Some of Extreme Eclipsing Binaries among Hot B Stars

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Abstract

In this work we used the catalog of spectral and luminosity classes of 6,037 stars in the direction of the Galaxy anticenter and selected a subsample list of 2067 stars covering whole B spectral and luminosity classes including peculiar B stars. We used TESS Quick-Look Pipeline (QLP) light curves for all those stars from the Mikulski Archive for Space Telescopes (MAST) database in FITS format tables and processed all of them using interactive python code. To avoid contamination of variability from neighboring stars we analyzed light curves per pixel for each star and extracted a light curve free of any contamination. For pulsation eclipsing binary stars we estimated frequency spectra using Lomb-Scargle Periodograms and excluded it from a source light curve to get a pure transit signal. We used than Transit Least Squares algorithm to determine the periods and epochs of eclipsing events and built the phase curves. As a result we are presenting 23 new detached eclipsing binary stars, 11 of which have high eccentricity and 12 of them show pulsation signals.

Keywords: *binary stars: eclipsing binaries: pulsating variables*

1. Introduction

The continuous photometric and astrometric monitoring of a large areas of the sky by the space-based telescopes such as CoRot (Auvergne et al., 2009), Kepler (Borucki, 2016), TESS (Ricker et al., 2015) and Gaia (Gaia Collaboration, et al., 2016) during the last two decades have the greatest impact to a progress of time-domain astronomy. The space missions were based on an experience gathered by previous excellent automated ground-based surveys as ASASS (Pojmanski et al., 2005), SuperWASP (Pollacco et al., 2006), OGLE (Udalski et al., 2015), PanSTARSS (Chambers et al., 2016) and others.

All these projects obtained a huge library of long spanning and high cadence time-series photometric data of unprecedented quality for millions of stars and this process continues even at present time especially with the NASA's Transiting Exoplanet Survey Satellite (TESS) and forthcoming Planetary Transits and Oscillations of Stars or PLATO mission (Rauer et al., 2014).

The processing of all these data allowed to discover thousands of eclipsing binary stars (EBs) over the whole sky (Deleuil et al., 2018; Howard et al., 2022; Jayasinghe et al., 2019, 2021; Kirk et al., 2016; Paczynski et al., 2006; Pawlak et al., 2016; Prša et al., 2011, 2022; Slawson et al., 2011; Soszynski et al., 2016). The largest collection recently released is the Gaia catalogue of EBs by Mowlavi et al. (2023), which contains more than two million stars.

The main goal of this work was to search for variability among hot B stars in the direction of the galactic anticenter and find binary systems showing pulsation effects.

2. Observations and Data Processing

As a main source for time-series photometric data we used the TESS light curves available through the Mikulski Archive for Space Telescopes (MAST) database.

The TESS is a near all-sky photometric survey searching for exoplanets transiting mainly nearby bright main sequence stars. TESS splits most of the sky into sectors and observes each for a minimum time baseline of 27 days. During the first two years of the mission, TESS observed about 160,000 selected stars at a 2 minutes cadence, and obtained 30 minutes cadence full-frame images (FFIs) for the entire sector region. In

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July of 2022, TESS completed its primary mission and began its first Extended Mission which switched to a 10 minutes cadence for FFIs. Starting in September of 2022, TESS began its second Extended Mission and increased the cadence for the FFIs to 200s.

In this work we used the catalog of spectral and luminosity classes of 6,037 stars in the direction of the Galaxy anticenter (Chargeishvili, 1988) as a basis for selection of B star subsample. We performed cross identification of this catalog with TESS Input Catalog and Gaia DR3 (Gaia Collaboration, et al., 2023) using ICRS equatorial coordinates from the source catalog through TAP Vizier Service using ADQL script. The final output subsample catalogue consists of 2067 stars covering whole B spectral and luminosity classes including peculiar B stars.

For the detection of the binary systems, we used the list of TESS TIC identifiers of the final subsample to download Quick-Look Pipeline (QLP) light curves from the MAST in FITS format tables and processed all of them using interactive python code with `tkinter` interface specially developed for this work by Kvernadze, T. (private communication). The code allows to combine the light curves for a selected sectors for a given star. Then it is possible to reject the outliers, de-trend a light curve using a cubic spline curve fitting algorithm from `scipy` package (Virtanen et al., 2020), make a frequency analyze using Lomb-Scargle periodogram from `astropy` (Price-Whelan et al., 2018), detect pulsating or transiting events and separate them if both exist. Further, we can build the phase curves using `PyAstronomy` package (Czesla et al., 2019) and plot them. The code calculates transit period and epoch for a selected time interval using Optimized Transit Detection algorithm of `TransitLeastSquare` package (Hippke & Heller, 2019) and allows also to export the final data for further analysis in other software packages.

TESS observed all our subsample stars in different sectors with various cadence: 19 – 1800 s; 43, 44, 45 – 600 s; 71 and 72 – 200 s. We used for analyze the data only from sectors 43-45 and 71-72 as they exist for all the stars and have good cadence cover.

3. Star Contamination Problems in TESS Images

The TESS payload consists of four identical cameras and a Data Handling Unit (DHU). Each camera consists of a lens assembly with seven optical elements, and a detector assembly with four CCDs and their associated electronics. All four cameras are mounted onto a single plate. The Table 1 shows the TESS Space Telescope and instrumentation parameters:

Number of cameras	4
CCDs per camera	4
Camera FOV	24°x 24°
CCDs	MIT/LL CCID-80
CCD dimensions	2048 × 2048 pixels
Pixel size	15 µm
Image scale per pixel	21″
Lens diameter	105 mm
Lens Focal Length	146 mm
Bandpass	600-1040 nm

Due to large image scale there are well known star contamination problems in the TESS light curves. Very often variability signals overlap in the neighboring stars and sometimes it is impossible to distinguish the source of a certain variability. This problem is well illustrated in a Figure 1, which shows the TESS star TIC 77709231 area star map from CDS portal (left) and the TESS Target Pixel File for the same star overplotted with the Gaia stars.

To avoid such contaminated false signals we analyzed each pixel surrounding a certain star from our list with a special python code which plots an area with short portion of a light curve for every pixel (see Figure 2) and allows to select a pixel in this area showing its light curve. Finally we extracted a light curve from a selected pixel apparently free of contamination. This was done for every sector and than all the data were combined into all sector light curve for further analyze.

This method helped us to find 2 new fainter EB stars: TIC 79967819 (Period 7.345 d, Epoch 2479.15 JD) and TIC 239811589 (Period 21.544, Epoch 2488.42) which was misidentified by Ijspeert & et al. (2024) as TIC 239811582.

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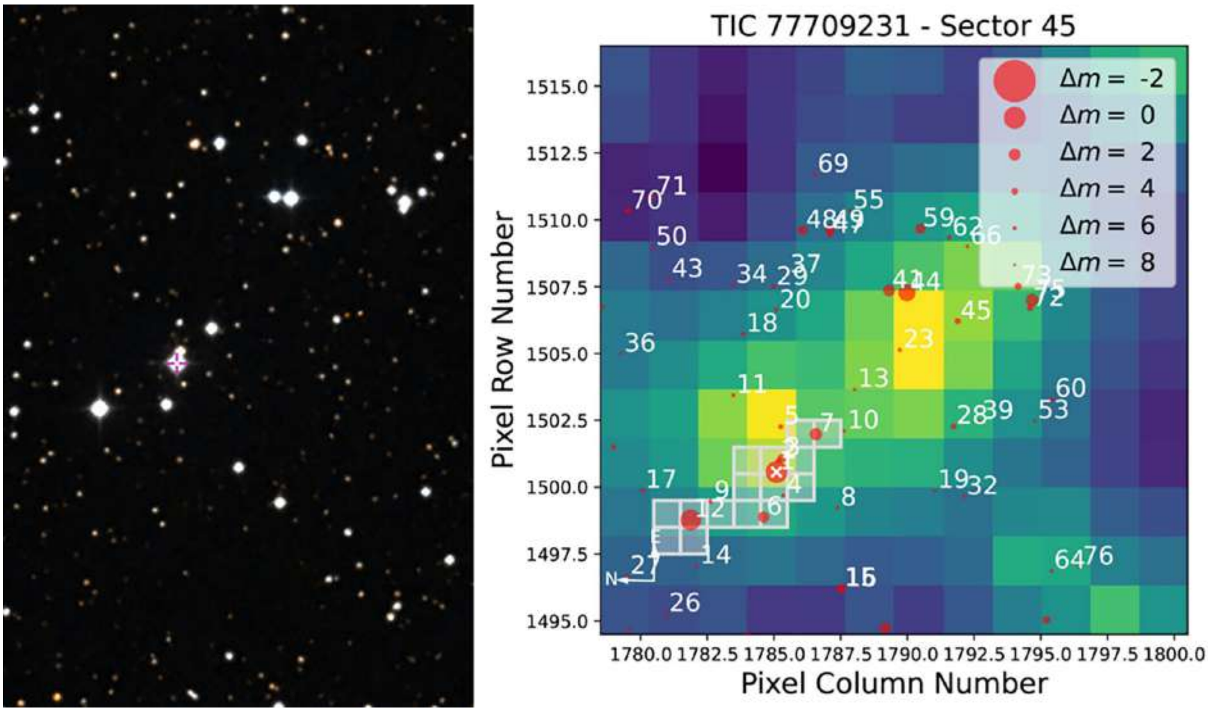

Figure 1. TIC 77709231 area star map on the left and the TESS Target Pixel File overplotted with the Gaia stars.

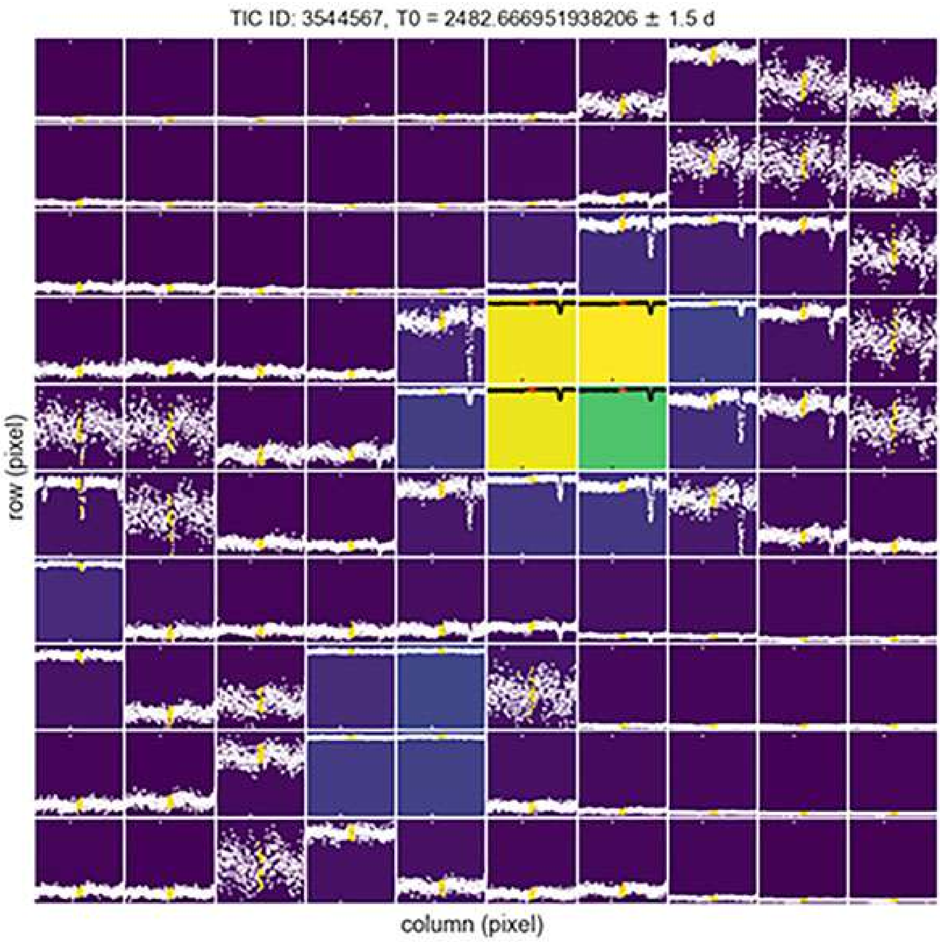

Figure 2. The light curves per pixel around star TIC 3544567.

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4. Results and Discussion

As a result we found about 100 stars having transit events in their TESS light curves. Many of those stars are already discovered and classified by different surveys (Heinze & et al., 2018; Ijspeert & et al., 2024; Wozniak et al., 2004). We selected and are presenting here 23 new detached eclipsing binary stars. Table 2 contains 11 stars having no pulsation in their light curves and 9 of which have large eccentricities. The 7 stars are included in some EB catalogues, but have incorrect periods. These stars are marked in the column 'note' and details are indicated in the footnote of the table.

The Table 3 shows 12 EB stars which also have pulsation in their light curves.

Table 1. New Eclipsing Binaries with large eccentricity in the Galactic Anticenter Direction

#	TIC ID	RA (J2000)	DEC (J2000)	Sp. Type	Dist. pc	V mag.	Period days	Epoch JD	ecc. phase un.	note
1	6496462	05:22:35.46	+22:42:57.2	B8 IV	530	11.36	6.641	2477.08	-	a
2	29272197	05:44:26.02	+23:37:45.9	-	820	12.09	10.523	2479.59	0.179	b
3	74975199	05:38:07.42	+24:18:51.9	B8 III	603	9.24	5.787	2478.47	0.554	c
4	76637917	05:48:30.10	+26:39:17.3	B2 IV	1136	10.59	22.667	2495.40	0.9	
5	77707971	05:51:47.04	+26:35:01.6	B8 IV	1106	11.57	1.128	2501.01	0.41	
6	77709231	05:51:42.53	+26:03:54.6	B2 III	1314	10.37	14.960	2502.52	0.13	
7	78064849	05:54:02.24	+28:49:25.4	B3 III	1785	11.78	6.458	2474.34	0.2	d
8	79967819	06:03:26.03	+29:21:03.8	-	1874	13.84	7.345	2479.15	0.499	
9	81187194	06:07:12.44	+24:38:48.9	B8 III	988	10.90	3.564	2474.47	0.655	e
10	239715814	05:27:44.49	+33:46:48.9	B3 III	531	9.63	9.504	2475.74	-	f
11	239811589	05:48:40.22	+30:13:29.6	-	3520	14.39	21.544	2488.42	0.68	g

Note of Alternative Periods (days): a - 1.02 (Wozniak et al., 2004), b - 12.37 (Heinze & et al., 2018) and 10.49 (Ijspeert & et al., 2024), c - 11.57 (Ijspeert & et al., 2024), d - 25.84 (Ijspeert & et al., 2024), e - 1.79 or 1.59 (Ijspeert & et al., 2024), f - 4.75 (Ijspeert & et al., 2024), g - 21.54 for 239811582 (Ijspeert & et al., 2024)

Table 2. New Pulsating Eclipsing Binaries in Galactic Anticenter Direction

#	TIC ID	RA (J2000)	DEC (J2000)	Sp. Type	Dist. pc	V mag.	Period days	Epoch JD	Main Puls. Per., d	note
1	3544567	05:31:22.19	+30:48:47.6	B5 II	1170	10.76	9.934	2483.90	10.25	a
2	76377679	05:46:34.16	+29:32:25.0	B8 V	1554	11.15	10.293	2504.80	1.827	b
3	76636939	05:48:34.09	+27:11:31.0	B9 V	1300	10.91	2.013	2502.13	0.5106	
4	80983687	06:06:57.30	+25:48:28.4	B8 V	891	11.02	0.620	2475.33		
5	81066202	06:06:57.91	+29:03:28.8	B0 I	2457	10.73	1.950	2488.00		
6	115388543	05:34:41.85	+33:53:57.5	B2 I	1821	10.79	4.972	2476.02		
7	115735790	05:36:54.23	+32:17:59.8	B5 III	801	11.50	2.290	2474.53		
8	116063559	05:38:31.82	+33:17:11.5	B3 IV	1251	9.70	2.678	2474.97		
9	127843251	05:25:41.71	+30:57:28.5	B2 V	1612	9.16	1.947	2475.49		
10	239816243	05:48:38.17	+31:58:29.8	B9 V	1141	10.57	8.362	2474.46	-	
11	285555623	05:26:20.12	+25:05:22.1	B5 V	1274	10.48	1.588	2475.08		
12	285966872	05:28:51.02	+26:28:09.0	B8 III	1519	12.06	10.424	2476.01		

Note of Alternative Periods (days): a - 5.94 (Wozniak et al., 2004), b - 5.13 (Wozniak et al., 2004))

Figure 3 depicts the phase curve of a detached eclipsing binary star TIC 29272197, which has high eccentricity of 0.179 in a phase curve units. This star is included in the catalogues of Heinze & et al. (2018) and Ijspeert & et al. (2024), but with somewhat different periods.

Figure 4 depicts the pulsation only light curve and eclipsing signal phase curve of the star TIC 77709231, separated using original python code. The phase curve shows high eccentricity of this binary equal to 0.13 in phase units.

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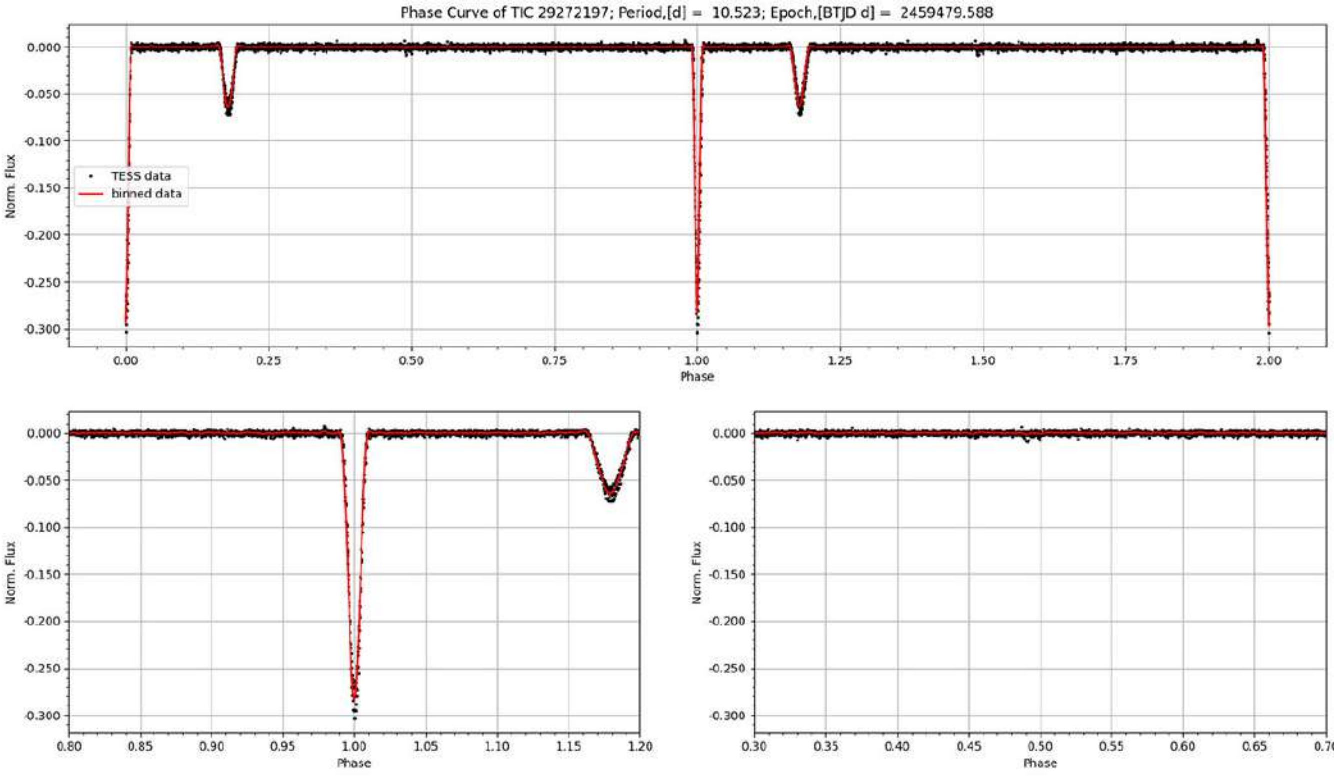

Figure 3. Phase curve of a detached eclipsing binary star TIC 29272197 with high eccentricity. The parts of the phase curve at the phases of 1.0 and 0.5 are zoomed and shown at the bottom.

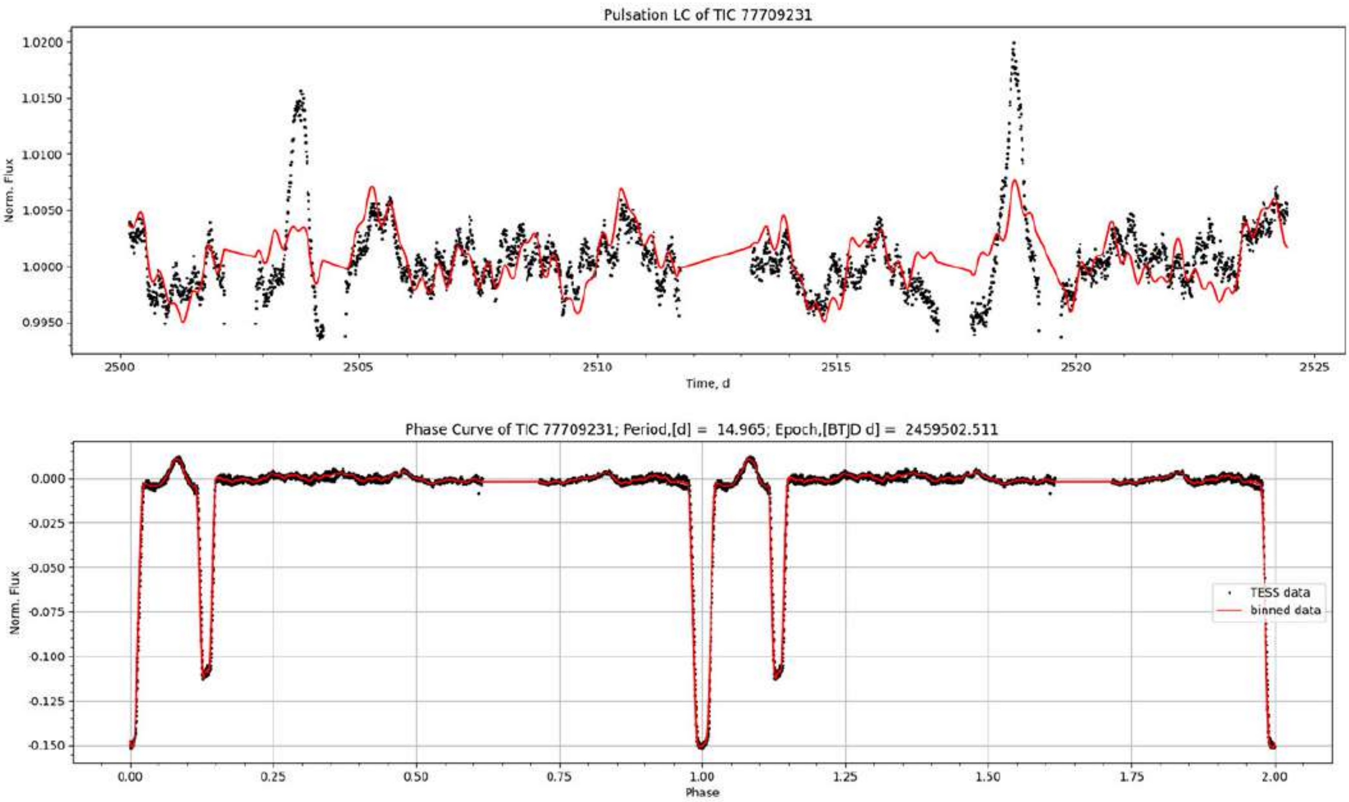

Figure 4. Pulsation only light curve (top) and a phase curve of an eclipsing event (bottom) of the detached eclipsing binary star with a large eccentricity TIC 77709231.

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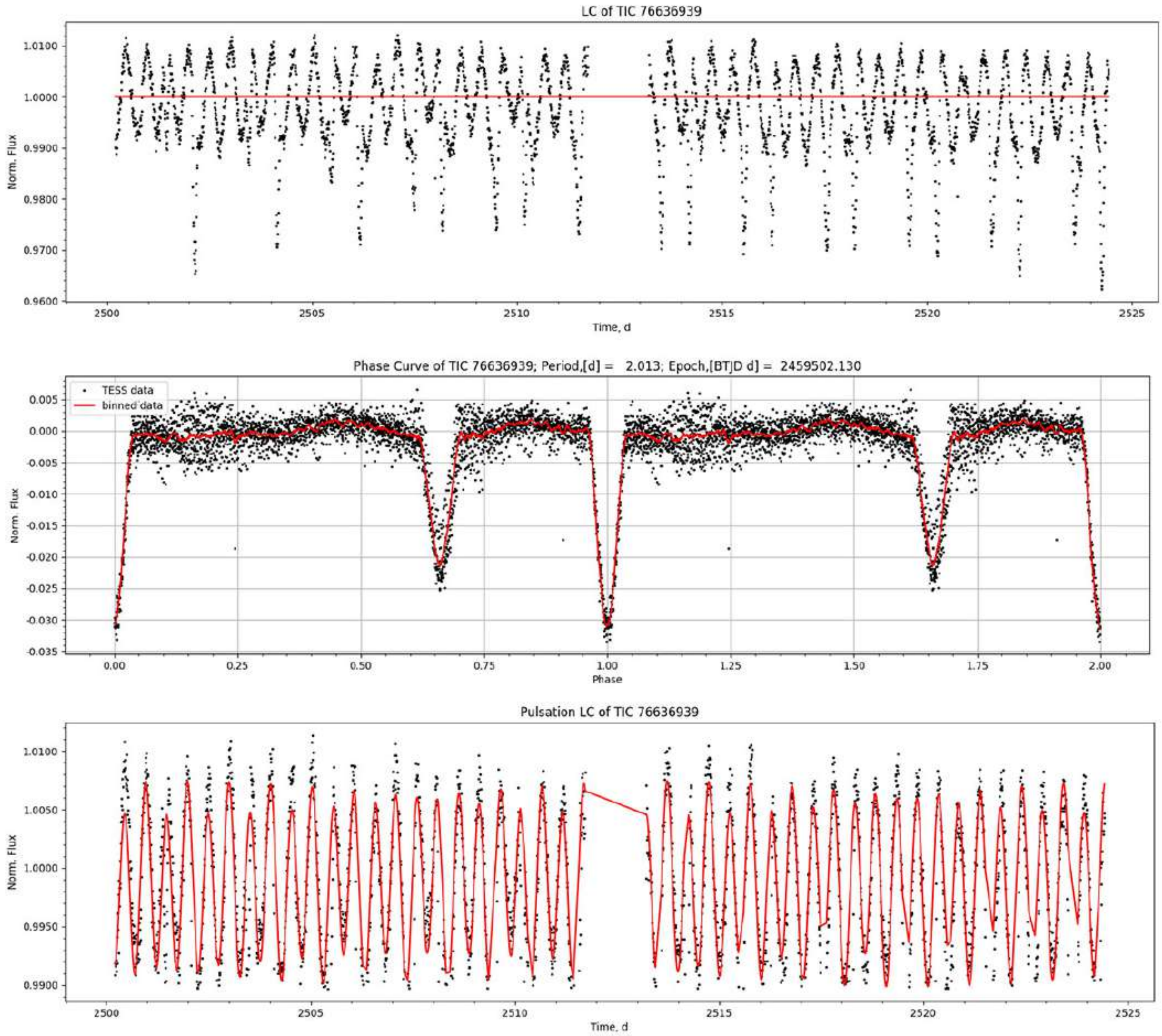

Figure 5. Source light curve (top), extracted eclipsing binary phase curve (middle) and pure pulsation light curve (bottom) of a new pulsating eclipsing binary star with a large eccentricity TIC 76636939.

References

Auvergne M., Bodin P., Boisnard L., et al. 2009, Astronomy and Astrophysics, 506, 411

Borucki W. J., 2016, Reports on Progress in Physics, 79, 036901

Chambers K., Magnier E., Metcalfe N., et al. 2016, eprint arXiv, 1612.05560

Chargeishvili K., 1988, Abastumani Astrofiz. Obs. Bull., 65, 18

Czesla S., Schröter S., Schneider C., et al. 2019, Astrophysics Source Code Library, 1906.010

Deleuil M., Aigrain S., Moutou C., et al. 2018, Astronomy and Astrophysics, 619, A97

Gaia Collaboration, Prusti T., de Bruijne J. H. J., et al. 2016, Astronomy and Astrophysics, 595, 36

Gaia Collaboration, Vallenari A., Brown A., et al. 2023, Astronomy and Astrophysics, 674, 22

Heinze A., et al. 2018, AJ, 156:241, 49

Hippke M., Heller R., 2019, Astronomy and Astrophysics, 623, A39

Howard E. L., Davenport J. R. A., Covey K. R., 2022, Res. Notes Am. Astron. Soc., 6, 96

doi: https://doi.org/10.52526/25792776-2025.72.1-23

IJspeert L. W., Tkachenko A., Johnston C., et al. 2021, Astronomy and Astrophysics, 652, A120

Ijspeert L., et al. 2024, Astronomy and Astrophysics, 691, A242

Jayasinghe T., Stanek K. Z., Kochanek C. S., et al. 2019, MNRAS, 486, 1907

Jayasinghe T., Kochanek C. S., Stanek K. Z., et al. 2021, MNRAS, 503, 200

Kirk B., Conroy K., Prša A., et al. 2016, AJ, 151, 68

Mowlavi N., Holl B., Lecoeur-Taïbi I., et al. 2023, Astronomy and Astrophysics, 674, A16

Paczynski B., Szczygiel D., Pilecki B., Pojmanski G., 2006, MNRAS, 368, 1311

Pawlak M., Soszynski I., Udalski A., et al. 2016, Acta Astron., 66, 421

Pepper J., et al. 2012, AAS Meeting, 219, 125.06

Pojmanski G., Pilecki B., Szczygiel D., 2005, Acta Astronomica, 55, 275

Pollacco D. L., Skillen I., Collier Cameron A. e. a., 2006, The Publications of the Astronomical Society of the Pacific, 118, 1407

Price-Whelan A. M., Sipőcz B. M., Günther H. M., Lim P. L., Crawford S. M., et al. 2018, Astron. J. , 156, 123

Prša A., Batalha N., Slawson R. W., et al. 2011, AJ, 141, 83

Prša A., Kochoska A., Conroy K. E., et al. 2022, ApJS, 258, 16

Rauer H., Catala C., Aerts C. e. a., 2014, Experimental Astronomy, 38, 249

Ricker G. R., Winn J. N., Vanderspek R., et al. 2015, Journal of Astronomical Telescopes, Instruments, and Systems, 1, 014003

Slawson R. W. Prša A., Welsh W. F., et al. 2011, AJ, 142, 160

Soszynski I., Pawlak M., Pietrukowicz P., et al. 2016, Acta Astronomica, 66, 405

Udalski A., Szymański M. K., Szymański G., 2015, Acta Astronomica, 65, 1

Virtanen P., et al., 2020, Nature Methods, 17, 261

Wozniak P., Vestrand W., Akerlof C., et al. 2004, AJ, 127, 2436

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