Peremennye Zvezdy (*Variable Stars*) **41**, No. 5, 2021

Received 7 September; accepted 29 September.

DOI: 10.24412/2221-0474-2021-41-19-26

Possible Periodic Spot Activity of the New W UMa-type Variable GSC 3599–2569

S.Yu. Gorda[1], Y.Yu. Vatolin[2]

[1] Kourovka Astronomical Observatory, Ural Federal University, Mira st. 19, Yekaterinburg, 620002 Russia

[2] Ural Federal University, Mira st. 19, Yekaterinburg, 620002 Russia

We present the results of long-term photometry (2009– 2021) of the new W UMa-type star GSC 3599–2569 discovered in 2013 at the Kourovka Observatory. We have found a change in the period of this eclipsing system. Based on more extensive observational data, the previously detected cyclical change in the brightness of the system, not associated with eclipses and caused by spot activity on the surface of the components, was confirmed. The length of this period has been specified. 11 new times of minima of GSC 3599–2569 are presented.

The variability of the star GSC 3599–2569 ($21^{\rm h}39^{\rm m}03\overset{\rm s}{.}991$, $+50°09'36\overset{''}{.}83$, 2000, Gaia EDR3) was discovered in 2013 during a search for stars exhibiting irregular brightness variations and located in the immediate vicinity of the young variable star V645 Cyg (Sobolev et al., 2013).

Data analysis showed that brightness variations of GSC 3599–2569 were periodic, $P = 0\overset{\rm d}{.}4029112 \pm 0\overset{\rm d}{.}0000002$, and the light curve had a shape typical of short-period eclipsing variables of the W UMa type (EW) with the same depths of minima (Gorda et al., 2015).

The finding chart of the new variable is presented in Fig. 1. Two stars in the immediate vicinity of the variable are marked as C and C1, they were used as the comparison and check star, respectively. The data for these stars are listed in Table 1. Unfortunately, in Gorda et al. (2015), the designations of the comparison and check stars are mistakenly exactly the opposite. Table 1 of the present paper presents the correct designations.

Table 1: Designations and coordinates of the stars

3UC	GSC	Design.	star	α(2000)	δ(2000)	m_V
281-202918	3599.2569	Var	variable	$21^{\rm h}39^{\rm m}03\overset{\rm s}{.}99$	$+50°09'36\overset{''}{.}8$	$13\overset{\rm m}{.}26$
281-203149	—	C	comparison	$21^{\rm h}39^{\rm m}16\overset{\rm s}{.}64$	$+50°07'19\overset{''}{.}7$	$13\overset{\rm m}{.}02$
281-203195	3599.2386	C1	check	$21^{\rm h}39^{\rm m}19\overset{\rm s}{.}55$	$+50°07'39\overset{''}{.}9$	$12\overset{\rm m}{.}53$

Long-term photometric observations of V645 Cyg and its vicinities were carried out from May 2009 to March 2018 with the AZT-3 reflector telescope ($D = 0.45$ m, $F_{\rm Newton} = 2.0$ m) and from February 2019 to April 2021 with the AstroSib-500RC Ricci-Chretien telescope ($D = 0.5$ m, $F = 4.0$ m) of Kourovka Astronomical Observatory of the Ural Federal University. Observations were carried out in the V and R filters, implementing a system close to the Johnson–Cousins system, when using Apogee Alta U6 CCD cameras with a Kodak KAF-1001E chip (1024×1024, 24 μm) and, since 2015, PL A230 of the

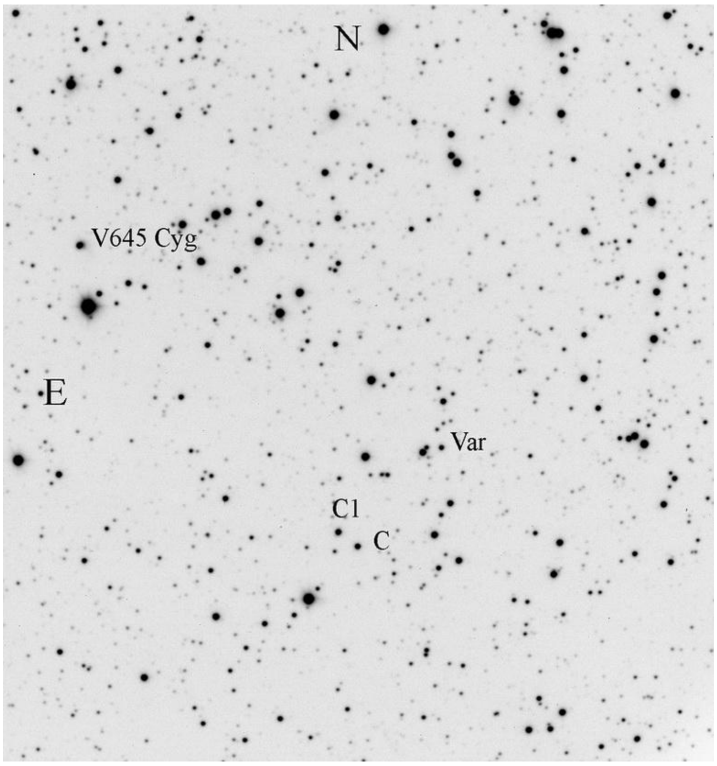

Figure 1. The finding chart for the new variable GSC 3599–2569, which is a 16.′7×17.′5 fragment of a frame taken with the 0.5-meter AstroSib-500RC telescope of Kourovka observatory. The variable star is marked as Var.

FLI company with an E2V 230-42 CCD chip (2048 × 2048, 15 μm). The working field sizes were $40' \times 40'$ and $24' \times 24'$, respectively for the first and second telescopes.

The results presented in Gorda et al. (2015) were obtained on the base of observations carried out from 2009 to 2013. Since observations of the star V645 Cyg were continued till 2021, a large number of frames of this area were obtained. It was interesting to continue the study of GSC 3599–2569 as well.

One of the results of the study of this eclipsing binary, presented in Gorda et al. (2015), was the discovery of small-amplitude fluctuations of the star's total brightness, not associated with the phenomena of eclipses and tidal deformations of the components of the eclipsing system. At present, effects of extra-eclipse low-amplitude brightness changes of EW eclipsing binaries are explained with the presence of cool or hot spots on the surfaces of their components. This idea was first proposed by Mullan (1975), who suggested that the presence and change of the magnetic fields of the components can lead to activity cycles similar to those observed for the Sun. For example, in the papers by Binnenijk (1984), Djurasević et al. (2001), and Zola et al. (2010), the extra-eclipse variations in the brightness of eclipsing W UMa systems are fully explained by the change in the area of spots on the surfaces of the components. Gorda (2020) discovered the cyclical nature of such brightness variations for the EW eclipsing variable AM Leo.

Cyclic brightness variations outside eclipses with a period of 940 days were also detected for the new variable star (Gorda et al., 2015). However, the derived period was comparable to the four-year observation interval of this star, which indicated insufficient reliability of the detected period. In order to confirm the presence of cyclic changes in the extra-eclipse brightness of the new close binary GSC 3599–2569 and to clarify the value of the period of these oscillations, we undertook this study.

Table 2: Times of minima of GSC 3599–2569. (O–C)I: calculated using a linear ephemeris; (O-C)II: calculated using a quadratic ephemeris

HJD 2450000+	Type of minimum	E	(O–C)I	(O–C)II
4979.35820	II	0.5	$0^{d}.00246$	$-0^{d}.00265$
5035.36540	II	139.5	0.00458	0.00010
5040.40000	I	152.0	0.00275	–0.00167
5089.35650	II	273.5	0.00517	0.00129
5092.37870	I	281.0	0.00552	0.00167
5153.21730	I	432.0	0.00407	0.00087
5176.18150	I	489.0	0.00216	–0.00080
5223.12250	II	605.5	0.00365	0.00117
5399.39400	I	1043.0	0.00017	–0.00061
5413.29580	II	1077.5	0.00143	0.00077
5414.30270	I	1080.0	0.00105	0.00040
5441.29710	I	1147.0	0.00019	–0.00021
5442.30580	II	1149.5	0.00161	0.00121
5478.16370	II	1238.5	0.00014	0.00006
5478.36430	I	1239.0	-0.00071	–0.00080
5533.16060	I	1375.0	-0.00075	–0.00036
5533.36200	II	1375.5	-0.00081	–0.00042
5543.23470	I	1400.0	0.00049	0.00097
5570.22820	I	1467.0	-0.00126	–0.00056
5582.11530	II	1496.5	-0.00013	0.00066
6205.21680	I	3043.0	-0.00548	–0.00071
6212.26750	II	3060.5	-0.00578	–0.00098
6274.11490	I	3214.0	-0.00572	–0.00063
6281.16600	II	3231.5	-0.00561	–0.00050
6517.27410	II	3817.5	-0.00525	0.00071
6853.30450	II	4651.5	-0.00532	0.00131
6912.33110	I	4798.0	-0.00565	0.00103
7281.19800	II	5713.5	-0.00673	–0.00015
8125.10350	I	7808.0	-0.00508	–0.00157
8131.14890	I	7823.0	-0.00339	0.00008
8225.42940	I	8057.0	-0.00482	–0.00194
8817.32030	I	9526.0	0.00508	0.00312
9119.30670	II	10275.5	0.00726	0.00209
9151.33580	I	10355.0	0.00468	–0.00086
9194.24780	II	10461.5	0.00632	0.00026
9195.25250	I	10464.0	0.00373	–0.00233

Photometric processing of CCD frames obtained after 2013 was carried out in the same manner as described in Gorda et al. (2015). During the processing, 11 new times of minima of the eclipsing binary were obtained. All times of minima derived by us from 2009 to 2021 are given in the first column of Table 2. The new times of minima are placed at the bottom part of Table 2 and are separated from earlier values with a horizontal line. Calculations of the times of minima using the linear ephemeris from Gorda et al. (2015) did not show a satisfactory agreement with the times of minima obtained from observations after 2014. We have derived a new linear formula using all the times of minima of this star obtained by us. The O–C residuals, i.e. differences between the times of minima obtained from observations and those calculated using the new ephemeris, are given in the fourth column of Table 2.

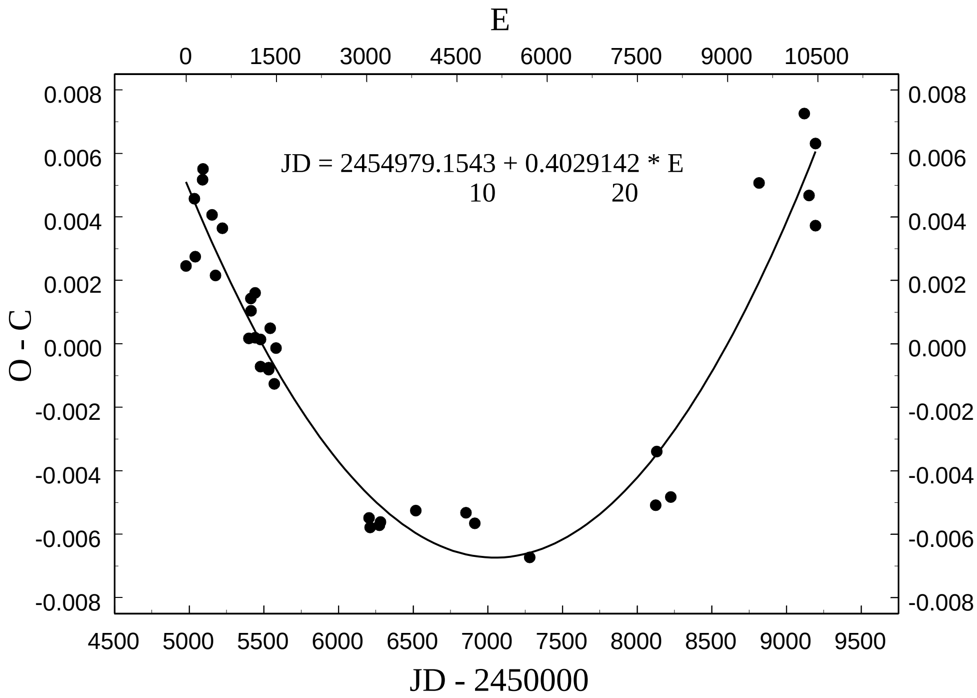

Figure 2. O–C residuals from the new linear formula versus time; dots are O–C residuals; the solid curve is the approximation parabola.

Figure 2 shows the O–C residuals for our new linear ephemeris versus time. We see that the O–C residuals are quite large and change with time in a nearly parabolic manner. This behavior of the O–C residuals indicates a change in the period of the eclipsing binary. Using a quadratic formula for calculating the times of minima permits to make the O–C residuals smaller by almost an order of magnitude (see the last column of Table 2). It appears from Fig. 3 that, in the case of calculating the times of minima using the quadratic formula, no systematic trend is found for the O–C residuals. The quadratic formula shown in Fig. 3 can be converted to a more convenient form for calculating photometric phases:

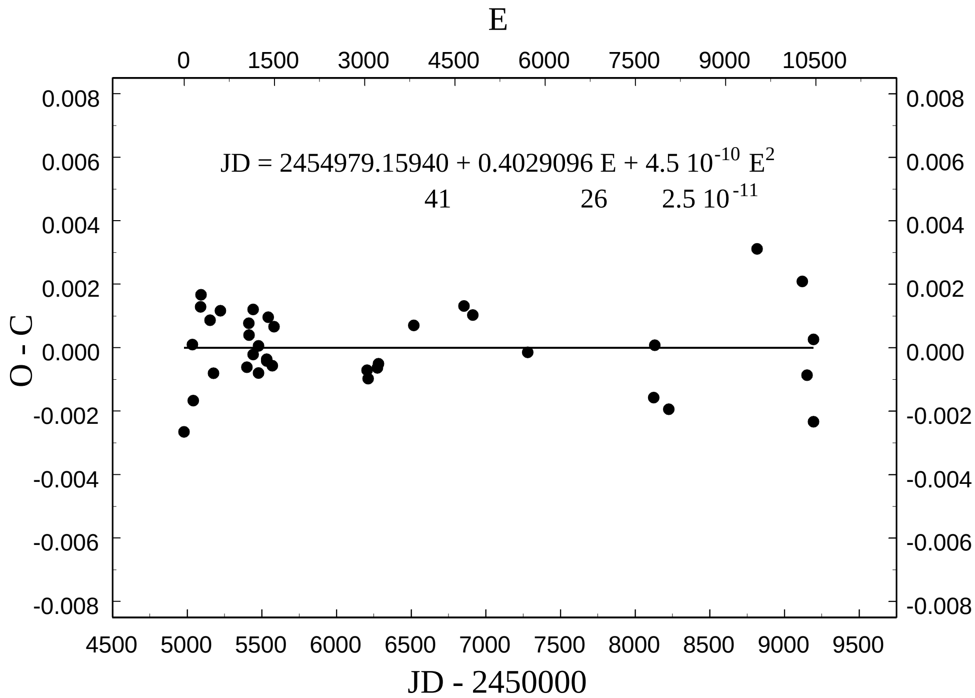

Figure 3. The O–C residuals when using the quadratic formula to calculate times of minima.

$$\mathrm{JD}_{\odot}\mathrm{Imin} = \underset{\pm 41}{2454979^{\mathrm{d}}.15940} + P' \cdot E. \tag{1}$$

$$P' = \underset{\pm 26}{0^{\mathrm{d}}.4029096} + \underset{\pm 2.5\cdot 10^{-11}}{4^{\mathrm{d}}.5 \cdot 10^{-10}} \cdot E. \tag{2}$$

Thus, at this time, the period of GSC 3599–2569 is $P' = 0^{\mathrm{d}}.4029143$. It is too early to discuss the true reasons for the change in the period of the eclipsing binary. At least three reasons can be suggested: mass transfer between the components, mass loss by the system, and the presence of a third body in the system.

After calculating the photometric phases, we found, as in the previous study, that the portions (segments) of the light curves of GSC 3599–2569 obtained on different nights at the same or close photometric phases were shifted relative to one another along the brightness axis. At the same time, the brightness differences between the comparison star and the check star remained unchanged within the observational errors ($\pm 0^{\mathrm{m}}.004 - \pm 0^{\mathrm{m}}.009$) throughout the entire time interval of our observations.

A new study of changes in the total brightness of GSC 3599–2569, not associated with the phenomena of eclipses and effects of tidal deformation of the components, was carried out using the method that we had previously used for similar purposes (Gorda et al., 2015; Gorda, 2020). The essence of the method is to calculate the night-average brightness difference between the light curve (segment of the light curve) obtained on a given night and the reference, theoretical curve synthesized on the basis of reliably established parameters of the eclipsing binary. For these purposes, we used theoretical light curves synthesized in the PHOEBE (Prsa & Zwitter, 2005) program using the orbital elements and parameters of the components of the eclipsing variable from Gorda et al. (2015). Specifically, the night-averaged shifts of the light curve portions relative to the theoretical curve were calculated using the following simple formula:

$$\delta m = \sum(\Delta m_i - \Delta m_i^{\rm theor})/N, \qquad (3)$$

where Δm_i is the magnitude difference (variable minus comparison star) for a single observation; $\Delta m_i^{\rm theor}$ is the difference for the theoretical light curve at the same photometric phase; and N is the number of observations made during the particular night. For the observation interval from 2014 to 2021, 45 new values of δm were obtained in the V and R filters, respectively. For the entire observation interval from 2009 to 2021, 74 values of δm were obtained in the V filter and 78, in the R filter.

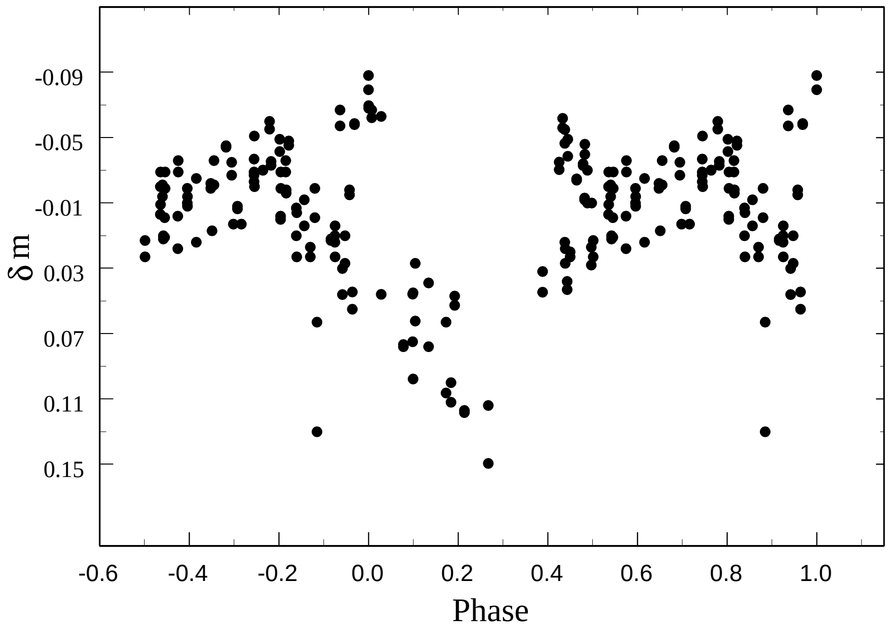

Figure 4. Light curve for extra-eclipse brightness of GSC 3599–2569.

We cheched the periodicity of the data series thus obtained using the WINEFK code by V.P. Goranskij that implements the Lafler–Kinman algorithm. The $1/\theta(\varphi)$ parameter, its large value indicating the presence of a periodicity, showed a noticeable and fairly wide peak at the frequency corresponding to the period $1187^{\rm d} \simeq 3.3$ years. Figure 4 shows the convolution of δm with the found period. The phases were calculated using the ephemeris from the WINEFK program:

$$\mathrm{JD}_{\delta m}\mathrm{min} = 2459194\overset{\rm d}{.}2 + 1187\overset{\rm d}{.}32 \cdot E_1. \qquad (4)$$

We see that the periodic nature of changes in δm is clearly present. Since only one period is clearly traced in the obtained data, in order to specify it, the data were approximated with a harmonic function using the following relation:

$$\delta m = a + b \cdot \mathrm{JD} \cdot \sin(2\pi(\mathrm{JD}/P + \varphi)), \quad (5)$$

where a and b are scale factors, P is the period, and φ is the phase coefficient. The coefficients were obtained by the nonlinear least-squares method. Then, the coefficients a and b were manually corrected to provide a more accurate correspondence of the approximating sinusoid to the observational data. Since we do not know the true shape of the δm variation profile, the sine fit was used only to determine the brightness variation period. As a result, the period $P = 1189^d \pm 14^d$ was obtained, which only slightly differs from that found using the WINEFK program.

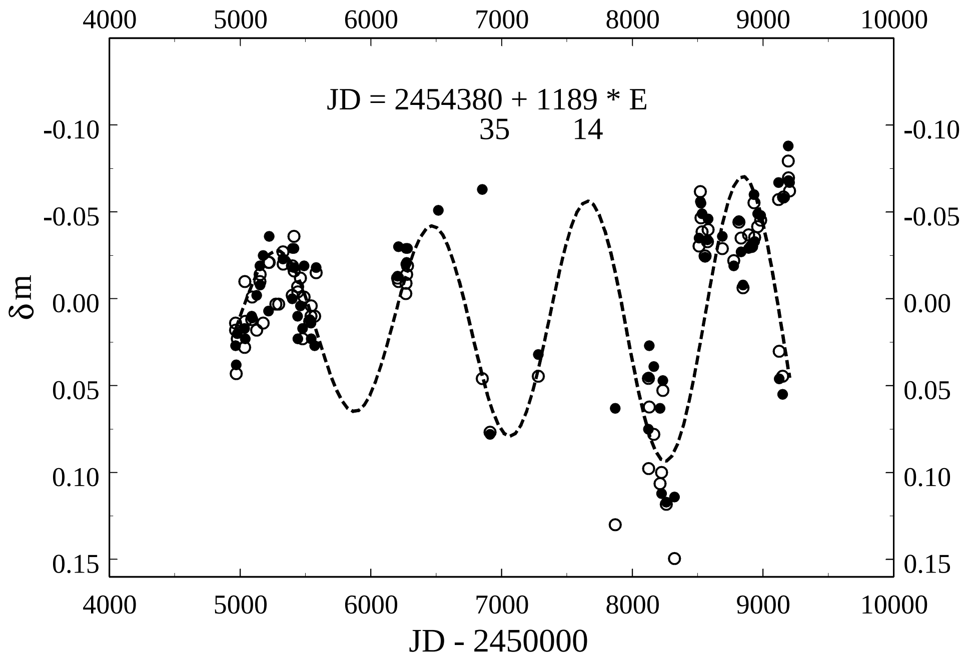

Figure 5. Variations of the extra-eclipse brightness (δm) of GSC 3599–2569 over time; dots, V filter; open circles, R filter; dashed curve, approximating curve.

We see from Fig. 5 that, after 2013 (JD = 2456500), there is a significantly larger scatter of δm than during the earlier time interval. This is due to the fact that the observations of V645 Cyg during one night were restricted to 1.5–4 hours, since its brightness changed little during the night. For this reason, only small portions of the light curve of GSC 3599–2569 were observed every night, when only one side of the spotted surfaces of the components was visible. This led to an underestimation or overestimation of δm values, but in general, since the observation process is quite random in time, the general trend in recording δm changes corresponded to reality. Ideally, for an accurate estimate of the δm value, it is necessary to obtain the full light curve on each observation night, which is extremely difficult, since the period of this eclipsing system is about 10 hours.

It should be noted that during the time of our observations, the amplitude of the cyclical variation of the star's extra-eclipse brightness was slightly increasing (see Fig. 5). Perhaps this is due to the presence of a second, longer cycle of changes in the magnetic field of the system, similar to how it manifests itself in a change in the degree of activity of the 11-year solar cycle. However, this assumption requires additional research.

Thus, as a result of this study, from observations of GSC 3599–2569 acquired during a time interval of 12 years, the cycle nature of variations in the extra-eclipse brightness of the star was confirmed. The period of these changes, which can be caused by changes in the magnetic fields of the components of the eclipsing system, manifesting themselves in the degree of spotting of their surfaces, has been evaluated.

Acknowledgments

This work was supported by the Ministry of Education and Science of the Russian Federation within the framework of the research activities project No. FEUZ-2020-0030, as well as Decree 211 of the Government of the Russian Federation (contract No. 02.A03.21.0006).

References:

Binnenijk, L. 1984, Publ. Astron. Soc. Pacif. **96**, 646
Djurasević, G., Rovithis-Livaniou, H., Rovithis, P., et al. 2001, Astron. & Astrophys. **367**, 840
Gorda, S. Yu., Lyaptsev, A.P., Sobolev, A.M. 2015, Astrophys. Bull. **70**, 113
Gorda, S. Yu. 2020, Astronomy Reports **64**, 922
Mullan, D.J., 1975, Astrophys. J. **198**, 563
Prsa, A. and Zwitter, T. 2005, Astrophys.J., **628**, 426
Sobolev, A.M., Gorda, S.Yu., Davidova, O.A., 2013, Inform. Bull. Var. Stars No. 6061
Zola, S., Gazeas, K., Kreiner, J.M., Ogloza, W. et al. 2010, Mon. Not. R. Astron. Soc. **408**, 464