenticate the classification of this star.

Conclusion and Future Work

In conclusion, we are inconclusive on the validity of TOI 3772.01 as an exoplanet. The target does have many traits of an exoplanet, such as the raw image data being similar to the detrended data, and low RMS. Despite this info, we concluded that TOI 3772.01 should be given more time and research. With possibly better data and more expansive findings we could firmly conclude a classification for this target.

References

Collins, K. A., Kielkopf, J. F., Stassun, K. G., & Hessman, F. V. (2017). ASTROIMAGEJ: Image Processing and Photometric Extraction For Ultra-Precise Astronomical Light Curves. *The Astronomical Journal*. DOI10.3847

Conti, D. M. (2020, September 4). *TFOP SG1 Observation Guidelines*. astrodennis. Retrieved August 16, 2024, from https://astrodennis.com/TFOP_SG1_Guidelines_Latest.pdf

Eastman, J., Gaudi, B. S., & Agol, E. (2013). *EXOFAST: A fast exoplanetary fitting suite in IDL*. ArXiv. https://doi.org/10.48550/ARXIV.1206.5798

O, Alfro. “OALFARO2/Alnitak.” GitHub, github.com/oalfaro2/alnitak. Accessed 13 Aug. 2024.

Zhang, Y., Yusuf, S., Helm, I., Collins, K., & Plavchan, P. (2022). NASA's Transiting Exoplanet Survey Satellite Mission Ground-Based Follow-Ups. *Journal of Student-Scientists' Research*, *4*.