Period switching in the symbiotic star BX Mon

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ABSTRACT

We report on a detailed analysis of the optical light curve (LC) of the symbiotic system BX Mon, the data of which were gathered from the literature. The LC covers the period from 1889 December to 2009 March, with a gap of no observations between 1940 March and 1972 February. The LC is characterized by strong oscillations of peak-to-peak amplitude from $2$ to $>3$ mag. Before the gap, the fluctuations were modulated mainly by a period $P_a = 1373 \pm 4$ d. After the gap, the dominant periodicity became $P_b = 1256 \pm 16$. Higher harmonics as well as a few beats of the two major periodicities can also be identified in the LC. We identify one of the beat periods, $P_r = 656$ d, as the sidereal rotation period of the giant component of the system. The period switching that took place during the gap in the observations was possibly associated with a certain cataclysmic event, hints of which may be recognized in the LC in the first 11 yr after the gap.

We suggest that the origin of the major oscillations lies in periodic episodes of mass accretion from the M giant on to the hot component of the system. After the gap, they are correlated with the periastron passage of the system and therefore appear with the binary period. Before the gap, the oscillations appeared with the diurnal cycle of an observer on the surface of the rotating M giant, whose Sun is the hot component. The event of the period switching is possibly related to an intensive magnetic activity in the outer layers of the giant star.

Key words: binaries: symbiotic – stars: individual: BX Mon – stars: magnetic field – stars: rotation.

1 INTRODUCTION

BX Mon was discovered on a Harvard objective prism plate by Mayall (1940). Its classification as a symbiotic system (SS) was based on its optical spectrum, showing a combination of strong hydrogen emission lines and TiO absorption bands of a late-type star (Iijima 1985; Kenyon 1986; Viotti et al. 1986). Its identification as SS has been questioned (Allen 1982), until medium ionization lines have been identified in the International Ultraviolet Explorer (IUE) spectra (Michalitsianos et al. 1982). Its infrared colours and spectral energy distribution (SED) are those of a normal M5 III star and exclude the presence of a Mira variable (Whitelock & Cathpole 1983; Viotti et al. 1986; Dumm et al. 1998). No nova-like eruption event has been recorded for this system.

BX Mon large photometric variability had already been discovered in 1940 by Mayall (1940) and a period of $1380$ d was suggested, with ephemeris JD(max) = 241 2490 d. Its optical and ultraviolet spectrum is also strongly variable. However, the spectroscopic variability is hardly explained by Mayall’s period (Iijima 1985; Viotti et al. 1986). Iijima (1985) noted that two epochs of low excitation states seem to occur at phases near the photometric maximum of Mayall’s ephemeris, suggesting that Mayall’s light-curve (LC) representation may contain a mistake or that a change occurred in the variations phase.

Dumm et al. (1998) analysed Mayall’s data and the data of the Royal Astronomical Society of New Zealand (RASNZ) obtained between 1989 and 1995, covering less than two cycles. Two possible periodicities have been suggested, $P = 1338 \pm 8$ d and $1401 \pm 8$ d. The period $P = 1401$ d seems to explain the IUE spectra variations (Dumm et al. 1998) and in particular the UV flux attenuation as due to eclipses of the hot component by the cool one.

Fekel et al. (2000), combining their own radial velocity measurements and few old data by Dumm et al. (1998), established an orbital period of $1259 \pm 16$ d. A period of $P = 1262 \pm 32$ d was determined from the RASNZ data analysis, which is consistent with the radial velocity period. More recently, Brandi et al. (2009) reanalysed the old and new radial velocity data and suggested a value of $1290$ d for the binary period.

In order to better understand the nature of BX Mon variability, we have reanalysed the long-term LC of BX Mon using Mayall’s

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data and the American Association of Variable Stars Observers (AAVSO) ones.

Section 2 presents the data set that we analyse in this paper. Section 3 describes the analysis that we applied to the data and our main results. In Section 4, we identify the clocks that give rise to the periodic variations in the LC of the system and propose a qualitative model which could explain how these clocks modulate the optical brightness of the system. Section 5 gives a brief summary.

2 HISTORIC LC OF BX MON

2.1 Data

Our reconstructed LC spans the time interval from 1889 December up to 2009 March, i.e. from JD = 241 1380 to 245 4905, with a large gap of more than 11 000 d, from 1940 March to 1972 February, for which we could not find any reported magnitude measurement. We refer to the two data sets on the two sides of the gap as sections A and F+B (the meaning will be explained below). Section A of the LC was retrieved from fig. 1 of Mayall (1940), which presents the estimated photographic magnitudes of the star on the Harvard plates from 1889 to 1940. Our section F+B of the LC is taken from the AAVSO data base of measurements covering the years between 1972 and 2009. We have binned the visual AAVSO data on 10-d averages.

Fig. 1 presents the LC of BX Mon showing variations, reaching more than 3-mag amplitude, and the large gap in time between the two sets of observations. The solid line in Fig. 1 is a running mean over a linearly interpolated LC of the system, with a running window of 2810 d. We have split section F+B into two distinct sections F and B, and the three sections of the LC are marked in Fig. 1. Section F covers 4010 d between JD = 244 1365 and 244 5375. In this section the average luminosity of the system over ~2810 d was significantly larger than during any other interval of the same length, as evidenced by the running mean curve in the figure. Two fluctuations in the brightness of the system occur in this section that ends with a rapid decline of the mean brightness back to the mean magnitude that the system had in section A.

3 DATA ANALYSIS

3.1 Power spectrum

Fig. 2(a) is the power spectrum (PS) of the LC shown in Fig. 1, computed according to the Lomb–Scargle prescription (Scargle 1982), and Fig. 2(b) shows the window function. As clearly seen, there are quite a number of peaks in the PS around the frequency correponding to \( P = 1300 \) d that are statistically significant. However, folding the LC on to any one of the corresponding periodicitics demonstrates that none of these periods fit the data of the entire LC.

Fig. 2(c) is the PS of section A of the LC. Four peaks stand out clearly above the noise level. Their corresponding periodicitics in days are listed in Table 1; the highest one corresponds to the period \( P_a = 1373 \) d. We remark here that the period values in Table 1 are the ones we derive by the fitting process that we apply, as explained in Section 3.2. For completeness, we list here the slightly different period values associated with the frequencies of the four peaks in the PS. They are \( 1370 \pm 10, 687 \pm 2.5, 498 \pm 1.4 \) and \( 343 \pm 1 \) d, respectively. The quoted error estimates correspond to the half widths at half-maximum of the corresponding peak profile in the PS. There is hardly any doubt that the second and fourth periodicitics in section A are the second and fourth harmonics of the major one \( P_a \), while the third one is an alias as identified by a ‘clean’ routine that we have developed and applied to the data.

Fig. 2(d) presents the PS of section B of the LC. The seven highest peaks are marked in the figure. The peak that is slightly higher than the seventh marked peak is shown by the ‘clean’ routine to be an alias of the major, dominant periodicity in this section of the LC.

| Table 1. Peaks in the PS. |
|---------------------------|
| Number | Period days | Comments | |
| --- | --- | --- | --- |
| **Section A** | | | |
| a1 | 1373 | \( P_a \) | \((1/P_a - 1/P_b)^{-1}\) |
| a2 | 687 | \( P_a/2 \) | |
| a3 | 498 | Alias | |
| a4 | 343 | \( P_a/4 \) | |
| **Section B** | | | |
| b1 | 1256 | \( P_b \) | |
| b2 | 7370 | Beat | \( 0.5 \times (1/P_b - 1/P_a)^{-1}\) |
| b3 | 1073 | Beat | \((3/P_b - 2/P_a)^{-1}\) |
| b4 | 1687 | Beat | \((3/P_a - 2/P_b)^{-1}\) |
| b5 | 431 | Beat | \((1/P_a + 2/P_b)^{-1}\) |
| b6 | 461 | Alias | |
| b7 | 656 | \( P_a \) | \((1/P_a + 1/P_b)^{-1}\) |
data. The periods corresponding to the six independent peaks are listed in Table 1. Again, the numbers in the table are the values derived by least-squares fitting, as explained below. The periods that correspond strictly to the peaks in the ‘clean’ PS are 1261 ± 17, 7706 ± 623, 1067 ± 31, 431 ± 2.0, 461 ± 2.2 and 661 ± 4.6 d.

3.2 Harmonics and beat periods

The major period in section B of the data is \( P_b = 1256 \) d. We identify it as the binary period of the BX Mon system. One then finds out that the frequencies of all the other true periods listed in Table 1 are simple linear combinations of the two major periodicities \( P_a \) and \( P_b \), with very small integer numbers as coefficients, as specified in Column 3 of Table 1. We obviously can express the frequencies of all periods listed in Table 1 as linear combinations of \( P_a \) and \( P_b \), rather than of the pair \( P_a \) and \( P_b \).

We now assume that all observed oscillations in the LC of BX Mon are indeed these combinations of the two major ones \( P_a \) and \( P_b \). We reverse the period search process and by least-squares procedure we look for the pair of periods around 1260 and 1373, which combined with the harmonics and their appropriate beats produce the best-fitting multiperiodic waves to sections A and B of the data set. The second column of Table 1 lists the values of the two major periodicities \( P_a \) and \( P_b \), so obtained and of their respective beat periods.

With the bootstrap technique (Efron & Tibshirani 1993), we have established a 99 per cent confidence interval of 4 d around the \( P_a \) period value and of 16 d around the \( P_b \) value.

Fig. 3(a) displays section A of the LC of BX Mon (dots). The solid curve is the best-fitting wave to the data with the period \( P_a \) and its second and fourth harmonics. Fig. 3(b) depicts the data points of section B, along with the best-fitting wave with the periods listed in Table 1. Fig. 4(a) shows section A of the data set folded on to the \( P_a \) period. Fig. 4(b) is the folded section B data on to the period \( P_b \).

The ephemeris for \( P_a \) is \( T_0(a) = \text{JD} 242 8499 + 1373 E \).

Fig. 3(b) and 4(b) show that in section B, there is no well-defined minimum point that appears with strict \( P_b \) periodicity. The minimum points in each cycle of the smooth curve with the six periodicities of section B fitted to the data are also distributed on the time axis with only quasi-\( P_b \) periodicity. The minimum points of each cycle of the observed data set are scattered around this ephemeris with a dispersion of \( \sim 100 \) d. Therefore, exact photometric ephemeris for the \( P_b \) periodicity in section B is not well defined. Ephemeris of a sine wave with the \( P_b \) period that best fits the data is \( T_0(b) = \text{JD} 244 9445 (\pm 100) + 1256 E \).

3.3 SED considerations

3.3.1 IUE observations

Table 2 lists the 13 low-resolution observations obtained by IUE between 1979 January and 1995 October, retrieved from the INES Archive Data for archival spectra.

The phase listed is computed with respect to our ephemeris, minimum light JD\( P_b = 244 9445 (\pm 100) \) d (see Section 3.2). We identify five epochs of UV observations. The exposure classification points in each cycle of the smooth curve with the six periodicities of section B fitted to the data are also distributed on the time axis with only quasi-\( P_b \) periodicity. The minimum points of each cycle of the observed data set are scattered around this ephemeris with a dispersion of \( \sim 100 \) d. Therefore, exact photometric ephemeris for the \( P_b \) periodicity in section B is not well defined. Ephemeris of a sine wave with the \( P_b \) period that best fits the data is

\[
T_0(b) = \text{JD} 244 9445 (\pm 100) + 1256 E.
\]

Table 2. IUE spectra of BX Mon.

| Image   | Date      | JD     | Exp time (s) | ph2 | Epoch |
|---------|-----------|--------|--------------|-----|-------|
| SWP03832L | 1979-01-06 | 244 3880 | 4619        | 0.57 | 1     |
| LWR03408L  | 1979-01-06 | 244 3880 | 2400        | 0.76 | 2     |
| SWP06344L  | 1979-09-01 | 244 4118 | 3600        | 0.65 | 3     |
| LWR05479L  | 1979-09-01 | 244 4118 | 3600        | 0.65 | 3     |
| SWP27797L  | 1986-02-26 | 244 6488 | 3600        | 0.53 | 4     |
| LWP07724L  | 1986-02-26 | 244 6488 | 2400        | 0.53 | 4     |
| SWP35767L  | 1989-03-14 | 244 7600 | 5400        | 0.53 | 4     |
| LWP15196L  | 1989-03-14 | 244 7600 | 1800        | 0.53 | 4     |
| SWP40243L  | 1990-12-01 | 244 8227 | 7200        | 0.53 | 4     |
| LWP56128L  | 1995-10-27 | 245 0017 | 14 400      | 0.53 | 4     |
| LWP56132L  | 1995-10-29 | 245 0019 | 6300        | 0.46 | 6     |
| LWP31630L  | 1995-10-29 | 245 0019 | 3600        | 0.46 | 6     |
As mentioned in Section 1, Dumm et al. (1998) noted two episodes of strong attenuation in the UV flux of the system as measured by the IUE telescope. The two episodes are separated from each other by 4347 d. In trying to interpret the events as an eclipse phase in the binary cycle of the system, Dumm et al. (1998) were forced to postulate a period of 1401 d.

The first IUE event, which took place at epoch 1, falls within our section F of the LC. As indicated by the mean brightness of the star, at that time some other unknown process dominated the optical luminosity of the system, probably the end of the event that brought about period switching in the quiescence state of the system. Therefore, the timing of that event of attenuation of the UV flux is probably unrelated to the clocks that drive the two major periodicities of the system. In fact, in the same section F, the two optical fluctuations in the brightness of the system are also not in phase with either of the two dominant periods in the LC.

The other IUE measurement of attenuated UV is epoch 5. There is virtually no trace of UV continuum emission from BX Mon in the wavelength range of 100–180 nm at that time (see Fig 5). Unfortunately, no frame of the LWP camera of IUE of the same date exists in the IUE archives. The lack of continuum emission may indicate an eclipse of the white dwarf (WD) of the system by the giant star, namely conjunction. This, however, is not necessarily so.

Lack of far-UV emission from the hot component of symbiotic stars has been also recorded when no eclipse is expected. An example is the IUE measurement SWP09385LL in AG Dra taken on 1994 June 27, near maximum light of the photometric binary cycle (phase = 0.96). Note also, that one cycle of 1256 d after the date of no short wavelength continuum in the IUE measurement in BX Mon, falls 24 d after the date suggested by Brandi et al. (2009) as the spectroscopic conjunction of the system. With the periodicity suggested by these authors, the mismatch is 58 d. The cycle following the IUE measurement falls also 38 d after the ephemeris time that we mentioned above as obtained by fitting a sine wave of the \( P_b \) periodicity to the entire data set of section B.

3.3.2 Attempts of model fitting

Fig. 5 shows the behaviour of the short wavelengths of all the IUE epochs within the time interval of our section B. The shape of the short wavelength continuum of observations 3, 4 and 6 is almost the same. In observation 5, only the emission lines are present while no continuum is detected. We retrieved the \( UBVRIc \) photometry (Munari et al. 1992) and a few \( HJKL \) measurements (Phillips 2007; Henden & Munari 2008), which have been transformed to the Johnson system (Bessel 1983) and to flux, according to the standard procedure (Zombeck 2000, p. 100). Data have been dereddened by \( E(B-V) = 0.25 \) (Dumm et al. 1998). We matched the \( HJKL \) photometry at JD = 244 7963 and 244 7996 and \( UBVRIc \) data at JD = 242 7977 with the IUE epoch 4. The ultraviolet SED for epoch 6, at maximum light, is quite similar to that of epoch 4, as shown in Fig. 5. There are no photometric data that can be matched with this epoch. The nearest in time \( UBVRIc \) photometry is at JD = 245 1582, a cycle later, and at phase = 0.66.

Using the methods presented also by Skopal (2005), we tried to construct a physical model of the various radiation sources within this stellar system, i.e. cool giant star, hot component, emission nebula, possible accretion disc. Such an attempt has already been made in the past by Kenyon & Webbink (1984) who were unable to come up with an acceptable fit.

Our attempts have also been severely hampered by the scarcity of multiwavelength spectral observations in this star, especially those that are performed simultaneously, even 27 yr after the pioneering work of Kenyon & Webbink (1984). Simultaneity is of course a necessary condition for an analysis of this kind to be meaningful for a system such as BX Mon, whose energy output varies in time by nearly two orders of magnitude. We do note, however, that in all our numerical attempts of model fitting, the contribution of the nebula to the IUE SWP camera is negligible. Therefore, SEDs 3, 4 and 6 shown in Fig. 5 represent the contribution of the hot component of the system.

Two of them (4 and 6) were made close to epochs of maximum brightness in the optical LC of our section B (see Fig. 3b). These spectra are comparable to IUE spectra during active events of other symbiotic stars such as Z And and AR Pav (see figs 3 and 19 of Skopal 2005). This fact and the resemblance of the optical LC of BX Mon to those of Z And and AG Dra (Skopal et al. 2007, figs 2 and 8), for example, strengthen our claim, made in Section 4, that in BX Mon the cyclic outbursts of the system are events of intense mass transfer.

4 DISCUSSION

Our time series analysis, in particular Fig. 3, suggests that two photometric cycles characterized the major brightness variations of BX Mon in the last 120 yr, \( P_a = 1373 \) d and \( P_b = 1265 \) d. The period \( P_a \) dominated the first 55 yr, while \( P_b \) was the major one in the last 26 yr of the star history. The structure of the entire LC observed in section A can be well reproduced by a harmonic wave of the \( P_a \) periodicity with its second and fourth harmonics, as seen in Fig. 4. The variability in section B is well represented by the major period \( P_b \) and the five other periods listed in Table 1, all of which are simple linear combinations of \( P_a \) and \( P_b \). Fig. 3(a) shows the sine wave of the period \( P_b \) and its second and fourth harmonics fitted to the LC of section A. Fig. 3(b) is the fit to section B of the series of \( P_b \) with the five beat periods listed in Table 1.

We note that the difference in the periods between sections A and B of the LC can hardly be attributed to the relatively small

![Figure 5. The short wavelength spectra of observations 3, 4 and 6.](https://academic.oup.com/mnras/article-abstract/414/3/2406/1041284/byteful)
difference in the colours of the two LCs, the Pg passband of the Harvard plates and the eye response function of the AAVSO observations. An orbitally related period has usually different amplitudes in different passbands, but never a different value. This difference must therefore be due to a real change in the period of the cyclic outbursts of the system that took place between the epoch before the gap in the observations around the middle of the twentieth century and the epoch after it.

4.1 Interpretation

4.1.1 Rotational period of the giant

Before discussing the two major periodicities of the system, we comment on the nature of the period $P_g = 656\,\text{d}$ that is identified in the LC of section B of the data (see Section 3.1). We suggest that this is the sidereal rotation period of the giant component of the BX Mon binary system.

Zamanov et al. (2008) measured the rotational velocity of this giant, quoting two possible values, $11.0 \pm 1.5\,\text{and} 9.4 \pm 1.5\,\text{km s}^{-1}$. Taking their first suggested value, adopting the value $139.6\,\text{R}_\odot$ for the radius of the MSIII giant of this system (van Belle et al. 1999) and assuming that the equatorial plane of the giant is seen roughly edge-on, the resulting rotational period of the giant is $P_{\text{rot}} = 646\,\text{d}$. This is almost identical to $656\,\text{d}$ that we obtained from the Fourier analysis. Thus, our interpretation of the results obtained by our time series analysis of the LC of the star as the rotation period of the giant leads us to practically the same consequence about this period that was obtained by entirely independent observers and method.

4.1.2 Two major periodicities

Our analysis shows that the two major periods of the system, $P_a = 1373\,\text{d}$ and $P_b = 1256\,\text{d}$, do not exist simultaneously in the LC of BX Mon, but rather that a major switch between the two took place during the gap in the record of the observations. Such a large change of 120 d in the photometric period of the system within 32 yr is quite abrupt. To the best of our knowledge, such a discrete change from one periodicity to another, both with amplitudes that amount to 80–90 per cent of the total optical emissivity of the star, has not been observed so far in any other symbiotic star. We venture to say not even in any other star. There must have been some dramatic event or process that took place in the BX Mon stellar system that was the cause of this period switch. A likely photometric remnant of this event may be detected in the first 4000 d after the gap in the observations. For some 2500 d during that time, the mean brightness of the system was higher than at any other interval of the same time length. Also, as already mentioned in Section 3.3, the two light fluctuations recorded during these 4000 d are not in phase with either of the two major periods of the system.

The value of $P_a$ is almost certainly the binary period of the system as determined spectroscopically by Fekel et al. (2000), who suggested the period $1259 \pm 16\,\text{d}$, and by Brandi et al. (2009), who suggested the value $1290\,\text{d}$. Our $P_a$ is of course consistent with Fekel et al.’s (2000) value and marginally also with that of Brandi et al. (2009).

It is more difficult to trace the origin of the $P_a$ period of this system. We have already noted in Section 1 that Mira pulsations of the giant star are an unlike origin of the $P_a$ periodicity. BX Mon occupies the domain of normal M stars in a $(J-H)-(H-K)$ relation (Whitelock et al. 1994; Phillips 2007) and does not show variability in the infrared (Viotti et al. 1986). The origin of the $P_a$ periodicity may become clearer when we consider it as a linear combination of the system binary period $P_b$, and the rotation period of the giant $P_g : P_a = (1/P_g - 1/P_b)^{-1}$ (see Table 1).

The period $P_b$ is the length of 1 ’d’ of an observer on the surface of the giant component of the system, whose Sun is the hot component. The giant rotates with the sidereal period $P_r = 656\,\text{d}$, in the same sense as the binary revolution of the period $P_b = 1256\,\text{d}$. The observer will see the Sun circling his or her sky in the retrograde direction with a period $P_r = 1373\,\text{d}$. If $P_r$ is the spin period of the giant, as is most likely the case, this is true regardless of any other physical assumption.

4.1.3 Proposed physical process

We now suggest, in mostly qualitative terms, a physical process by which the ticks of this clock translate to outbursts in the LC of the system.

If the radius of the giant star is not very small compared with the average radius of its theoretical Roche lobe, the outer surface of it is distorted by the tides induced by the hot component. The tidal bulge created in the giant atmosphere rotates on its surface with the $P_a$ periodicity. This effect is well described and formulated in quantitative terms by Lecar, Wheeler & McKee (1976). If there is a region fixed on the surface of the giant, for example around a pole of a stellar oblique dipole magnetic field, where matter is less bound gravitationally, an intense mass accretion from the giant may be triggered at every passage of the bulge through that region. Each episodic in this cyclic train of events liberates intense gravitational energy. It is likely to be a trigger of an instability outburst in the accretion disc around the WD of the system, liberating even a larger amount of gravitational energy. Finally, the process may end up by a large amount of hydrogen-rich matter falling on the surface of the WD causing or enhancing the already existing process of nuclear burning there, liberating yet another large amount of energy.

A quantitative analysis of thermodynamical and energy transfer processes that would show how the cyclically liberated energy is eventually appearing as cyclical outbursts of the optical radiation of the system is beyond the scope of our paper, which is concerned with the temporal behaviour of the optical continuum emission of the system.

However, we refer the reader to the work of Sokoloski et al. (2006) who made a detailed analysis of multiwavelength observations in one of the outbursts of the symbiotic star Z And. The optical LC of Z And shows fluctuations that are rather similar to those of BX Mon, in their amplitude as well as in their time-scale. Sokoloski et al. (2006) suggested a ‘combination nova’ model as an interpretation of the spectroscopic and photometric observations, from the X-ray to the radio spectral regions, performed over one oscillation episode of Z And. A similar analysis of one light fluctuation of BX Mon requires a similar number of simultaneous or nearly simultaneous multiwavelength observations, which are not yet in existence. This work is concerned with understanding the clocks that regulate this behaviour. The Z And case serves as a demonstration that qualitatively and energy-wise, our suggested mechanism of how the diurnal cycle on the surface of the giant is translated to outbursts of the system, is a plausible one. Naturally, much more work, especially in observations, is required in order to put this interpretation on firmer grounds.

The characteristics of the fluctuations in section B of the LC are similar to those in section A. They too have the nature of outbursts rather than of smooth continued variability. As discussed in Section 4 (see Figs 3a and b), even if the hot component is eclipsed by
the giant at conjunction, the effect of it in the optical broad-band photometry of the system is negligible. Therefore, the origin of the intense periodic fluctuations with the binary periodicity in section B can hardly be attributed to the changing geometrical aspects of the system associated with the binary revolution. In particular, it is very unlikely that they are marks of eclipses. This becomes quite clear by comparing Fig. 3(b) or Fig. 4(b) with fig. 1 of Skopal et al. (2000), depicting the LC of the symbiotic star AR Pav in which most of the variability is indeed due to eclipses.

The radial velocity curve of BX Mon presented by Fekel et al. (2000) indicates that the binary orbit is quite eccentric. These authors suggest an eccentricity of 0.45–0.55. It is therefore consistent with our qualitative model to suggest that the fluctuations with the \( P_b \) periodicity in section B of the LC also have their origin in intense mass accretion events in the system. Since the gap in the observations in the middle of the twentieth century, these outbursts take place whenever the system is near its periastron passage, hence the binary periodicity. This periodicity is hardly seen in section A since the events of accretion from the bulge of the giant deplete the mass reservoir in the atmosphere of the giant to the extent that not much mass is left to be accreted at periastron passages. Once the accretion from the bulge is inhibited, accretion at periastron takes over.

Some support for this suggestion comes from the phase that the periastron passages of the system occupy in the photometric cycle. The vertical dashed lines in Fig. 3(b) mark the times of periastron passage. These are based on the date JD 244 9680 of periastron passage, as given by Fekel et al. (2000), with all other vertical lines being drawn on the time axis at equal intervals of 1256 d.

4.2 7370 periodicity

The period \( 2 \times 7370 = 14740 = (1/1256 – 1/1373) \) d is the interval between the noon time of an observer on the surface of the rotating giant when his Sun, the hot component, is seen at a certain position in his sky, relative to distance stars, and the next noon time when he sees his Sun in the same direction in his sky. After half of this time, the Sun will be seen at the observer’s mid-day at exactly the opposite direction. Thus, twice every 14 740/1373 giant days, i.e., with the periodicity \( P_b \), the maximum alignment between any fixed diameter line in the giant star and the radius vector from the centre of the giant to the instantaneous L1 point of the binary system is reached along the direction in space of the major axis of the giant elliptical orbit. This can be expressed mathematically by the relationship \( 1/P_1 = 0.5/(1/P_b – 1/P_e) \).

We again note that if \( P_b \) is the rotation period of the giant, this is a simple geometrical truism, regardless of any other physical consideration.

We can now again suggest how this clock is modulating the brightness of the system, as manifested by the period \( P_1 = 14740/2 = 7370 \) Earth days, identified in section B of the data (see Table 1). This period is the time interval between two successive events that we have just described, with the axis of a magnetic dipole field of the giant playing the role of the diametric axis mentioned above. In this scenario, the North and the South Poles of this field are alternating successively in getting closest to the L1 point during periastron passage. So while in section B, the timing of the intense mass transfer is controlled by the binary revolution through periastron passages, the magnetic field is still modulating to some extent the intensity of the mass transfer episodes. The most intense transfer events occur when the giant makes a periastron passage while one of its magnetic poles is closest to the L1 point of the system at that time. We do not pretend to know how a magnetic field around the L1 point affects the rate of mass transfer through this point. We note, however, that the same qualitative scenario would explain the observed 7370-d modulation also if a magnetic field around the L1 point inhibits rather than intensifying mass transfer through this point.

4.3 Three remaining periods

The frequency of the period \( P_3 = 431 \) d that appears in section B satisfies the equality \( 1/P_1 = 1/P_3 + 1/P_b \) (see Table 1). Such a beat of the \( P_b \) and the \( P_3 \) periodicities will result if the intensity of a light source in the system that is modulated by the giant rotation period \( P_b \) is modulated also by a cyclically varying agent with the binary period \( P_b \). This would be the case if the origin of the \( P_b \) periodicity is a stable or quasi-stable non-uniform distribution of brightness on the surface of the giant star, such as the presence of large starspots. The rotation of the giant gives rise to the \( P_b \) variability, as measured by an observer on Earth. This light variation is, however, further modulated due to the system binary revolution, for example by obscuration of the giant by some material component at fixed coordinates in the binary revolving frame (e.g., gaseous disc around the WD). Such modulation can also be the work of the well-known reflection effect in close binaries. The giant hemisphere facing the hot component is brighter than the other giant hemisphere. As the system revolves an observer on Earth, see the brighter hemisphere periodically at the binary periodicity. Thus, the light from BX Mon contains a component whose brightness depends on time as \( I(t) = C \times \cos[(2\pi/P_1) t] \times \cos[(2\pi/P_3) t] \), disregarding possible phase terms. Elementary equalities of trigonometry imply that the Fourier
decomposition of the time series of the LC of the star should include a component with the frequency of the above expression. This effect was first discussed in details by Warner (1986).

As mentioned in Section 3.1, the other two additional periods that modulate the optical LC of the star in section B, $P_1 = 1067$ and $P_2 = 1687$, can also be understood as beats of the two fundamental periods of the system $P_a$ and $P_r$ or as simple linear combinations of the pair $P_b$ and $P_a$ (see Table 1). We do not present in this paper specific geometrical realizations of these two linear combinations. We do note, however, that various beats of the spin frequency of a star in an interacting binary system with the orbital frequency of the system is not a rare phenomenon.Appearances of such beat frequencies, or sidebands, are particularly prevalent in magnetic cataclysmic (CV) variables, as discussed by Warner (1986). Recent examples and discussions of beats and sidebands in LCs of interacting binaries are the works of Woudt et al. (2009) or of Bloemen et al. (2010).

The stellar system BX Mon is of course vastly different from the stars discussed in the cited examples, all of which belong to the family of CV stars. However, the interplay between gravitational and magnetic effects and the varying aspects of the revolving binary system, which is the major cause for the appearance of spin–orbit beats in the LC, is common to both the symbiotic and the CV classes of stars. We point out, however, that even if no specific model can be suggested for explaining the P2 and P3 periodicities as beats of the two fundamental frequencies in BX Mon, this would not affect the analysis of the other four BX Mon periodicities that we are present here.

5 SUMMARY

We have established the existence of two distinct periods in the historical LC of BX Mon. Between the years 1889 and 1940, i.e. section A, the brightness of the star fluctuated with a peak-to-peak amplitude of 2–3 mag. with a period of $P_a = 1373 \pm 4\,d$. This period appears in the LC with its second and fourth harmonics. After the gap in the observations between 1940 and 1972, the LC of the star in section B again fluctuates with a peak-to-peak amplitude of 1–2 mag. This time, however, the major period is the binary period of the system $P_b = 1256 \pm 16\,d$.

To the best of our knowledge, such an abrupt switch between a photometric period of a binary system, which is 10 per cent longer than the orbital period of the system, and its binary periodicity has no parallel in the observational study of any symbiotic star. It has probably neither been observed in any other binary star.

In both sections of the data set, we identify periods that are various beats of the two major periodicities; in particular, in section B, we identify the $P_r = 656\,d$ period as the sidereal rotation period of the giant component of the BX Mon binary system. We suggest that the major fluctuations in the brightness of the star are due to events of intense accretion from the giant star on to its hot companion. Between 1889 and 1940, these events took place periodically with a period of 1373 d. After 1972, they occurred in the system at the binary orbital frequency.

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