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Asynchronous polar BY Cam: the geometry of accretion

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This paper presents an analysis of the new light curves obtained in 2015–2016 and their comparison with earlier published observations of BY Cam. It is shown how the mode of accretion changes from one orbital cycle to another during one night, and how the mode of accretion changes at the same phases of the synodic cycle for data obtained at different time intervals. Studying the accretion geometry at different orientations of the magnetic field of the white dwarf, we show an observational confirmation of complex structure of the magnetic field.

Keywords: Variable stars: polar: BY Cam

1 Introduction

Polar BY Cam belongs to close binary systems consisting of two stars, one of which is a low-mass main sequence star of K–M spectral class, it fills its Roche lobe. This triggers the transfer of matter to the white dwarf through the inner Lagrangian point and its surroundings. The main feature of the polars is that the white dwarf has a strong magnetic field of about 10^7–10^8 Gs, and because of this the matter transferring through the point of Lagrange immediately streams into the zone of the magnetic field, and, without forming a disk, begins to move along the fieldlines in the region of magnetic poles, where it forms an accretion column. It is the radiation from the column that we see in the visible wavelength range (Warner 1995). A white dwarf in BY Cam has a magnetic field of 28 MG (Mason et al. 1987, 1998; Silber et al. 1992, 1997).

Another feature of this system is its asynchronicity, when the rotation period and the orbital period do not coincide (Silber et al. 1992), as a result of which the

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orientation of the magnetic field relative to the red dwarf constantly changes with the synodic period or with the beat period $P_{\rm beat}$: $1/P_{\rm beat} = 1/P_{\rm rot} - 1/P_{\rm orb}$. Thus, BY Cam gives the possibility of studying the structure of the magnetic field of the white dwarf. Three periods are known in BY Cam: orbital period $P_{\rm orb}$= 0.139759 ± 0.000003 days (Mason, 1996), rotation period $P_{\rm rot}$ = 0.138428 ± 0.000002 days (Mason 1989), synodic period $P_{\rm beat}$ = 14.568 ± 0.003 days (Pavlenko 2006).

The main goal of the work was to study how the accretion geometry changes at different magnetic field orientations, how the accretion behavior changes from one orbital cycle to another, how many accretion zones are on the white dwarf surface, and whether they remain constant during the synodic period.

2 Observations

The paper provides an analysis of the results of photometric observations of the polar BY Cam obtained in 2015 and 2016. The processing included 36 nights of observations. All observations were collected in integral light. During this time interval, BY Cam was observed at the Crimean Astrophysical Observatory with the 38-cm Cassegrain telescope, at the Observatory at the peak Terskol with 60-cm Zeiss telescope and in Slovakia with telescopes of 18 cm and 60 cm. These new data were compared to data obtained starting from 2004, we accumulated 210 nights in total. Image processing was carried out using aperture photometry in MaxIm DL package. The accuracy of a single brightness measurement was in the range from 0.01 to 0.07 magnitude.

3 Analysis of the light curves of BY Cam

All the data obtained were used to construct light curves. For the most part of the nights, the light curves covered two or more orbital cycles. For each orbital cycle on the light curve we found the phase of the synodic cycle according to the ephemeris JD = 2453089.247 + 14.568E.

In Fig. 1, examples of light curves are given – the dependence of a relative magnitude on the heliocentric Julian date. We can see that the shape of the light curves is different from night to night. Analyzing the light curves we can see that all of them have common properties: 1 – all light curves contain more than one hump, that is, in one orbital cycle we see more than one accretion region where the substance accretes, and since accretion is directly related to the region of magnetic poles, it means accretion goes more than one pole during the orbital cycle; 2 – all the light curves have a hump, which has a large amplitude (in Fig. 1 it is marked as number 1), that is, the accretion is distributed unevenly between the accretion regions; 3 – in addition to the main hump (of a greater amplitude) in all the light curves we see one or two humps smaller in amplitude (indicated by number 2 in Fig. 1); 4 – the main hump can have a different shape and duration.

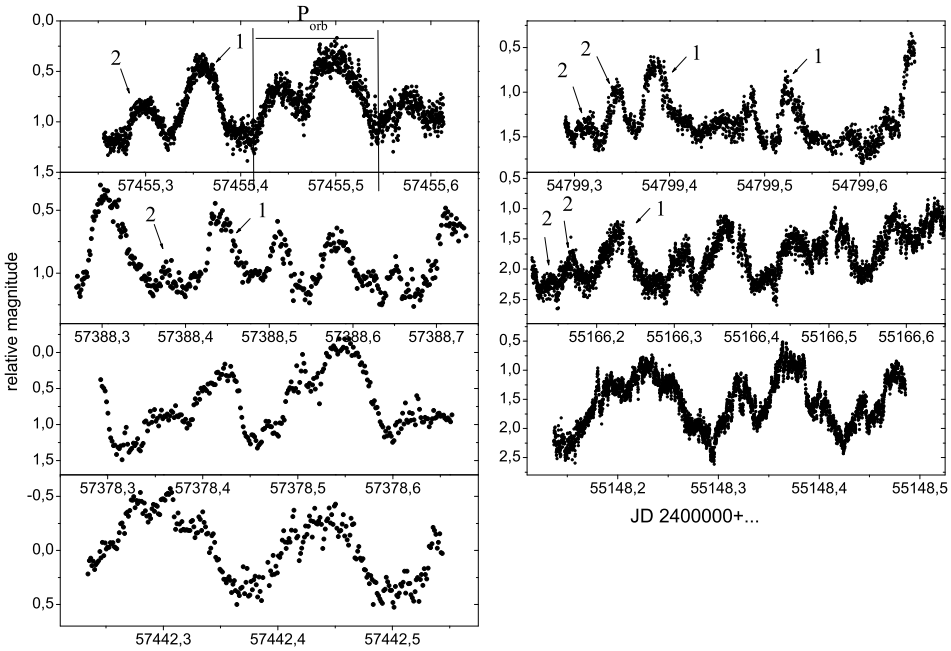


Figure 1 Examples of light curves for BY Cam obtained in 2016 (left column) and for comparison the light curves of BY Cam for previous years (right column).

4 Accretion behaviors from one orbital cycle to another

Most of the light curves of BY Cam cover more than one orbital cycle, and it allows us to see how the accretion behavior changes from cycle to cycle. Since the system is asynchronous, the orientation of the magnetic field with respect to the red dwarf changes with each orbital cycle, therefore, it is expected that the accretion behavior will change from one cycle to another. Most of the light curves during one orbital cycle have two- or three-hump structure, for example, the light curves on JD 57455, JD 57388, JD 57378 (Fig. 1).

The light curve JD 57388 spans more than three orbital cycles, and during this time it can be seen that the two-humped curve, where most of the accretion goes to one accretion region, became a three-hump with a decrease in the amplitude of the main hump. And since the matter streams to the area of accretion poles, so this curve can serve as an observational confirmation of the complex structure of the magnetic field in the white dwarf of BY Cam. This assumption has already been made earlier in Mason et al. (1995), Silber et al. (1997), Pavlenko (2006). The behaviour of the accretion can vary within few cycles.

The light curve JD 57442 shows one broad hump, this shape of BY Cam light curves is often found during the overall observational period of the polar. It is difficult to discuss the number of active accretion areas with reference to these light curves. One of the explanations of the wide profile may be the presence of a wide accretion

region at some orientation of the magnetic field or the combination of radiation from several accretion regions.

5 Behavior of accretion at the same phases of the synodic cycle based on data obtained at different time intervals

In Fig. 2, the light curves with the same phase of the synodic period for data obtained at different times are presented. The phase of the beat period was considered according to the ephemeris given earlier. Comparing these curves it is possible to judge about the change of the geometry of accretion over time.

Consider the light curves at phase 0.1 of the beat period. For comparison with JD 57388, we give two more light curves obtained in 2005 (JD 53513) and 2006 (JD 54081). The light curve JD 57388 spans more than three orbital cycles. During the first orbital period, we see two humps, from which we can assume that we see two accretion regions. One hump has three times greater amplitude than the second, the length of this hump is 0.09 day, and the length of the smaller hump is 0.04 day. The bigger hump has more smooth light decay. If we look at the second orbital cycle, one can see more accretion zones, as there were three humps. The main hump is the same, but it changed its amplitude and duration, which was 0.06 day, right and left

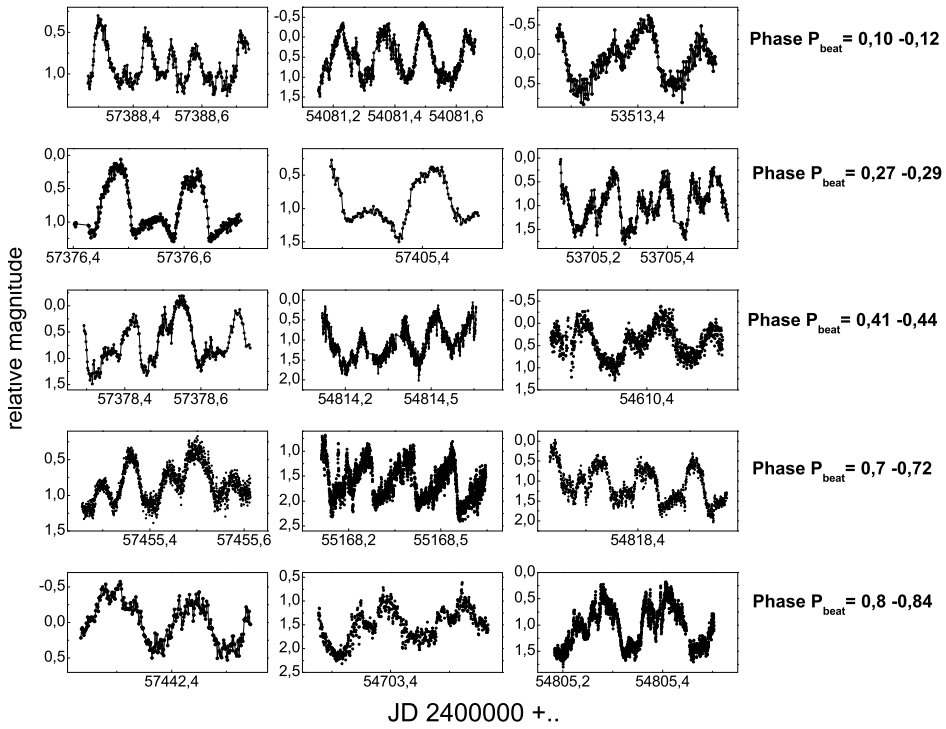


Figure 2 Example of light curves at the same phases of the synodic cycle based on data obtained at different time intervals.

of it we can see the little humps, which together with the main hump last 0.09 per day. Most likely these smaller humps were in the first period and were in the wings of the increase and decrease of brightness of a larger hump. For objects of this type, the number of humps helps us to assume the number of accretion zones and as a consequence the number of poles, as accretion falls in the region of magnetic poles. But when the humps do not have symmetrical shape or very wide profiles, it is clearly not appropriate to talk about the number of accretion zones. When comparing the light curves at this phase of the synodic cycle, we see that the shape of the light curve remains constant regardless of time. It has either a three-hump shape with one large hump or is two-humped, but then the main hump is wide.

Analyzing the light curves obtained at different times, but at the same phase of the synodic cycle, that is, at the same orientation of the magnetic field, we conclude that the accretion behavior remains constant, there is always the main accretion region, that is, the pole where most of the accreting matter and less active accretion regions. With the same configuration, the amplitude and visibility duration of these accretion regions may vary, but this may be due to a change in the amount of the accreting matter.

6 O–C

The moments of the highest hump maxima were determined from all the light curves during this observation period from JD 57134 to JD 57715. As we know, the largest hump is responsible for the accretion area, where at this phase of the synodic cycle there is a large part of the accretion flow. There are curves where the main hump has several equivalent peaks, then the maximum was determined for each peak. Using ephemeris $\mathrm{JD}_{\max} = 2453089.307 + 0.1384274\mathrm{E}$, which was taken from the early papers of Pavlenko (Pavlenko et al. 2006) we calculated the times of the maxima of the main humps. And using these two found values we calculated parameter O–C. Figure 3 shows the dependence of O–C on the phases of the beat period.

By changing the O–C parameter depending on the phase of the synodic cycle, we can judge how the accreting substance flows and at which phases of the synodic cycle the accretion flow is switched from one pole to another. From Fig. 3, we can see that at different intervals of the phases of the beat period the course of O–C changes. The transition from one dependence to another is accompanied by jumps. In phases 0.25 and 0.79 we see a jump on the half of the orbital period, which corresponds to the switching of the accretion stream from one dipole pole to another, the same result was obtained earlier for other observation moments, which is described in Pavlenko et al. (2007) and Babina et al. (2008). At intervals of phases from 0.0–0.25 and 0.79–1.0, O–C changes to a quarter of the orbital period. The explanation for this can be switching from the dipole pole (region of accretion near the dipole poles) on equatorial region, or the switching of the stream from one region at the equator to the other region located at the same equatorial pole. This configuration of the magnetic field in BY Cam was proposed in the early papers of Pavlenko (Pavlenko et al. 2006). The polar BY Cam is not synchronous, that is, during the synodic cycle, the orientation of the magnetic field of the white dwarf continuously changes with the beat period relative to the red dwarf. Consequently, during the beat period

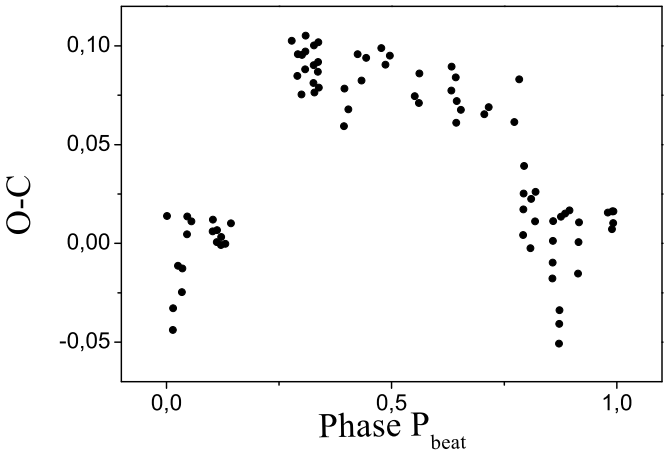


Figure 3 The dependence of O–C from the phase of the synodic cycle for data 2015–2016.

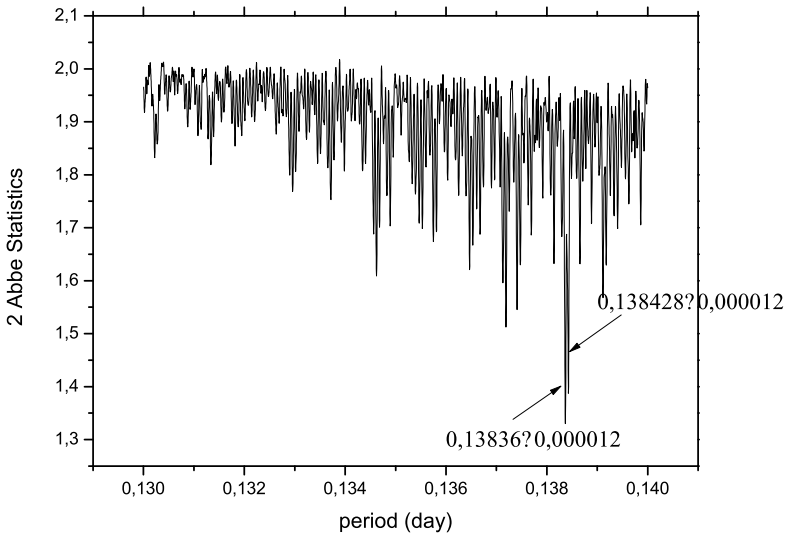


Figure 4 Periodogram for BY Cam data.

the white dwarf rotates to the accretion stream by different poles, as a result most of the accretion substance is switched to the pole, which is now closer to the moving accretion stream.

O–C values in the phase range between 0.25 and 0.78 remain constant. Selecting the data that lie in this range of phases, we built a periodogram in order to see what period gives a greater contribution. The result is shown in Fig. 4.

The search for periods was carried out using the ISDA (Pelt 1992) program package by the nonparametric Stellingvverf method. The periodogram was obtained in the period range from 0.13 days up to 0.14 days. The most significant periods were 0.1386

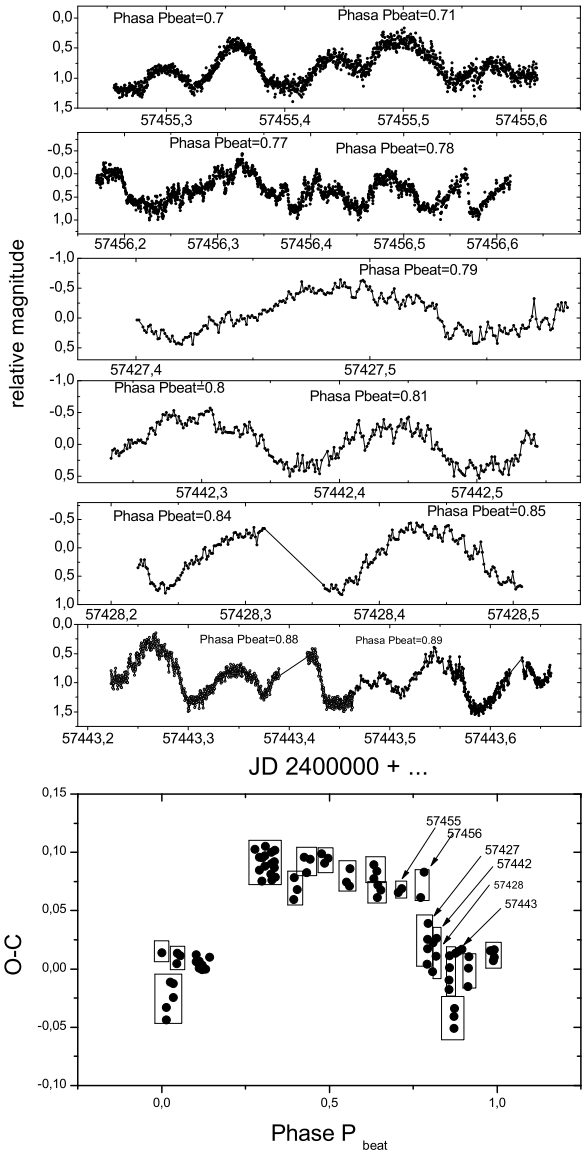


Figure 5 Dependence of the O–C with the designation of observations (below), which were at the jump and the light curves obtained on these dates.

± 0.000012 days and 0.1388428 ± 0.000012 days, where the second period coincides with the system's period of rotation. It turns out that during the phases of the synodic cycle from 0.25 to 0.78, most of the accretion stream constantly goes to one pole. The periodogram confirms the result obtained by the O–C method.

From the dependence of O–C on the phase of the synodic period (Fig. 3) we see that at the phase of 0.78 days there is a jump on the half of the orbital cycle, that is,

at this phase the stream switches from one accretion region to another. From Fig. 5 it can be seen that we have some observations at the moment of the jump in period, the light curves of which are shown in Fig. 5.

The light curves, which refer to the beginning and the end of this jump have a two-humped shape during one orbital cycle, accretion goes onto two regions. And the light curves which are at the jump, have one wide hump, this feature is not enough to discuss the number of active accretion zones.

Conclusion

As a result of the work done, we have shown that we see more than one hump on all light curves, which means that accretion goes to more than one pole. All light curves have a hump of large amplitude, that is, the accretion is distributed unevenly between the accretion regions, and hence the magnetic poles. The obtained light curves clearly indicate a complex configuration of the magnetic field in the white dwarf in BY Cam. Analysis of O–C shows that in one synodic cycle the accretion stream switches twice between the dipole poles, and between the switches the accretion stream mainly goes to one pole. Comparing the new photometric data with those previously obtained we show that the behaviour of accretion at the same phases of the synodic cycle does not change from year to year. With the same magnetic field configuration, the accretion distribution between the accretion regions is constant.

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