Physics of Magnetic Stars, 2007, pp. 223–229

Magnetic fields and secondary rhythms in the Beta Lyrae system

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Abstract.

In this review the results of the present-day state of the magnetic field research and its causal relationship with the secondary periods in the Beta Lyrae interacting binary system are given. The magnetic field demonstrates the complicated time-dependent behavior. For instance in 1981–1999 the changes of the magnetic field on the long-time-scale variability averaged 2.5 kG. The observable facts can evidence that the donor should be considered as a magnetic rotator and that around the Beta Lyrae binary system magnetosphere is formed. The presence of the donor as the magnetic rotator in the interacting binary system can produce a set of causal relationships. One of the recently originated topics is the connection between the magnetic field and the secondary periodicities in the Beta Lyrae system. First of all were considered three observable secondary periods with duration of 1.85 d, 4.74 d and 282.425 d. These and other secondary periods form the interconnected magnetohydrodynamical system of the periodicities and resonances in the Beta Lyrae system. Such secondary rhythms must change with the observable increase of the orbital period in the mass transfer process. The theoretical base for this phenomenon can be the conception of the parametric resonance when the losing matter of the donor is a variable parameter.

Key words: interacting binary system: accretion, precession, magnetic field, secondary periods

A quarter of a century ago I made a statement about the discovery of magnetic field on the surface of the donor of the Beta Lyrae interacting binary. It was during the conference of the working group “Magnetic stars” here, in the Special Astrophysical Observatory. Now I will perform a short analysis of the present-day state of the magnetic field research and its causal relationship with the secondary periods in this system. As it is known, Beta Lyrae has a period of about 13 days, with no constant light at any phase of the orbital period. Its spectrum displays the different systems of absorption and emission spectral lines that arise from different sources. At all its orbital phases are seen the relative sharp absorption lines ($vsini \approx 55\ km \cdot s^{-1}$) of the component of the donor that produces radial-velocity curve with a semi-amplitude of $\approx 185\ km \cdot s^{-1}$. Only several of very weak absorption lines tracing the orbital motion of the component of the accretor (its semi-amplitude of RV curve is $\approx 41\ km \cdot s^{-1}$) were found but it made possible to evaluate the masses of these components (Skulsky, 1975, 1992a). The bright but less massive donor ($\approx 3\ M_{\odot}$) is losing its matter very actively ($\approx 2 \cdot 10^{-5}\ M_{\odot} \cdot y^{-1}$) in the rapid mass loss stage (the first mass transfer in this binary system). It leads to the observable increase of the orbital period 18.9 $s \cdot y^{-1}$ and to the observable developed circumstellar gaseous structures. As a result, the more massive accretor ($\approx 13.5\ M_{\odot}$) is surrounded and camouflaged by an intricate massive accretion disk. In external part of this disk the absorption lines are formed which are observed only in phases before and after the primary mid-eclipse (so-called "satellite" lines). They are red-shifted before and blue-shifted after the mid-eclipse by the value greater than 200 $km \cdot s^{-1}$ forming the Schlesinger-Rossiter's effect of this disk. The satellite lines are showing the precession motion of the disk's external part as an independent part of the accretion disk (Skulsky, 1993b).

The first study of the Beta Lyrae magnetic field was carried out using four hundred spectrograms with 9 Å/mm dispersion obtained in 1980-1988 on the 6 m telescope of the Special Astrophysical Observatory (Skulsky, 1982, 1985, 1990). Finally, the measured Zeeman splittings of mainly ionized metal lines of the atmosphere of the donor showed the negative variable effective field with a mean value that equals $H_e = -1200\ G$ (Burnashev and Skulsky, 1991). The maximum and minimum amplitude of the magnetic field quasisinusoidal curve $A = \pm 475\ G$ was connected to the phases 0.355 P and 0.855 P of the orbital period that was equal to $P = 12.9355\ d$ in 1980. Interpreting this field as the dipole one we can assert that along these phases passes the magnetic field dipole axis of the donor and can see its two poles. Because of this, we made a search for the confirmation of magnetic field and possible connections with the different characteristics of the physical processes in the Beta Lyrae system.

Using our absolute spectrophotometric data (Burnashev and Skulsky, 1978), we detected that the variability of the equivalent width of depression at the $\lambda\,5200$ Å correlates with the magnetic field's variability (Skulsky, 1985; Burnashev and Skulsky, 1986). As is well known, there are the relationships between the photometrical indices of this depression and the magnetic field's strength. We also found a clearly defined correlation between the variability of the absolute flux in H_α-emission and the magnetic field variation along the orbital period (Burnashev and Skulsky, 1980, 1991). The high spectral resolution in the H, HeI, $SiII$ emission lines (in particular, H_α, $HeI6678$, $HeI7065$ have the strong and slightly distorted by their own absorption emissions that are fully over the continuum) showed a distinct correlation of Doppler shifts of the emission centers of these lines with the magnetic field orbital variations (Skulsky and Malkov, 1992; Skulsky, 1992a, 1993a,b). There are spectral, photometric and polarimetric data in independent publications which correlate with the magnetic field curve too. For example, it concerns the strong emission lines in the visible range of spectra (see Fig. 8 and Fig. 9 in Harmanec at al., 1996) or high excitation lines in the far ultraviolet, first of all, $CIII1175$, $NV1238$, $SiIII1301, 1303$, $SiIV1402$ (it is seen, in particular, in Figs. 2–6 in the paper by Hack et al., 1977). The extremes of the dependencies of their equivalent widths and RV-curves (especially of their line centers) on the phase of the orbital period coincide with the phase extremes of the magnetic field curve. The inference: " β Lyr is not an eclipsing binary at the wavelengths shortward of 1200 Å" (Polidan, 1989) also evokes the great interest. Really, int Fig. 6 of this paper the light curve at λ 955 A has only one minimum that is near the phase 0.355P of the magnetic field pole of the donor. Moreover, Harmanec and Scholz (1993) noticed double-wave variations on the radial velocity curve of HeI3888. It means that this curve minimum at phase 0.855P coincides with the magnetic field pole phase. The sharp absorption of this line originates from the lower metastable level and describes the rare matter in the external gaseous shell that moves out of the binary system (Struve 1941, Skulsky 1992b).

These and other observable facts can evidence that the donor should be considered as a magnetic rotator and that around the Beta Lyrae binary system a magnetosphere is formed. In this aspect the donor shows some similarity with the helium-strong stars (this component has been affected in hydrogen burning through CNO-cycle and atmosphere of the donor has an excess of helium and deficit of hydrogen — Boyarchuk, 1959; Skulsky 1986). In these stars there is the magnetically controlled circumstellar matter and the circumstellar plasma are channeled to form jet-like outflows from the magnetic pole regions (Shore and Braun, 1990). In the Beta Lyrae present-day publications there exists such conception as "extended jets" (Harmanec at al., 1996), or "a bipolar flow of gas oriented perpendicular to the orbital plane of the binary" (Hoffman et al., 1998) without clear-cut explanations of their origin. It seems that such jets or bipolar flows become natural when they are directed along the dipole axis of magnetic field of the donor (the deviation angle of this axis with respect to the orbital plane is high enough — Skulsky, 1985).

The first independent measurements of Zeeman splitting in $SiII6347, 6371$ emission-absorption lines carried out in 1991-1992 with Stokesmeter and CCD detector mounted in front of the coude spectrograph of the 2.6 m Shajn telescope at the Crimean Astrophysical Observatory (Skulsky and Plachinda, 1993). They confirmed the magnetic field existence but showed a considerably smaller field value $\pm(100-200)$ G and rather different shape of its amplitude change. Subsequent measurements of the magnetic field they realized by using metal lines in 1993–1995 and 2000–2004. The same spectral lines for the measurements of the magnetic field were used at the Catania Astrophysical Observatory in summer 1999. The magnetic field of 1993–2004 demonstrates complicated time-dependent behavior (Skulsky and Plachinda, 2004). But in 1999 the effective magnetic field was fully positive with the mean value $+1290$ G (Leone at al., 2003). Therefore from 1981 to 1999 the change of the magnetic field of the donor on the long-time-scale variability averaged 2.5 kG.

As it should be expected, our comprehension of the Beta Lyrae magnetic field remains insufficient. This field shows obvious variability on the surface of the donor and correlates with the processes in the circumstellar matter. In particular, the magnetic field has a direct connection with the secondary periodicity in the binary system — Skulsky, 2000, 2001. Considering the nature of the magnetic field Leone at al., 2003 recorded “this magnetic field, to our knowledge, is unique” and even set up a hypotheses that “the dynamo-active accretion disk can be at the origin of some phenomena presented by the β Lyrae system”. We can accept that the ellipsoidal disk rotation around the accretor puts in action the wave effects in the atmosphere of the donor. Moreover, Dolginov and Yakovlev (1975) showed that the magnetic field of the donor could be generated by the tidal wave mechanism. In any case, the magnetic field can play a definite role in the Beta Lyrae interacting system, although this field has been discovered for the first time on the surface of the bright but less massive donor. In so far as the possible relationship between binary nature and physical activity of the donor star is irrefutable, the presence of the donor as a magnetic rotator in the interacting binary system can produce a set of causal relationships. For example, the recently originated topic of the connection between magnetic field and the secondary periodicities in the Beta Lyrae system is unusual too (Burnashev and Skulsky, 1980, 1991; Kosovichev and Skulsky, 1990; Skulsky, 2000, 2001). Here we shall consider the development of this topic and its current state with particular attention.

The problem of the second non-orbital periodicity is, first of all, that the long-period changes in the light curve of the Beta Lyrae binary system have a century history (see, for example, Blagg (1928); Gutnik (1945)). However, this problem stands relevant in the last decades when several secondary periods were determined on the basis of methodically independent observations (Alduseva and Kovalenko, 1976; Burnashev and Skulsky, 1980; Guinan, 1989; Van Hamme at al., 1995; Harmanec at al., 1996; Peel, 1997). As it will be clear from our further account, these observable periods can be part of the interconnected system periodicities. One of the period with the duration of 1.85 d is very close to the seventh part of the orbital period ($P \approx 12.935$ d) and is concerned with the magnetic field of the donor. This periodicity was detected as oscillations of the absolute radiation flux in the strong H_α-emission (Burnashev and Skulsky, 1980). Such periodicity may be obtain from the tabular observation data of the magnetic field in 1980–88, namely, separately from the fullest observations in 1981 and 1982 (Skulsky, 1990). The spectropolarimetric data (Hoffman et al., 1988) showed also that there is a 1.85-day period in the intrinsic polarization in V and BJ filters. Such a short period shows the total amplitude of all variable parameters. At the same time, long-period changes are observed, first of all, in the light curve of the Beta Lyrae system. Van Hamme et al. (1995) found the long-time (283.39 ± 0.26)-day period due to the deviations from 150 years-averaged light curve. After the similar procedure Harmanec et al. (1996) found a secondary

(282.425 ± 0.070)-day period at the amplitude of $A = (0.^m0326 \pm 0.^m0008)$ using the most accurate observations during the last 36 years. At the present time the secondary (283 ± 1)-day period is considered as a fact. This provokes to interpret the physical nature of the so-called 283-day period.

Most likely, the solution of this problem could be explored in two directions. First of all, we elucidated the observed secondary period $T = 282.425\ d$ (we refer it to 1980 and will use as the most precise value of this long-time period — Skulsky, 2000) can be equal to the precession period of the disk formed around the accretor. We proceeded from analogy between the Beta Lyrae system and the cataclysmic variable stars with the accretion disk. For example, SU UMa stars with the relation of the mass $q \leq 0.3$ have an established relationship (Osaki, 1985) between the disk precession period P_{pr}, the orbital period P and the external critical radius of the accretion disk R_d (in units of the component separation A):

$$P_{pr} = 1.333P(R_d/A)^{-3/2}(q+1)^{1/2}q^{-1} \tag{1}$$

The mass ratio in the Beta Lyrae binary system (Skulsky, 1992, 1993a) is equal to $q = 0.222$ and the radius of the Roshe lobe of the accretor is $0.51\ A$. The disk external critical radius $R_{d,ex} = 0.452\ A$ and the internal one $R_{d,in} = 0.295\ A$ we obtained from the light curve in $\lambda\ 6488\ A$ (Burnashev and Skulsky, 1980, 1991) and from the radial velocities of the disk satellites lines (Skulsky 1992, 1993b). Then the external edge of the accretion disk is rotating around the accretor during $P_{pr,ex} = T = 282.425\ d$. The accretion disk internal edge is turning twice slower, $P_{pr,in} = 2T = 564.85\ d$. They are in a 1:2 ratio that is the octave. Moreover, the rotation period of the disk matter on the Keplerian orbits of external edge is $0.5\ P$ at the linear velocity $208\ km \cdot s^{-1}$ and on the disk internal edge these numbers are $0.25\ P$ and $266\ km \cdot s^{-1}$, accordingly. It is within the ambit of the radial velocities of the satellite lines that are formed in the disk (Skulsky 1992, 1993b). Also we must take into account that in some epochs of Beta Lyrae observation its light curve demonstrated simultaneously the 283- and 340-day periods. These secondary periods can interfere and produce the compound picture of the beating in the resulting light curve (Peel, 1997). We supposed that they can reflect the large-scale structure of the accretion disk and distinguished four substructures of this disk. Their dynamic parameters are related to each other as integers. Particularly, the precession periods of these substructures are related as $3 : 4 : 5 : 6 = 282.425\ d : 339.05\ d : 423.68\ d : 564.85\ d$ (in 1980 when the orbital period came to $P = 12.9355\ d$).

On the other hand, the long-term 283-day period can be justified on the basis of the ideas about the tidal waves in the binary systems (Kato, 1974; Kosovichev and Skulsky, 1990). Hence we postulate that the asynchronism of the orbital period P and the rotational period of the donor $P_{rot,don}$ call into being a tidal wave on the surface of the donor that is equal to the 283-day period. Really, their beating period (or a fundamental tidal period) we can find with the well-know relationship

$$1/P_{bt,don} = 1/P - 1/P_{rot,don}. \tag{2}$$

It is equal to $P_{bt,don} = T_{f,don} = 564.85\ d$ (provided that the value of the rotational period of the donor was accepted equal to $P_{rot,don} = 13.2386\ d$, in 1980). The first harmonics of the beating period is the period of the running tidal wave at the surface of the donor:

$$T_{run,don} = P_{rot,don}P/2(P_{rot,don} - P) = 282.425\ d. \tag{3}$$

Since $T_{run,don}$ can be equal to the observable secondary period $T = 282.425\ d$ it can produce proofs to the physical nature of the 283-day period. In that case, in the Beta Lyrae system there can exist synchronism between the precession rotation of the accretion disk, disturbed by the donor, and the tidal wave on the surface of the donor, caused by the revolution of the accretor around the donor.

The support of the asynchronism of the donor we obtained as a result of joined study of the short and long secondary periods (Skulsky, 2000, 2001). It connected these periods in the interconnected magnetohydrodynamic system of the periodicities. At the beginning we noted that there exists a causal relationship between the long-term period $T = 282.425\ d$, the orbital period P and the new short-term period $T_1 = 4.74\ d$ (Harmanec et al., 1996). According to Skulsky (2000) this relationship was referred to 1980 and presented as: $3\left\{(12.9355d)^{-1} - 2(282.425d)^{-1}\right\} = (4.7466\ d)^{-1}$ or analytically as:

$$T_1^{-1} = 3P^{-1} - 6T^{-1}. \tag{4}$$

The relationship (4) has all coefficients as integers. An important point is that this relationship was obtained from the deviation from averaged curve of the radial velocities of the strong emission lines H_α and $HeI6678$. At the same time the first short-term secondary period that was equal to 1.85 d was revealed from the absolute radiation flux curve in H_α-emission and turned out to be in the magnetic field of the donor (Burnashev and Skulsky, 1980, 1991). At the same time the value of the period $T_1 = 4.7466\ d$ in terms of the orbital phase $T_1 = 0.367\ P$ i.e. is close to the value 0.355 P that is the phase of the first magnetic pole of the donor. It is of interest that the secondary periods T_1 and T have strongly differing durations: $T \approx 60T_1$. Starting from the physics of the oscillatory processes, we supposed the existence of the physically similar period $T_2 \approx T_1 + P/2$ (i.e. T_2 is to be in a phase of the second magnetic pole of the donor, which in interference with T_1-period can give a long-term T-period as their beating period (in the interaction of these three secondary periods with the orbital one). The expected period was $T_2 = 10.9326\ d = 0.845\ P$ and the expected causal relationship was as follows (Skulsky, 2000):

$$T_2^{-1} = P^{-1} + 4T^{-1}. \tag{5}$$

This is only one relationship with all coefficients as integers that satisfies the above requirements. From (4) and (5) for the orbital and long-term periods follow relationships:

$$P = 9T_1T_2/(3T_1 + 2T_2) \quad \text{and} \quad T = 18T_1T_2/(3T_1 - T_2). \tag{6}$$

The period of the resulting oscillation for the periods T_1 and T_2 is the following:

$$T_{res} = 2T_1T_2/(T_1 + T_2) = 6.6193\ d. \tag{7}$$

It is close to half of the orbital period. In accordance with relationship (2), this result shows that $2T_{res} = 13.2386\ d = P_{rot,don}$, i.e. it is equal to the rotational period of the donor as a magnetic rotator. The value of the beating period of the $2T_{res}$ and P is equal to the fundamental tidal period on the surface of the donor

$$T_{f,don} = 2T = 2T_{res}P/(2T_{res} - P) = 564.85\ d. \tag{8}$$

The beating period of the T_{res} and $P/2$ is equal to the observable long-term period $T = 282.425\ d$ which is the period of the running tidal wave $T = T_{run,don} = 0.5T_{f,don}$. On the other hand, in accordance with (6) the period $T = T_{run,don}$ is in resonance interaction with the short-time periods of T_1 and T_2 which trace the magnetic field structure of the donor. It seems that the asynchronism of the donor has an influence on the magnetohydrodynamic oscillatory processes on the surface of the donor.

In this connection we must consider the physical nature of the shortest (1.85-day) observable secondary period that was discovered earlier (Burnashev and Skulsky, 1980). As was shown (Skulsky, 2000, 2001) the pair periods $T_1 = 0.367\ P$ and $T_2 = 0.845\ P$ was determined relative to phase 0.0 P on the gravitational axis (this axis passes through the phases from 0.0 P to 0.5 P). This determination is arbitrary, and in reality the group of the already discovered periods should be a fragment of a fuller system of periods. For example, denoting the periods T_1 and T_2 as $T_{1,I}$ and $T_{2,I}$, we can obtain three other variants II, III, IV of the paired periods: $T_{1,II} = 0.5\ P - T_{1,I} = 1.7211\ d = 0.1331\ P$ and $T_{2,II} = P - T_{2,I} = 2.0029\ d = 0.1548\ P$; $T_{1,III} = T_{1.I}$ and $T_{2,III} = T_{2,I} - 0.5\ P$; $T_{1,IV} = T_{2,I}$ and $T_{2,IV} = T_{1,I} + 0.5\ P$. For variants II, III, IV, according to formula (7, we derived such resulting periods: $T_{res,II} = 1.8513\ d = 0.1431\ P$, $T_{res,III} = 4.6024\ d = 0.3557\ P$, $T_{res,IV} = 11.0717\ d = 0.8559\ P$, which is in direct relationship with the magnetic field of the donor. Really, $T_{res,II} = 1.85\ d$ is equal to the observed short-term secondary period. $T_{res,III} = 0.3557\ P$ and $T_{res,IV} = 0.8559\ P$ with an accuracy of 0.001 P coincide with the phases 0.355 P and 0.855 P of the magnetic field poles of the donor. Passing along the phases of the 0.355 P and 0.855 P the axis of the magnetic field of the donor can be considered as averaged. It is deflected from the gravitation axis of the binary system by the seventh part of the orbital period which is equal to the observed 1.85-day secondary period. It is obvious that the structure of the magnetic field of the donor is not the structure with a classical dipole.

At the same time, the nature of the 1.85-day observable period can have another aspect of its explanation. So, the calculated eigenmodes of oscillations of the donor (Kosovichev and Skulsky, 1990) show that the duration of its fundamental mode of the quadrupole type is close to the 1.85-day secondary period. This mode is described by the spherical harmonic $l = 2$ for the polytropic model with the index $2 \leq N \leq 2.5$. The rotation of the donor causes splitting of the angle frequency of the eigenmodes. Then the mode with $l = 2$ can split into the azimuth oscillations $m = \pm 2$, which are equal to the periods of 1/6 and 1/8 of the orbital period. These periods are close to the pair of periods $T_{1,II}$ and $T_{2,II}$ too. Coinciding with the periods of the eigenmode of the donor, all three non-radial oscillations would manifest themselves if only one out of the three will be seen. It was showed also (Kosovichev and Skulsky, 1990) that the 1.85-day period can arise due to the resonance amplification of the donor surface motions amplitude between the nonradial oscillations of the donor and the tidal wave at its surface (from formula (3) the observable long-term 282.425-day period is equal to the tidal wave period of the donor).

As part of the study, we can postulate that the 1.85-day secondary period is equal to the rotation period of the accretor $P_{rot,ac}$ (really, at the contemporary loss of the matter of the donor the orbital period have a constant increase of 18.9 $s \cdot y^{-1}$; with such an increase the orbital period was about 2 days 50000 years ago). In that case, the beating period of the rotation period of the accretor with the orbital period is equal to the fundamental tidal period on the surface of the accretor $P_{bt,ac} = T_{f,ac} = PP_{rot,ac}/(P - P_{rot,ac}) = 2.159\ P$. It is equal to P/6 and according to Kosovichev and Skulsky (1990) $P_{bt,ac}$ is equal to the possible eigenmode with l=2 that splits into azimuth oscillation $m = 2$ on the surface of the donor (the tidal period of the accretor is $P/12$). The resulting periods concerning the accretor $P_{res,ac} = 2PP_{rot,ac}/(P + P_{rot,ac}) = 0.251\ P$ and $P_{res,ac} = 2P_{rot,don}P_{rot,ac}/(P_{rot,don} + P_{rot,ac}) = 0.250\ P$ (here $P_{rot,don}$ is the rotation period of the donor) are equal to each other and to $P/4$. Such periods can be in resonance between themselves.

Concluding this report, we could say that on the surface of the donor as a magnetic rotator and in the binary system in whole certain system of interacting secondary periods can be observed. In particular, there exist long-term periods that characterize the understructure of the differentially revolving accretion disk. All these secondary periods form the interconnected magnetohydrodynamical system of periodicities and resonances in the Beta Lyrae system. Their resonance relationships can be constant but all these periods and resonances as the secondary rhythms must change with increasing orbital period in the mass transfer process. The theoretical basis for this phenomenon can be a conception of the parametric resonance when the losing matter of the donor is a variable parameter. At the stage of the active mass transfer from the donor to the more massive accretor it leads to the observable increase of the orbital period and to a system of the secondary periods interconnected with this period.

We hope to publish a fuller study in the future.

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