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2MASS J23453766+7134365, New Eclipsing Binary with a Possible Pulsating Component

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We present our study of 2MASS J23453766+7134365, an eclipsing variable star with a possible pulsating component, from a field in Cepheus. The star exhibits V-shaped eclipses with a depth of approximately $0\overset{m}{.}25$ in the V band every $2\overset{d}{.}44$; secondary minima are not detected. Also, sinusoidal brightness variations are detected with an amplitude of less than $0\overset{m}{.}1$ and a period of $0\overset{d}{.}6791$. They appear and disappear quasi-periodically with a characteristic time of several days. For the study of this star, we used the archive of Astrosib RC500 telescope (Mt. Terskol observatory). We conducted follow-up observations with the RC600 telescope (Caucasian Mountain Observatory) and Astrosib RC500 telescope (INASAN Kislovodsk observatory). Also, we used photometric data from the ZTF, ASAS-SN, and TESS surveys.

1 Variability discovery of 2MASS J23453766+7134365

In 2022, a long time series of a field in Cepheus (approximate center $23^{h}46^{m}00^{s}$, $+71°30'$, J2000) was obtained using the Astrosib RC-500 telescope of Terskol observatory during photometric monitoring of program objects. A log of observations of this field is presented in Table 1. In total, we acquired 4067 measurements in the V band and 4742, in the R band.

Astrosib RC-500 is a Ritchie–Chretien narrow-field photometric telescope with the focal ratio $F/8$ and aperture 500 mm. It is equipped with a Fli Proline 16803 CCD camera. The camera chip size is 4096×4096 pixels, with the pixel size of 9 microns. When using a 36×36 mm CCD detector, the telescope's field of view is $30' \times 30'$. The telescope is equipped with a Bessel system $UBVRI$ filter wheel for multicolor photometry. It is installed on an Astrosib FM700 mount with worm drives. The telescope is installed as a part of the program of the Institute of Astronomy of Russian Academy of Sciences aimed at creating robotic observatories (Naroenkov & Nalivkin 2018, 2019) and operates in an automatic mode.

The telescope's field of view and long exposures used during observations of the field mentioned above made it possible to conduct variable star search in this data. Time series of archive observations were processed with the VaST software package (Sokolovsky & Lebedev 2018) to detect variable objects. We found a photometrically variable source not mentioned as a known variable in the VSX database[1] or in the GCVS (Samus et al. 2017). It was identified as 2MASS J23453766+7134365 (further, 2M2345) in the 2MASS All-Sky Catalog of Point Sources (Cutri et al. 2003).

[1] https://www.aavso.org/vsx/

Table 1. Observations of the field in Cepheus with Astrosib RC500-Terskol

Date	Filter	No. of observations
2022-09-05	V	220
2022-09-10	V	169
2022-09-11	V	197
2022-09-14	V	130
2022-09-15	V	228
2022-09-17	V	92
2022-09-19	V	532
2022-09-20	V	285
2022-09-23	V	147
2022-09-24	V	118
2022-09-27	V	253
2022-09-30	V	388
2022-10-06	V	222
2022-10-07	R	357
2022-10-11	V	227
2022-10-12	V	378
2022-10-13	V	255
2022-10-14	V	226
2022-10-25	R	346
2022-10-28	R	289
2022-10-29	R	446
2022-10-30	R	320
2022-11-01	R	210
2022-11-06	R	384
2022-11-07	R	231
2022-11-08	R	475
2022-11-10	R	381
2022-11-11	R	216
2022-11-12	R	439
2022-11-14	R	446
2022-11-15	R	202

2 Data collection and reduction

Because the target star observed in the archival dataset is significantly brighter than 2M2345, the exposures of the archival frames were too short to derive the light curve and light elements of 2M2345 with a high precision. To overcome this problem, we collected ZTF photometry (Bellm et al. 2019; Masci et al. 2019) using the SNAD ZTF viewer (Malanchev et al. 2023), ASAS-SN photometry (Shappee et al. 2014), and TESS data (Ricker et al. 2014); they were processed using the Lightkurve library algorithms (Lightkurve Collaboration, 2018). Reductions of TESS data are described in detail in Tarasenkov (2024). The light elements were determined using the WinEfk tool developed by V. P. Goranskij[2]. The archival light curve, folded with the elements we obtained, is presented in Fig. 1. The coordinates and parallax were taken from Gaia DR3 (Gaia Collaboration 2023).

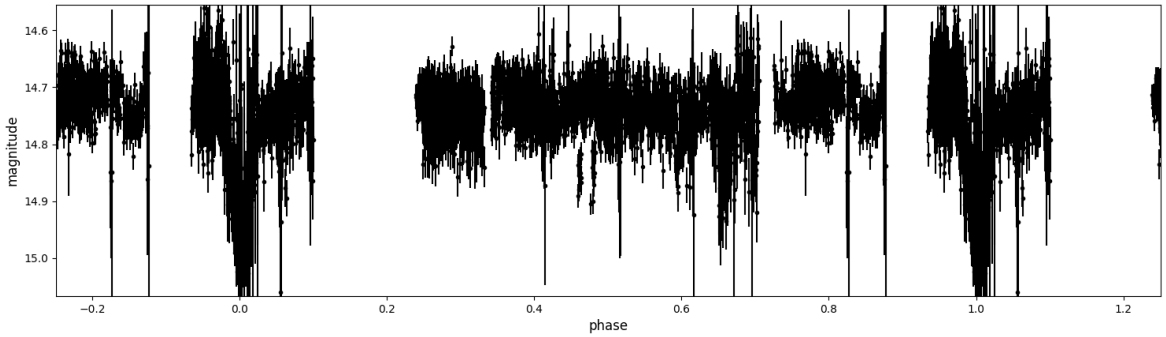

Figure 1.
Terskol archive light curve, filter V.

We also conducted follow-up observations with the RC600 telescope of the Caucasian Mountain Observatory (Berdnikov et al. 2020) and the Astrosib RC500 telescope of the INASAN Kislovodsk Observatory (Naroenkov et al. 2024). In total, we obtained 413 measurements in the V band, 1382 measurements in the R band, along with magnitude estimates in U, B, and I. The log of our follow-up observations can be found in Table 2.

To perform photometry, we used AstroimageJ software (Collins et al. 2017). We analyzed nearby stars and selected non-variable ones, with magnitudes and color indices close to those of 2M2345, as photometric standards. The $UBVRI$ magnitudes of standard stars were taken from APASS (Henden et al. 2012) and the Gaia DR3 Syntphot catalogue (Gaia Collaboration et al. 2023). A finding chart with comparison stars is shown in Fig. 2.

3 Stellar characteristics and evidence for pulsations

The star exhibits V-shaped eclipses with a depth of approximately $0\overset{\mathrm{m}}{.}25$ in the V band every $2\overset{\mathrm{d}}{.}4405$; secondary minima are not detected. This indicates that eclipses are tangential, and the brightness of the secondary component may be significantly lower than that of the primary. The light elements for eclipses are: Min $= 2460365.975 + 2\overset{\mathrm{d}}{.}4405 \times E$. The light curves of 2M2345, folded with these elements, are shown in Fig. 3 (TESS data) and Fig. 4 (our observations and ZTF data).

Table 2. Follow-up time series observations of 2MASS J23453766+7134365

Date	Filter	No. of observations	Telescope
2023-11-07	R	120	RC500-Terskol
2023-11-11	R	51	RC500-Terskol
2023-11-11	V	37	RC600-CMO
2023-12-07	R	60	RC500-Kislovodsk
2024-01-03	R	18	RC500-Kislovodsk
2024-01-24	V	188	RC600-CMO
2024-01-30	R	70	RC500-Kislovodsk
2024-02-24	U	17	RC500-Kislovodsk
2024-02-24	B	17	RC500-Kislovodsk
2024-02-24	V	188	RC500-Kislovodsk
2024-02-24	R	17	RC500-Kislovodsk
2024-02-24	I	17	RC500-Kislovodsk
2024-03-03	R	90	RC500-Kislovodsk
2024-04-02	R	214	RC500-Kislovodsk
2024-04-28	R	130	RC500-Kislovodsk
2024-05-19	R	189	RC500-Kislovodsk
2024-05-22	R	90	RC500-Kislovodsk
2024-06-11	R	125	RC500-Kislovodsk
2024-06-16	R	24	RC500-Kislovodsk
2024-06-21	R	62	RC500-Kislovodsk
2024-06-23	R	122	RC500-Kislovodsk

Also, sinusoidal brightness variations are detected with an amplitude of about $0\overset{\mathrm{m}}{.}1$ and a period of $0\overset{\mathrm{d}}{.}6791$. The ephemeris for them is Max $= 2458373.245 + 0\overset{\mathrm{d}}{.}6791 \times E$. These variations are visible both in ground-based observations (Fig. 5, folded RC500-Kislovodsk and ZTF data) and in TESS space mission photometry (Fig. 6, folded Sector 52 data). They appear and disappear quasi-periodically with a characteristic time of several (6–7) days. Such variations may be associated with pulsations of one of the components of the binary system caused by tidal interactions (Jayaraman et al. 2024). This effect is clearly visible in TESS light curves (Figs. 7–8) and is stable on timescales of years (Sector 17–18 data were obtained in 2019, while Sectors 78–79 were observed in 2024).

According to color–spectral type relations (Fitzgerald 1970; Ducati et al. 2001), the "integral" spectral type of the system is K2–K5.

Main properties of 2M2345 are presented in Table 3.

4 Results and conclusions

2MASS J23453766+7134365 was detected in the archive of Astrosib RC500 telescope of the Terskol observatory and identified as an eclipsing variable star with the period $2\overset{\mathrm{d}}{.}4405$. The primary eclipses are V-shaped with a depth of approximately $0\overset{\mathrm{m}}{.}25$ in V band; secondary minima are not detected. Also, sinusoidal brightness variations are detected with an amplitude of less than $0\overset{\mathrm{m}}{.}1$ and a period of $0\overset{\mathrm{d}}{.}6791$. They appear and

[2] http://www.vgoranskij.net/software/WinEFengVers2015-09-08.zip

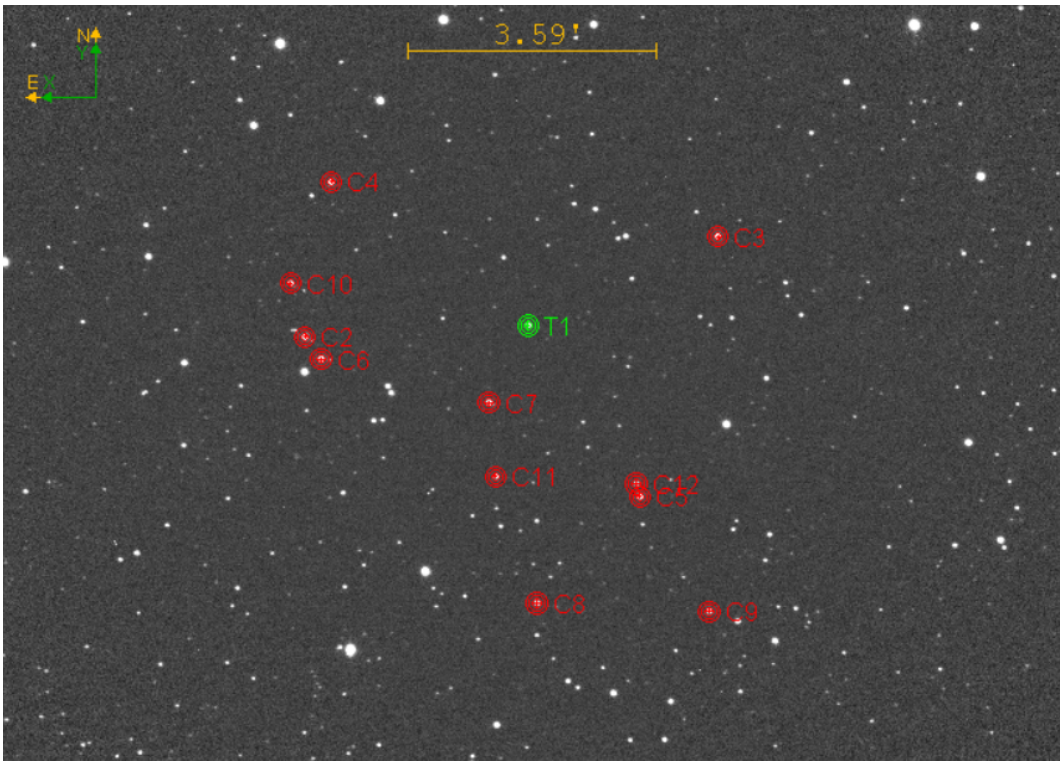

Figure 2.
The RC500-Kislovodsk field. 2MASS J23453766+713436 is marked with a green circle and signed T1, photometric comparison stars are marked with red circles and signed C2–C12.

disappear quasi-periodically, with a characteristic time from 6 to 7 days. This effect may be a consequence of pulsations of one of the components.

For further study of the star, we conducted follow-up observations with the RC600 telescope (Caucasian Mountain Observatory) and the Astrosib RC500 telescope of the INASAN Kislovodsk observatory; we also collected photometric data from the ZTF, ASAS-SN, and TESS surveys. High-quality light curves in many photometric bands were obtained, and the light elements of the system were derived. The light elements for eclipses are $\mathrm{Min} = 2460365.975 + 2\overset{\mathrm{d}}{.}4405 \times E$; for sinusoidal variations, the light elements are $\mathrm{Max} = 2458373.245 + 0\overset{\mathrm{d}}{.}6791 \times E$. The nature of the object is not fully understood, and it requires further research.

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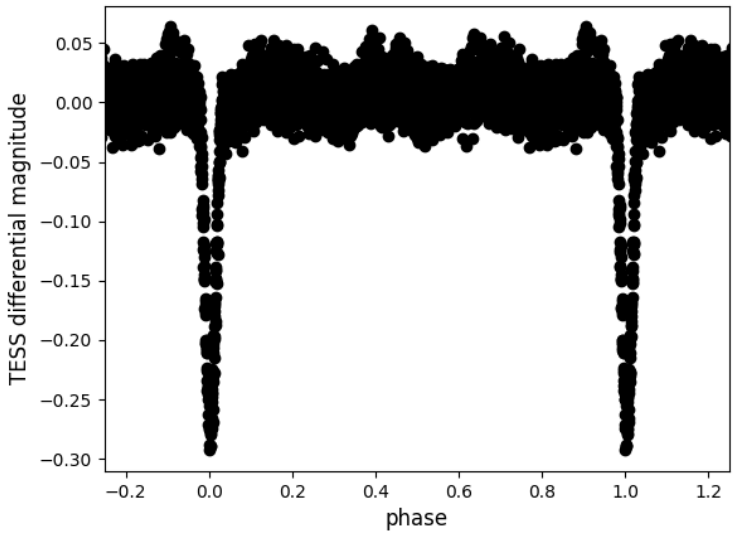

Figure 3.
TESS Sector 52 light curve, folded with the eclipse period $2\overset{\mathrm{d}}{.}4405$.

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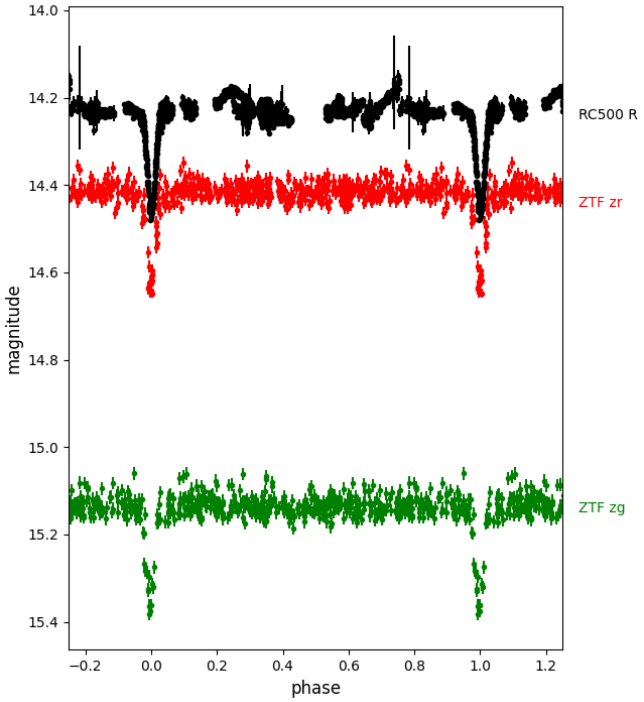

Figure 4.
Astrosib RC500-Kislovodsk and ZTF light curves, folded with the light elements Min = 2460365.975 + $2^{\mathrm{d}}.4405 \times E$.

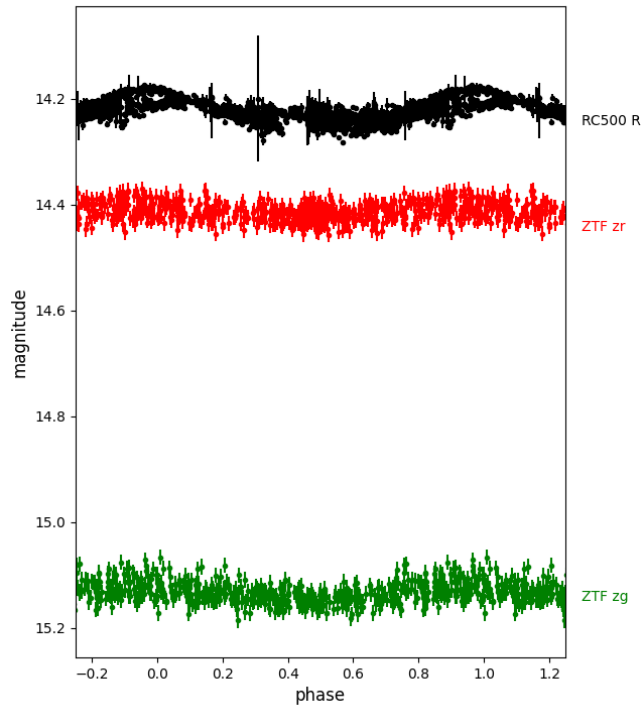

Figure 5.
Astrosib RC500-Kislovodsk and ZTF light curves, folded with light elements Max = 2458373.245 + $0^{\mathrm{d}}.6791 \times E$. Eclipses are excluded.

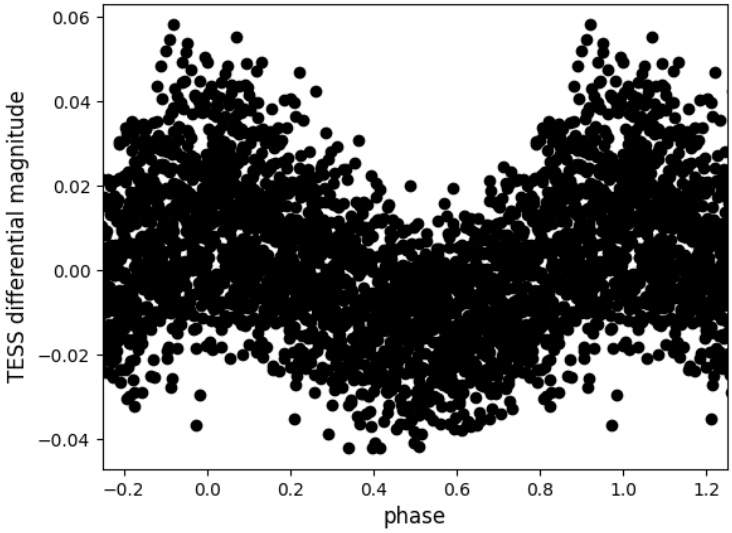

Figure 6.
TESS Sector 52 light curve in pulsation-active state, folded with the period $0\overset{\mathrm{d}}{.}6791$. Eclipses are excluded.

Table 3. Properties of 2MASS J23453766+7134365

Parameter	Value	Source
RA J2000	$23^{\mathrm{h}}45^{\mathrm{m}}37\overset{\mathrm{s}}{.}67$	Gaia DR3 (Gaia Collaboration et al. 2023)
DEC J2000	$71°34'36\overset{''}{.}36$	Gaia DR3 (Gaia Collaboration et al. 2023)
Parallax, mas	0.6360 ± 0.0158	Gaia DR3 (Gaia Collaboration et al. 2023)
Orbital period	$2\overset{\mathrm{d}}{.}4405$	This work
Pulsation period	$0\overset{\mathrm{d}}{.}6791$	This work
U magnitude	$16\overset{\mathrm{m}}{.}03 \pm 0\overset{\mathrm{m}}{.}32$	This work
B magnitude	$15\overset{\mathrm{m}}{.}67 \pm 0\overset{\mathrm{m}}{.}07$	This work
V magnitude	$14\overset{\mathrm{m}}{.}78 \pm 0\overset{\mathrm{m}}{.}08$	This work
R magnitude	$14\overset{\mathrm{m}}{.}23 \pm 0\overset{\mathrm{m}}{.}03$	This work
I magnitude	$13\overset{\mathrm{m}}{.}70 \pm 0\overset{\mathrm{m}}{.}02$	This work
J magnitude	$12\overset{\mathrm{m}}{.}918 \pm 0.025$	2MASS (Cutri et al. 2003)
H magnitude	$12\overset{\mathrm{m}}{.}600 \pm 0\overset{\mathrm{m}}{.}028$	2MASS (Cutri et al. 2003)
K magnitude	$12\overset{\mathrm{m}}{.}473 \pm 0\overset{\mathrm{m}}{.}025$	2MASS (Cutri et al. 2003)
Luminosity, L_{Sun}	7.72	TIC v8.2 (Paegert et al. 2021)

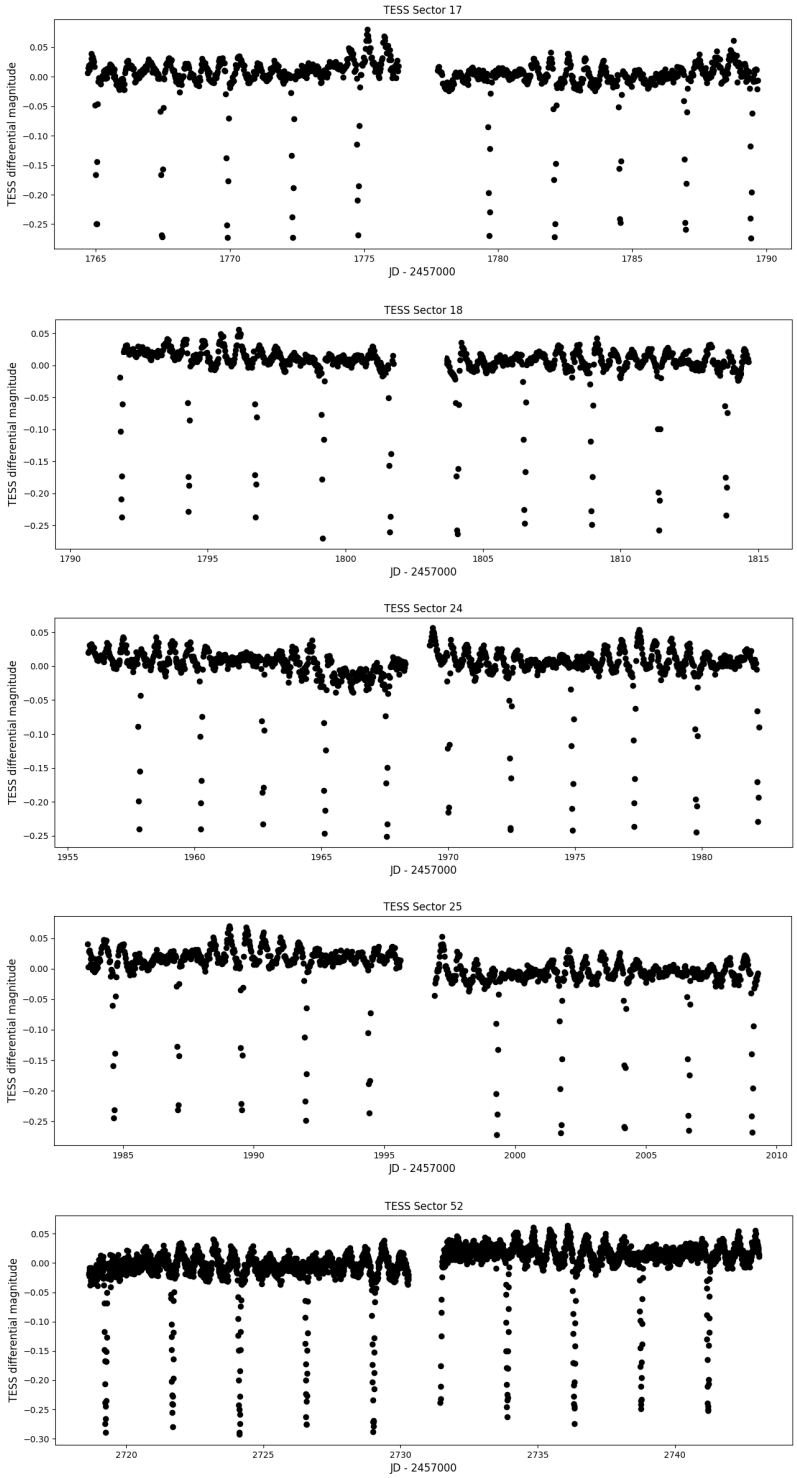

Figure 7.
TESS lightcurves of 2M2345, Sectors 17–52.

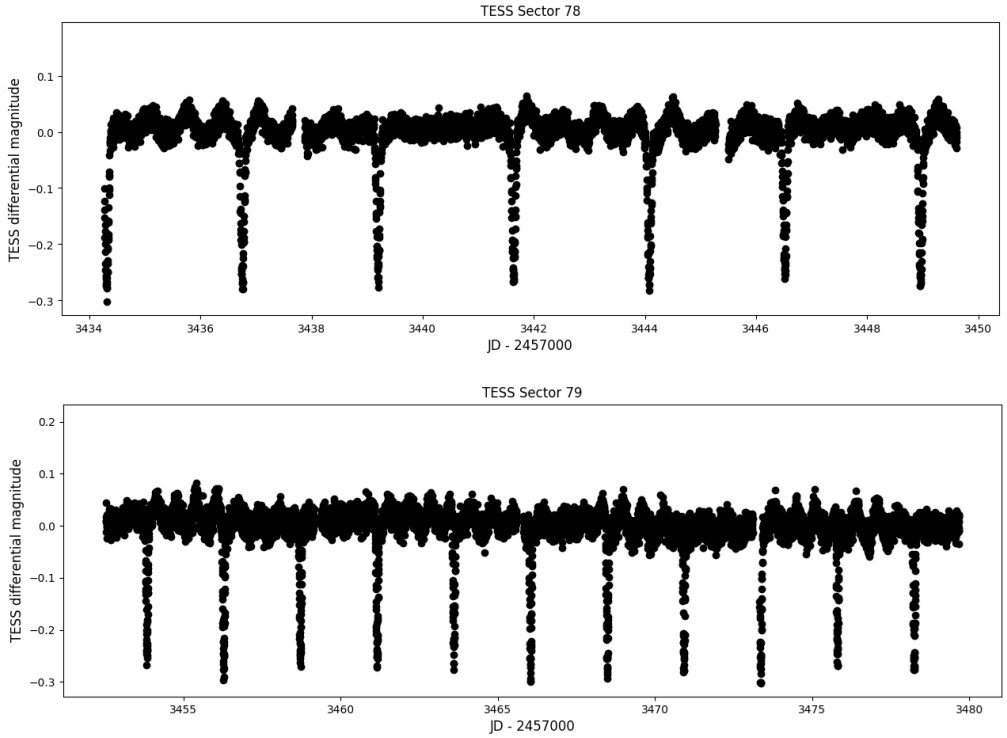

Figure 8.
TESS lightcurves of 2M2345, Sectors 78 and 79.