MAGNETIC ROTATOR AND ITS EVIDENCE IN β LYRAE SYSTEM

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A main attention is paid to the evidence that the losing star of β Lyrae interacting binary system should be considered as the magnetic rotator with magnetosphere formed around it. Fragment of analyzing the observed secondary periods is presented, which has led to interconsistent magneto-hydrodynamical system of periodicities and resonances. In particular, new periods are discovered with the duration of $10^{d}_{.}93$, $13^{d}_{.}23$ and $564^{d}_{.}85$. The latter period is fundamental one, and the longest observed period of $282^{d}_{.}425$ is its harmonics and the period of running tidal wave. The reasons of the different values of this long-term period duration, obtained by different groups of observers are presented.

We make a conclusion on the base of long-term observations and studies of the spectrum of β Lyrae interacting binary system that unordinary approaches to its studies and search for new phenomena are necessary in order to understand the nature of this unique object. In 1980-1998 we have carried out measurements of Zeeman splitting of atmospheric lines of the bright component, which resulted in the discovery of the variable effective magnetic field with the orbital phase (Skulsky, 1982, 1985). Having solved this quasisinusoidal curve, we obtained that the mean field value is equal to $H_e = (-1198 \pm 32)$ G with the amplitude of $A = (475 \pm 51)$ G, and the field maximum and minimum corresponding to phases of $0.355P$ and $0.855P$ (Skulsky, 1990; Burnashev and Skulsky, 1991). Magnetic field is discovered for the first time on the surface of the component (hereafter, loser), which continues losing its mass very actively at the stage of finishing the first mass transfer in the binary system. That is why we have performed another research. CCD-observations of the two emission-absorption lines SiII6347, 6371 completed in the early nineties at the 2.6-m telescope, confirmed the magnetic field existence, but they showed a considerably less mean field value and rather different shape of its amplitude change (Skulsky and Plachynda, 1993). With the use of our absolute spectrophotometrical data, we have found out (Burnashev and Skulsky, 1986), that the variations of the equivalent width of depression at the λ 5200 Å in the β Lyrae spectrum correlate with the magnetic field variations (the relationship takes place between the photometrical indexes which are sensitive to the depression value, and the magnetic field strength values). The changes of absolute flux in the H_α-emissions are also synchronous with the effective magnetic field variations of the loser (Burnashev and Skulsky, 1991). The results of high spectral resolution CCD-observations of the H, HeI, SiII emission lines, in particular these of H_α and HeI7065 ones (their strong emission profiles are comparatively less distorted by absorption) have shown an evident correlation of Doppler shifts of emission line centers with the phase variations of effective magnetic field strength (Skulsky and Mal'kov, 1992; Skulsky, 1992a; Skulsky, 1993b). We have also detected another facts arguing that having the magnetosphere formed around the loser, the magnetic field influences upon the mass transfer between the components and the gaseous structure formation in the β Lyrae interacting binary system (see also Skulsky, 1992b, 1992a, 1993c).

Magnetic field behavior in the β Lyrae system is very ambiguous one, the field changes differently in the different lines, also short- and long-term variations take place there. That is why we expected independent studies of the magnetic field to be performed by other observers. However, having the publications reviewed in this field, we have found out that such investigations were not performed till the present time, and the magnetic field does not used mostly when studying this system. Therefore, we would like to stress the fact firstly, that the loser is magnetic rotator, and especially that photometrical and polarimetrical investigation data as well as spectral ones published in different periods by many observers, correlate well with the curve of magnetic field strength variation. Let us look at some of these papers. First of all it concerns radial velocities of strong emission lines in the visible range (for example, see Fig. 8 and 9 in the paper by Harmanec *et al.*, 1996; hereafter, HMB96), as well as many lines of the far ultraviolet, in particular high excitation lines CIII1175, SiIV1402 (for example, see Fig. 2–6 in the paper by Hack *et al.*, 1977). The extremes for all of these dependencies coincide with the magnetic field extremes. Let us remind that "β Lyr is not an eclipsing binary at wavelengths shortward of 1200 Å" (Polidan, 1989). Really, light curve of the β Lyrae at λ 955 Å presented in Fig. 6 of those paper, does not look like an eclipsing curve of one component by another at all, but its minimum coincides with the magnetic field maximum in the $0.355P$ phase, and variable maxima of this light curve are located within the range of second extremum of magnetic field strength curve, *i.e.*, both curves are intercorrelated. Some groups of researchers, in particular HMB96 and Hoffman *et al.*, 1998, find arguments to introduce terms "extended jets" or "a bipolar flow of gas oriented perpendicular to the orbital plane of the binary" in order to explain the phenomena related to the mass transfer between the components and mass loss outside the binary system. However, such jets or bipolar flows become quite natural when they are directed along the magnetic field dipole axis of the loser, all the more so that the deviation angle of this axis is rather high with respect to the orbital plane (Skulsky, 1985).

Secondly, we present here the information about some results of our analysis of periodicities and oscillations being observed within the last 20 years. As it was found out by us, this phenomenon is related directly to the magnetic field of the loser. Description of this phenomenon could be started from the detection of real variations of physical parameters with the secondary system period of 1.85 days. This period is surprisingly close to the seventh part of the orbital period, and as a rule it appeared well at the convolution of observed data with this period within one-two years of observations. We have firstly detected such periodicity on the variation curve with the orbital period phase of the absolute radiative flux in the strong emission line H_α (Burnashev and Skulsky, 1980). Variation curve of magnetic field of the loser with the orbital period phase showed the noticeable oscillations with this period as well (Skulsky, 1990). The work by Hoffman *et al.*, 1998 on β Lyrae spectropolarimetry is also important for us. Having their observation data convoluted with the $1\overset{d}{.}85$ period we received yet another confirmation of existence of this period with high variation amplitude.

The reliable data were published recently concerning the detection of another two periods, but these ones are featured by a considerably less variation amplitude. One of these periods, which exceeds much the orbital one, is also discussed for over 20 years (Alduseva and Kovalenko, 1976; Guinan, 1989). It was calculated recently in the range of $(283 \pm 1)^d$ on the base of independent light curves by two groups of observers. Van Hamme *et al.*, 1995 (hereafter, HWG95) obtained its averaged value with the duration of $(283.39 \pm 0.26)^d$ by means of the light curves within more than 150 years of observations. Having the most accurate observations of the last 36 years reduced into the single V-band intensity orbital light curve, the HMB96 group has calculated this period (by means of deviations from the averaged light curve) also with higher accuracy $(282.425 \pm 0.070)^d$ at the variable amplitude of $A = 0\overset{m}{.}0236 \pm 0\overset{m}{.}0008$. There was no physical explanation presented to the evident difference by $0\overset{d}{.}965$ almost between the results of identical determinations of this period, which exceeds much the 3σ value, as well as for the physical reasons of arising this period.

The second period with the duration of 4.7479 is less than orbital one, and it is calculated by means of solving curves of radial velocities of strong emission lines by HMB96 group. They have noticed that this period is in "causal relationship" with the long-term and orbital periods (for the season of 1994 with $P = 12\overset{d}{.}9385$):

$$3 \times \{(12\overset{d}{.}9385)^{-1} - 2 \times (282\overset{d}{.}425)^{-1}\} = (4\overset{d}{.}7479)^{-1}$$

The evidence of three secondary periods in different observations enforced us to analyze them. It is appeared that all the three periods are in resonance relationship, which is to be considered as the new phenomenon. However, let us present the fragment of this study concerning the two last periods detected by means of the light curves and the radial velocity curve. This will allow us to be sure in their relationship with magnetic field, to understand the nature of the long-term period and difference in its duration calculated by two groups of researchers.

Let us write the obtained equation in analytic form, having denoted long-term and short-term periods as T and T_1, respectively:

$$T_1^{-1} = 3(P^{-1} - 2T^{-1}). \tag{1}$$

Let us notice firstly, that the T_1 period is defined from the radial velocity curves of emission lines and they correlate with the magnetic field strength curve (Skulsky, 1992a, 1993b). Secondly, $T_1 = 0.367P$, *i.e.*, it is close to $0.355P$ phase of the loser magnetic field maximum (Burnashev and Skulsky, 1991). Also this period gives the information about the orientation of the axis of the surface magnetic field in relation to gravitational axis-line of both component centers. That is why the T_1 period could be considered as the specific oscillation in the phase space of the orbital period, connected with the proper phase angle of the first extremum of the magnetic field. This allowed to make the following assumption: there exists also physically similar period of $T_2 \cong T_1 + P/2$ (*i.e.*, it should define the second extremum of the magnetic field of the loser) which is conjugated with T_1 in such way that their overlapping gives the long-term period T as their beating period (at the simultaneous interaction of these three secondary periods with the orbital one). Expected period T_2 has appeared to be close to $0.855P$ phase of the magnetic field minimum, so we have found the second "causal relationship":

$$(12.^{d}9385)^{-1} + 4 \times (282.^{d}425)^{-1} = (10.^{d}93494)^{-1}$$

where $T_2 = 10.^{d}93494 = 0.845P$, and the orbital period value corresponds to 1994 as it was in Equation (1). Having written this equation in the analytical form as well:

$$T_2^{-1} = P^{-1} + 4T^{-1}, \tag{2}$$

we found the causal relationships for orbital and long-term periods from the system of Equations (1) and (2):

$$P = \frac{9T_1T_2}{3T_1 + 2T_2} \quad \text{and} \quad T = \frac{18T_1T_2}{3T_1 - T_2}. \tag{3}$$

Having substituted T_1 and T_2, we found a numeric value of $T = 282.^{d}439$, which agrees well with the value of $T = 282.^{d}425$ determined by HMB96 group. Therefore, the assumption of resonance relationship between T_1, T_2 and T is correct.

Relationships (3) look like classical formulas of superposition of oscillations with close periods. Having applied these formulas, we receive the resulting period

$$T_{rez} = \frac{2T_1T_2}{T_1 + T_2} = 6.^{d}62099, \tag{4}$$

which is close to the half-orbital one and their interaction should give the beating period:

$$T_{bt} = \frac{T_{rez}P}{2(T_{rez} - P/2)} = 282.^{d}269. \tag{5}$$

This value also agrees well with the T value of HMB96 group.

However, these are noticeable differences and our analysis showed that the HMB96 group did not take the orbital period variations into account (β Lyrae system has constant increase of the orbital period dP/dt = 18.9 s per year (Mandushev, 1988; Harmanec and Scholz, 1993; Wilson and Van Hamme, 1999)). That is why we made the necessary corrections to (1) and (2) Equations and reduced all their periods to the one effective season of the light curve averaged over 36 years of observations. It was 1980, and the set of corresponding periods is given below.

Now we can easily explain also the differences in period durations $T = (283.39 \pm 0.26)^{d}$ and $T = (282.425 \pm 0.070)^{d}$ obtained by two groups of researchers HWG95 and HMB96, respectively. Taking into consideration that HWG95 determined the period $T = 283.^{d}39$ as the averaged value over the 150 years of observations, and using the (1) – (5) system of equations, we have obtained the value of $T_{bt} = 283.^{d}3904$ for the light curve centered in the season of 1920. The corresponding set of periods for 1920 is given in the table as well:

1980	1920
$P = 12.^{d}9355$	$P = 12.^{d}9224$
$T = 282.^{d}42524$	$T = 283.^{d}3904$
$T_1 = 4.^{d}746634$	$T_1 = 4.^{d}739723$
$T_2 = 10.^{d}932617$	$T_2 = 10.^{d}928985$
$T_{rez} = 6.^{d}619338$	$T_{rez} = 6.^{d}611950$

Therefore, difference $\Delta T = 0.^{d}965$ between T values obtained by HWG95 and HMB96 groups of authors, is explained by the sample of observations forming these light curves. Time difference between effective forming of these light curves equals to 60 years which gives the orbital period increase by $\Delta P = 0.^{d}0131$. This has led to the changes of related periods T_1, T_2 and T.

Physical nature of the long-term period T could be also easily understood now by means of substituting the value of full orbital period and doubled value of T_{rez} into Equation (5) (it means, assuming that magnetic and rotation period values of the loser are equal and $P_{mag} = P_{rot} = 2T_{rez}$ since axial rotation period of the loser is observed to be a little longer than the orbital one (Kosovichev and Skulsky, 1990; Harmanec and Scholz, 1993)). In this case their beating period in 1980 was equal to:

$$P_{bt} = \frac{P_{orb}P_{rot}}{P_{rot} - P_{orb}} = 564.^{d}85158 = 2T.$$

Thus, $P_{bt} = 564^{d}_{.}85$ is the fundamental period in β Lyrae system, and the period $T = 282^{d}_{.}425$ means its first harmonics and (on the base of the theory of tidal waves in a binary systems (Kato, 1974; Kosovichev and Skulsky, 1990)) simultaneously is the period of running tidal wave at the loser surface. Really, this wave appears because of asynchronism of orbital and rotational periods:

$$P_{run} = \frac{P_{rot}P_{orb}}{2(P_{rot} - P_{orb})} = T = 282^{d}_{.}42579.$$

Let us make a conclusion:
long-term period T is the period of running tidal wave at the loser surface and at the same time it is in resonance relationship with the short-term periods T_1 and T_2, which determination is strongly connected with the magnetic field structure and geometry; all periods, fundamental one as well as short-term ones, form the interconsistent magnetohydrodynamical system of the periodicities which is being changed gradually together with the orbital period change during completion of the quick final stage of the primary mass transfer between β Lyrae interacting system components.

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