PHOTOMETRIC ACTIVITY OF THE FAST-ROTATING dM4.5e STAR V639 HER

© 2025 N. I. Bondar*, K. A. Antoniuk, N. V. Pit

Crimean Astrophysical Observatory of the Russian Academy of Sciences, Nauchny, Russia

**e-mail: otbn@mail.ru*

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Abstract. This paper presents photometric studies of the M-dwarf V639 Her (M4.5Ve, $M = 0.31M_{\odot}$) from CCD observations 2019 on the 1.25-m KrAO telescope in the BV(RI)c bands. Based on the results of analyzing the light curves in these bands, we obtained a value of the rotation period of the star equal to 1.457 days. With this period, small-amplitude changes in the brightness of the star occur in the observed parts of the spectrum, and the color of the star becomes redder as the light decreases. The observed photometric features indicate the presence of cold spots on the surface of the star. The characteristics of the rotational modulation - amplitude and phase of the minimum - are obtained from the phase light curves for each observing season. It is shown that the distribution of spots and the stability of the rotational modulation parameters persist for about 100 days.

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1. INTRODUCTION

The star V639 Her ($V = 12^m.93$) is a faint component of the astrometric double system GJ 669 AB, 10.75 pc distant. It is a broad pair of M dwarfs with a projection distance of16” .8 [Weis, 1991; Quiroga-Nuñez et al., 2020]. The bright component, GJ 669 A=V647 Her ($V = 11^m.34$, M3.5) [simbad.harvard.edu], has a convective zone and a radiative core. We reviewed the photometric activity of this star in [Bondar' et al., 2024]. V639 Her ($V = 12^m.93$), according to its mass ($M = 0.31M_{\odot}$), spectral class (M4.5 Ve), and modeling results [Chabrier and Baraffe, 1997], is already a fully convective red dwarf star. Manifestations of its magnetic activity are observed in all bands. Optical flares and emission in hydrogen lines have been detected [Sandig, 1951; Roques, 1954, 1955; Samus et al., 2017], radio emission has been studied with different telescopes from 1976 and X-ray emission has been recorded by the XMM and Chandra satellites [Quiroga-Nuñez et al., 2020].

According to the axial rotation rate, V639 Her is a slowly rotating star [Jenkins et al., 2009; McLean et al., 2012], but later [Jeffers et al., 2018; Pass et al., 2022] obtained *vsini*= 7 km/s, which corresponds to a photometric period of 1.45 days found by [Hartman et al., 2011] if we assume a rotation axis inclination angle of i= 40°.

We performed photometry of the GJ 669 AB system in the $BV(RI)_c$ bands at 2019 on the1.25 м reflector of the Crimean Astrophysical Observatory (KRAO) in order to refine the rotation periods of the system components and to study their photospheric activity [Bondar' et al., 2022].

This paper presents the light curves of the star V639 Her (GJ 669 B) obtained from photometry data 2019 and the results of the search for periodic variability. On the basis of the analysis of the rotational modulation of the light and color changes, a conclusion is made about the presence of cold spots and their localization on the surface of the star, and an estimate of their lifetime is obtained.

2. VARIABILITY OF LUMINOSITY AND COLOR BY PHOTOMETRY 2019

The observations of V639 Her in2019 were made in the $BV(RI)_c$bands from June 21 to November 24 (Table 1). A description of the instrumentation, registration methods, and data processing is given in [Bondar' et al., 2022]. The light measurements of V639 Her were made using the same frames from which the stellar magnitudes of V647 Her were measured. The position of the stars in the frame field is shown in Figure 1. Over an interval of 156 days, 92 nights of observations were performed, in each filter we obtained three frames (sometimes five) with the image of the star, the temporal resolution was 64 sec in the B and V filters, and 14 sec and 9 sec in the R and I filters, respectively. Image processing with the MaximDL program resulted in 280 light estimates of the star in each filter relative to the comparison star TYC 2082-2143-1(V =$11^m.22$, B-V =0.592 [Hog et al., 2000]). As shown in [Bondar' et al., 2024], the control star TYC2082-2142-1 (V = $11^m.99$, B-V =$0^m.22$) did not show any variability in the brightness determined relative to the indicated comparison star, its mean value was kept at $0^{(m)}\cdot 007$.

The photometric variability of the star over the observation interval is represented by the light curves in Figure 2. In each panel of Figure 2, the light estimates measured in the instrumental system are represented by small circles, and those averaged over the observation date are represented by large circles. In each filter, the instrumental magnitudes were determined according to the expression $m = m_0 - 2.5\lg I_s$, where m is the instrumental stellar magnitude in the chosen filter for the star, $m_0$and $I_s$are the corresponding zero-point and intensity values of the star.

As a result, we obtained series of values Δb, Δv, Δr and Δi, determined relative to the comparison star: $\Delta b = b_s - b_{comp}$, $\Delta v = v_s - v_{comp}$, $\Delta r = r_s - r_{comp}$, $\Delta i = i_s - i_{comp}$. The primary processing of the series involved calculating the mean luminosity value for each series and excluding values outside the 2.5σ confidence intervals. It is known that V639 Her is an active flaring red dwarf, and it is possible that the light enhancements we have recorded, exceeding the 3σ level and confirmed by several measurements, are due to flare events.

Table 2 summarizes for each filter the mean values of theΔ m magnitude from the V639 Her observations in 2019 the errors in their determination, as well as the maximum changes in light. The data series in the V and R bands were obtained with the smallest errors (Fig. *2b*,*c*). These series were used to search for periodic changes using several methods in the range of possible values of periods of 1-40 days. The results obtained by the Lomb-Scargle method for the values $\Delta v= v_s\text{-}v_{comp}$, are shown in Fig. 3. The most powerful peak in Fig. *3b* corresponds to the period P_1=1.4548 (0.0016) days, the dashed lines on the observation interval mark the *FAP* values (0.3, 0.05, 0.01). It is known that the periodic variations in the light of BY Dra-type stars caused by the presence of spots are mostly not sinusoidal. Therefore, we performed an additional search for the period using the Lafler-Kinman and Diming methods [V.P. Goransky WinEfk program http://www.vgoranskij.net/software/] and confirmed the presence of the period $P_1$with a value of 1.4576 days. The second peak on the periodogram corresponds to the period 2.9152 (3.1911) days and is probably a harmonic of the period P_1. The convolutions with the refined value of the period P_1were constructed for the series in all filters. In the left and middle panels of Fig. 4 they are shown for the more accurate dataΔ v and Δr in filters V and R, determined with error σ~$0^m.02$. Changes in the values of Δb and Δi were observed with the same period, but the errors characterizing the deviations of the convolved values from the approximating polynomials were $\sigma(\Delta$ b) = $0^m.038$, $\sigma(\Delta$ i) = $0^{(m)}$ ·036, we regarded the results of the analysis of these series as qualitative confirmation of the changes in star (*v-r*) luminosity and color.

The obtained convolutions showed that the star becomes more red with decreasing luminosity. The same trend was shown by the star's light-color diagrams. In the right panel of Fig. 4 shows a diagram ofΔ v - (*v-r*), the regression line is plotted with *coefficients* of a = 0.730 (0.134), b = 1.191 (0.143).

We consider the value of the period P_1 = 1.4576 days found by us to be the photometric period of the star's rotation (P_{rot}) , and with this period we consider the manifestations of the rotational modulation of the luminosity in different observing seasons.

3. ROTATIONAL LIGHT MODULATION

To study the characteristics of the rotational modulation of the star's brilliance and color changes, phase curves were constructed with the elements P_{rot}= 1.4576 days, T_0= 2458655.8974. The characteristics of the rotational modulation, the phase of the minimum of the luminosity and the amplitude (the difference of the luminosity in the phases of the minimum and maximum) are presented in Table 3, and the phase curves are shown in Fig. 5. In the phase curve in Figure 5 (left panel), two time intervals are highlighted: one lasting 42 days and the other 108 days. In the first interval, the gloss changes occurred with a maximum amplitude equal to $0^{(m)}$ ·1 and one minimum was observed at phase 0.32; in the other interval, the amplitude decreased by 30% and two minima were observed, at phases 0.22 and 0.92. The changes in color (*v-r*) with rotation period are shown in the right panel of Fig. 5. The observed small-amplitude variability of the luminosity with the rotation period of the star and the reddening of the star at its decrease indicate the presence of cold spots on its surface.

Changes in the parameters of the rotational modulation - amplitude and phase of the minimum - are qualitative indicators of changes in the parameters of the spots and their location. In June-July, a significant area of spotting was prominent on one of the hemispheres, while in August-November, spots of smaller area were present on both hemispheres of the star. As can be seen from Table 3, the stability of the spot parameters and their surface distribution can be maintained for about 100 days.

4. CONCLUSION

The components of the GJ 669 AB system that we have studied are young stars; they belong to the Hyades kinematic group, which has an age of 625 Ma. Our photometric studies have shown that the rotation period of the more massive star V647 Her is 20.69 days [Bondar et al., 2024], and the star V639 Her is a fast-rotating M-dwarf. According to the results of broadband photometry 2019 the rotation period of V639 Her is 1.4576 days, which is in agreement with the values found [Hartman et al., 2011; Newton et al., 2016]. With this period, there are changes in the star's luminosity and color - as the luminosity decreases, the color of the star becomes more red, indicating the presence of cold spots on its surface. According to the phase curves constructed for each observing season, at different epochs regions of significant tarnish can be observed on one or both hemispheres of the star. The parameters of the spots and their surface distribution are preserved for 100 days.

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CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest.

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Table 1. Dates of photometric observations of V639 Her at 2019 on the AZT-11 telescope.

Date 2019 г.	JD2450000+.	Number measurements
21.06 - 28.06	8656 - 8663	21
02.07 - 31.07	8667 - 8696	48
01.08 - 31.08	8697 - 8727	57
01.09 - 30.09	8728 - 8757	58
01.10 - 24.10	8758 - 8781	45
01.11 - 24.11	8789 - 8812	51

Table 2. Light characteristics of V639 Her relative to comparison star TYC 2082-2143-1 according to data from 2019

Filter	Average light value Δ m, mag	σ, mag	$\Delta m_{\min} - \Delta m_{\max}$, mag
B	2.592	0.052	0.22
V	1.849	0.023	0.11
R	0.909	0.020	0.08
I	-0.832	0.032	0.17

Table 3. V639 Her. Rotational modulation characteristics.

Date 2019 г.	JD-2450000	Interval, days	Phase minimum	Amplitude, mag	
				Δv	$(v\text{-}r)$
21.06 - 02.08	8656 - 8698	42	0.32	0.10	0.03
08.08 - 24.11	8704 - 8812	108	0.22, 0.92	0.07	0.03

FIGURE CAPTIONS

Fig. 1. Position of the investigated stars in the 10'9 frame field ×10’ .9.

Fig. 2. Light variations of V639 Her based on observations 21.06 - 24.11 .2019 г

Measured relative to the comparison star TYC 2082-2143-1 magnitudes are small circles, date-averaged magnitudes are large circles; solid lines indicate mean values, dashed lines indicate *1σ* and *3σ* levels.

Fig. 3. *a*) A series of date-averagedΔ v-values; *b*) frequency analysis by the Lomb-Scargle method, the peak on the periodogram corresponds to P_{rot}= 1.4548 days, dashed lines - the corresponding *FAP* levels; *c*) a series ofΔ v-values (circles) and approximation of the variability by a sinusoid (solid line).

Fig. 4. Variations in the star's luminosity and color. The left and middle panels show convolutions of the data in V and R filters with P_{rot}= 1.4576 days. The right panel shows the color changes (*v-r*) as the light changes Δ *v*. Linear regression coefficient r^2= 0.47, σ = 0.020, N= 83.

Fig. 5. Rotational modulation of theΔ v luminosity and color (*v-r*) of V639 Her in .2019 г The interval 21.06 - 2.08 are squares; 8.08 - 24.11 are circles. Lines are approximating polynomials.

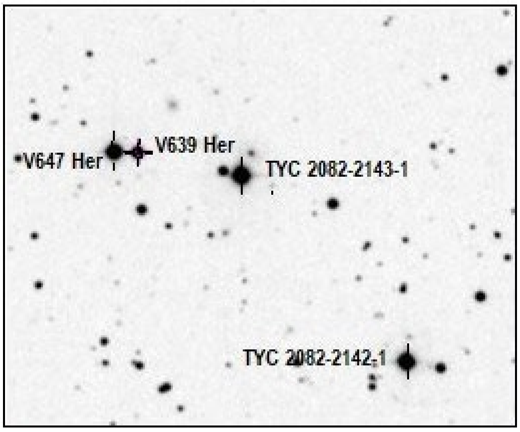
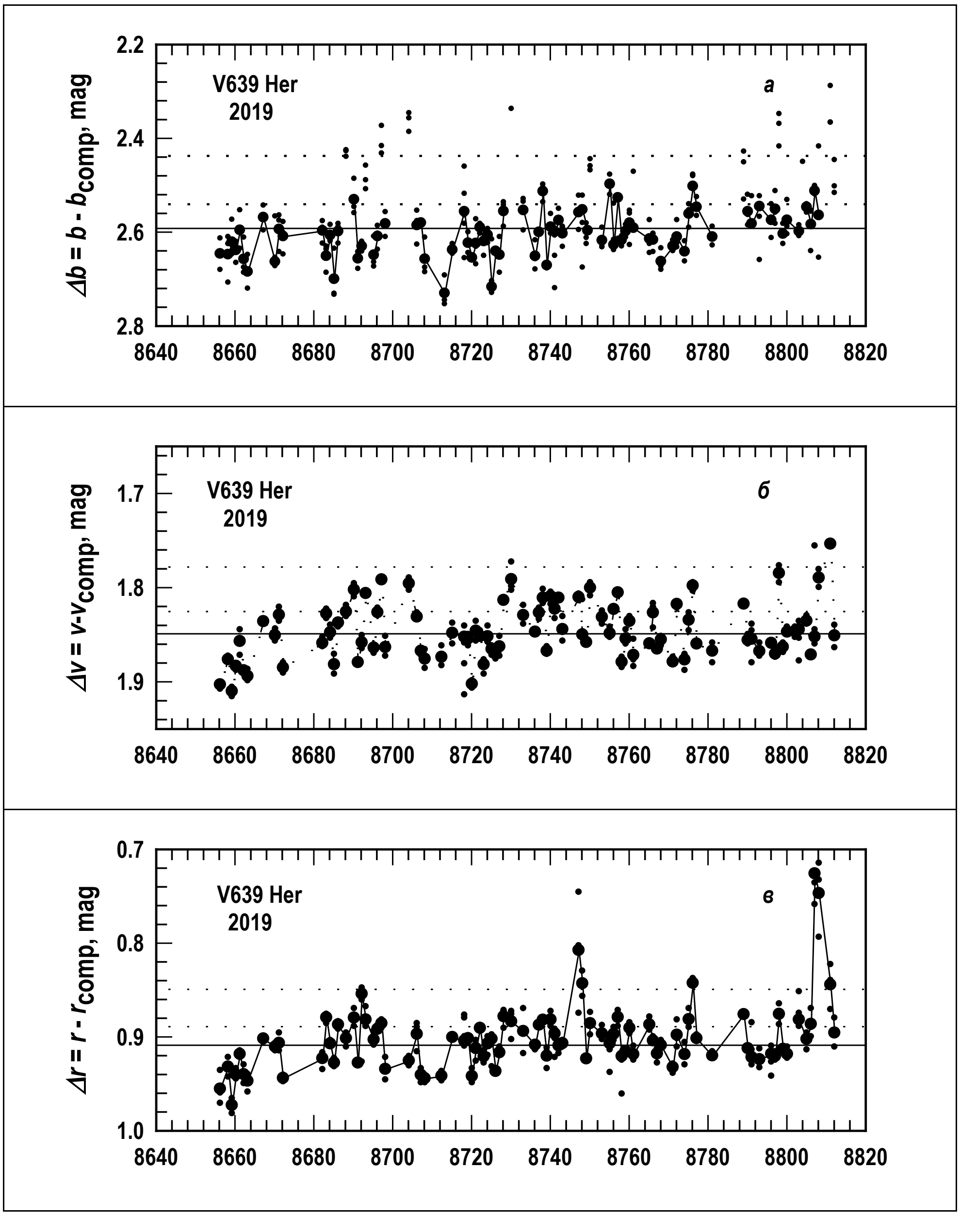

V647 Her
V639 Her
TYC 2082-2143-1
TYC 2082-2142-1

Fig. 1.


Δb = b - bcomp, mag
V639 Her
2019
a
2.2
2.4
2.6
2.8
8640
8660
8680
8700
8720
8740
8760
8780
8800
8820
Δv = v-vcomp, mag
V639 Her
2019
б
1.7
1.8
1.9
8640
8660
8680
8700
8720
8740
8760
8780
8800
8820
Δr = r - rcomp, mag
V639 Her
2019
в
0.7
0.8
0.9
1.0
8640
8660
8680
8700
8720
8740
8760
8780
8800
8820

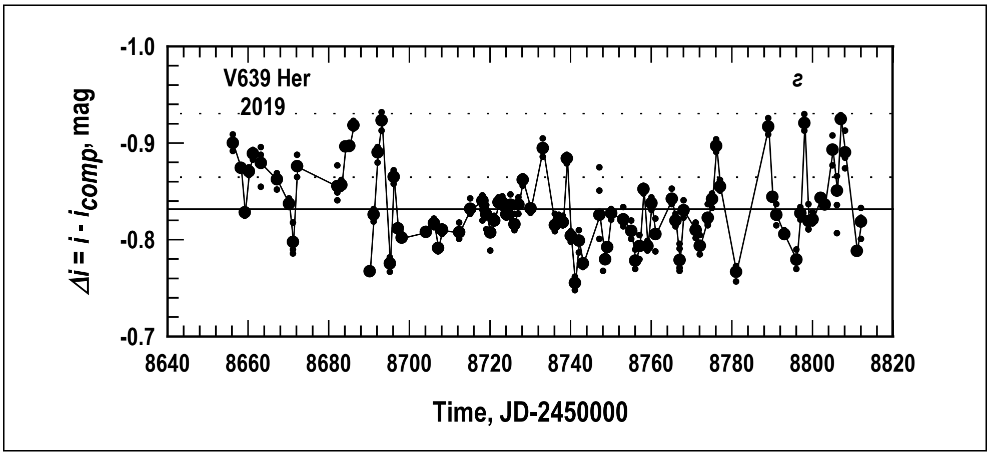

V639 Her
2019
г
Δi = i - i_comp, mag
Time, JD-2450000

Fig. 2.

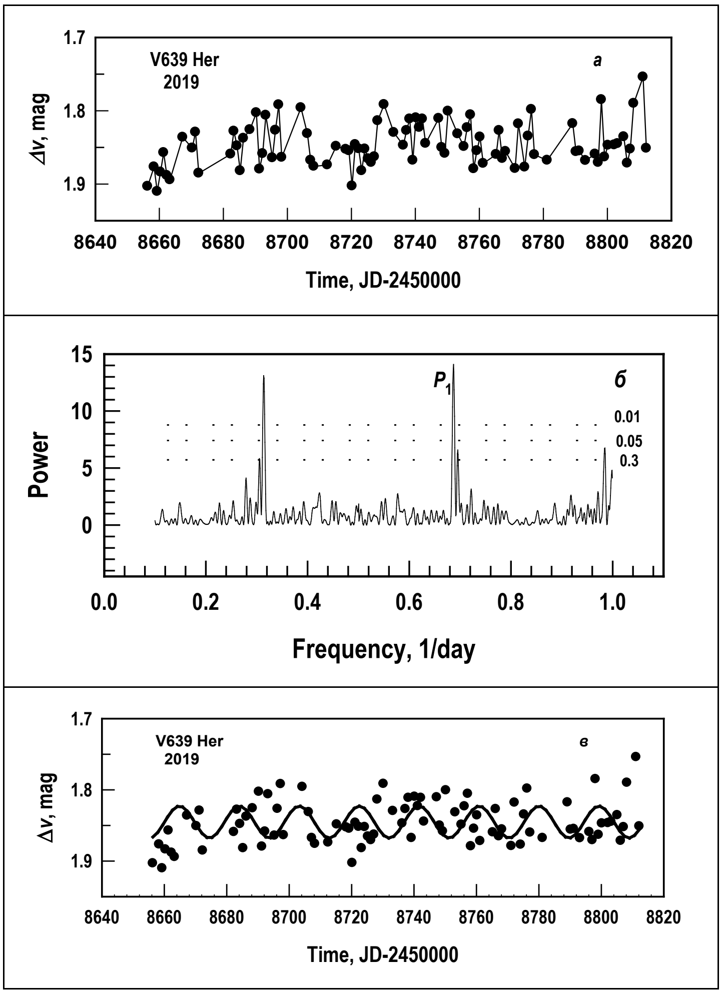

V639 Her
2019
a
Δv, mag
Time, JD-2450000
P1
б
0.01
0.05
0.3
Power
Frequency, 1/day
V639 Her
2019
в
Δv, mag
Time, JD-2450000

Fig. 3.

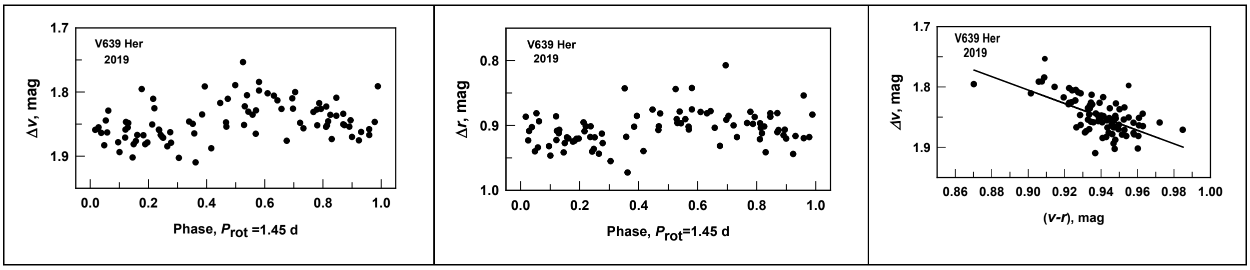

V639 Her
2019
Δv, mag
Phase, P_{rot}=1.45 d
Δr, mag
(v-r), mag

Fig. 4.

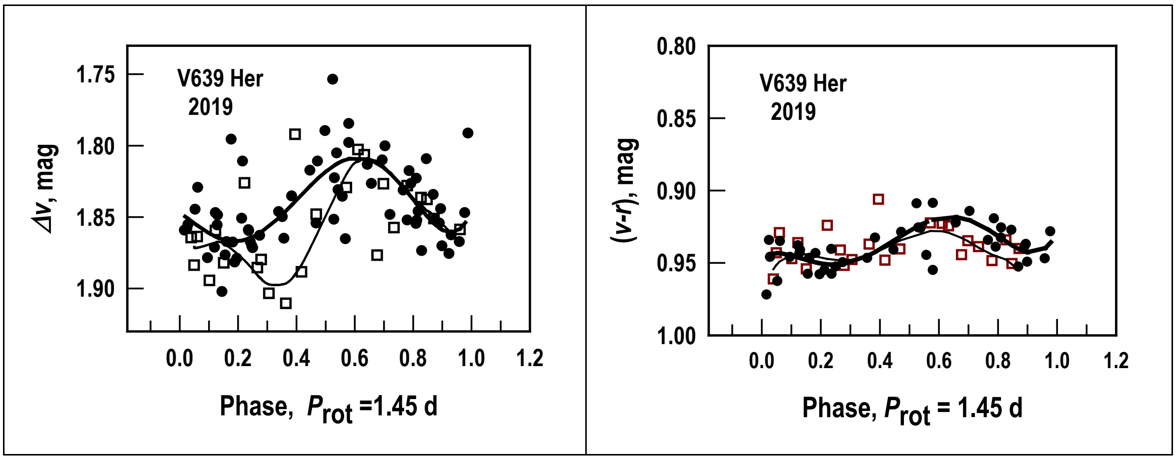

V639 Her
2019
Δv, mag
Phase, P_{rot} =1.45 d
(v-r), mag
Phase, P_{rot} = 1.45 d

Fig. 5.