The A-Star Puzzle
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The magnetic field of β Lyrae

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Abstract. The complicated and intricate time-dependent behavior of the magnetic field of β Lyrae from 1980 to 2004 is discussed.

Keywords. Binaries: close: eclipsing, stars: magnetic fields, stars: individual: (β Lyrae)

1. Introduction

A system of periodicities is observed for the eclipsing binary β Lyrae. The most important and the primary period is the orbital one $P_{\rm orb} \cong 12.94\,$d, which is increasing by 18.9 $\rm s\,y^{-1}$ (Harmanec & Scholz 1993) because the bright B8 II star ($\sim 3\,M_{\odot}$) is losing mass to a more massive ($\sim 13\,M_{\odot}$) and invisible in the optical spectrum component, which is surrounded by an accretion disk. A shorter transient period of 1.85 d was observed in the absolute radiative flux of the $\rm H_{\alpha}$ emission (Burnashev & Skulsky 1980, 1991). A $P \cong 4.74\,$d was established from the radial velocity behavior of the strong emission lines by Harmanec *et al.* (1996). There are also considerably longer periods: 283 ± 1 d which was evaluated from the analysis of light curves by Van Hamme *et al.* 1995 and Harmanec *et al.* (1996), and $P \approx 340\,$d that was evaluated by Peel (1997). Leone *et al.* (2003) discussed all magnetic field measurements of β Lyrae from 1980 to 2000. The magnetic field demonstrates complicated and intricate time-dependent behavior. Here we add our magnetic field observations from 2001 to 2004 to the discussion.

2. Observations

The first extensive study of the magnetic field of β Lyrae was carried out in 1980-1988 using the 6-m telescope of the Special Astrophysical Observatory (Skulsky 1982, 1985, 1990). The Zeeman splitting was measured in the lines of the atmosphere of bright B8 giant. These photographic observations showed a negative mean value $-1240\,$G. The amplitude of the variance versus orbital period was $\sim \pm 450\,$G. Measurements of Zeeman splitting in Si II $\lambda 6347$ and $\lambda 6371$ were made in 1991-1992 with the Stokesmeter and a CCD detector, mounted in front of the coudé spectrograph of the 2.6-m Shajn telescope of the Crimean Astrophysical Observatory (Skulsky & Plachinda 1993). The presence of the magnetic field of the primary component was confirmed. The amplitude of variability against orbital period was $\sim \pm 100\,$G and the mean value was zero. Since 1993 we have continued the observations using some metallic lines. Results of photographic measurements and our magnetic field measurements during 1993-1995 and 2000 using the complete sample of spectral lines as well as results of magnetic field measurements at the Catania Astrophysical Observatory in Summer 1999 are combined in Leone *et al.* (2003). The mean value of measured effective magnetic field in 1999 was $+1290\,$G. Therefore, the change of the magnetic field in β Lyrae for long-time-scale variability is 2.5 kG. Leone

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et al. (2003) hypothesized: “This magnetic field, to our knowledge, is unique. Since we measured the magnetic field in metal lines of the brightest star of the system, we can conclude that this is the first magnetic B-type giant star. In this case, the magnetic field is significantly different from that of Magnetic Chemically Peculiar stars...”

The matter in the elliptic accretion disk is revolving differentially (Skulsky 1992, 1993). Therefore the presence of “the dynamo-active accretion disk can be at the origin of some phenomena presented by the β Lyrae system” (Leone *et al.* 2003).

It is possible to assume also that the ellipsoidal disk rotation as the whole will modulate the wave effects (the nonradial oscillations and tidal wave resonance phenomena) in the donor’s atmosphere. Therefore, the accretion disk may introduce systematic changes in the observations of the donor’s magnetic field, corresponding to the eccentric accretion disk’s orientation around the accretor. Moreover, the magnetic field of the donor can be generated by the tidal wave mechanism (Dolginov & Yakovlev 1975).

Multiperiodicity and resonances are observed in the cataclysmic variable stars with accretion disks (SU UMa-type dwarf novae). Osaki (1985) showed that for the SU UMa stars a relationship between the external critical radius of the disk ($\sim 0.46\,A$, where A is the distance between the centers of stars), the relation of the masses ($q \leqslant 0.3$), the orbital period P_{orb}, and the disk precession period $T = P_{\mathrm{pr}}$ (a period of the elliptic accretion disk’s rotation around the accretor) are as follows:

$$P_{\mathrm{pr}} = \frac{4}{3} P_{\mathrm{orb}} (R_{\mathrm{ext}}/A)^{-3/2} (q+1)^{1/2} q^{-1} \tag{2.1}$$

The mass ratio in β Lyrae system is $q \cong 0.22$ (Skulsky 1993, Linnel & Hubeny 1996). The disk’s external critical radius, R_{ext}, and internal one, R_{in}, were obtained from the radial velocities of the disk satellite lines (Skulsky 1992, 1993) and from the light curve for $\lambda 6488$ (1991): $R_{\mathrm{ext}} \cong 0.452\,A$ and $R_{\mathrm{in}} \cong 0.295\,A$. The precession period which is determined from the formula (2.1) is 282.4 d. Thus, the external edge of the accretion disk is rotating around the accretor in 282.4 d. This period is equal to the period of the tidal wave on the surface of donor that is in the resonance with it. Moreover, the accretion disk’s internal edge is turning twice slower and its rotational periods equals the fundamental period $T_{\mathrm{f}} = 564.8$ d (Skulsky 2000). The rotation period of the disk matter in the Keplerian orbits of the disk’s internal edge is $0.25\,P$ (P is the orbital period) at the linear velocity of 266 km s^{-1}, and at the disk’s outer edge is $0.5\,P$ and 208 km s^{-1}, respectively. It coincides with the observable frames of the radial velocities of the satellite lines which are formed in the disk (Skulsky 1992, 1993).

All Crimean observations since 1993 have been reprocessed using a Monte-Carlo method of numerical simulation of the standard deviations (Plachinda 2004). Spectral lines with huge errors of magnetic field measurements have been eliminated from the sample. These results of Crimean observations from 1993 to 2004, results of photographic measurements from 1980 to 1988, and results of Catania observations in 1999 are shown in Figure 1. In Figure 2 we show effective magnetic field of β Lyrae measured at Crimea only, which are folded with the orbital period reported by Harmanec & Scholz (1993): $JD_{\mathrm{Prim.eclipse}} = 2408247.966 + 12.91378 \times E + 3.87196 \times E^2$. That the Crimean observations do not show any periodicity with the orbital period. This period is not clearly present in Catania observations of 1999 also, despite the observations in the 1980s.

Van Hamme *et al.* 1995 (1995) found the period $T_1 = 283.39 \pm 0.26$ d from 150 year averaged light curves. Harmanec *et al.* (1996) found the period $T_2 = 282.425 \pm 0.07$ d based on the accurate observations during the last 36 years. The discrepancy between T_1 and T_2 is 0.965 d. Skulsky (2000) showed that the discrepancy is caused by the annual increase of the orbital period ($\partial P/\partial t = 18.9\,\mathrm{s\,y}^{-1}$, Harmanec & Scholz 1993). This period,

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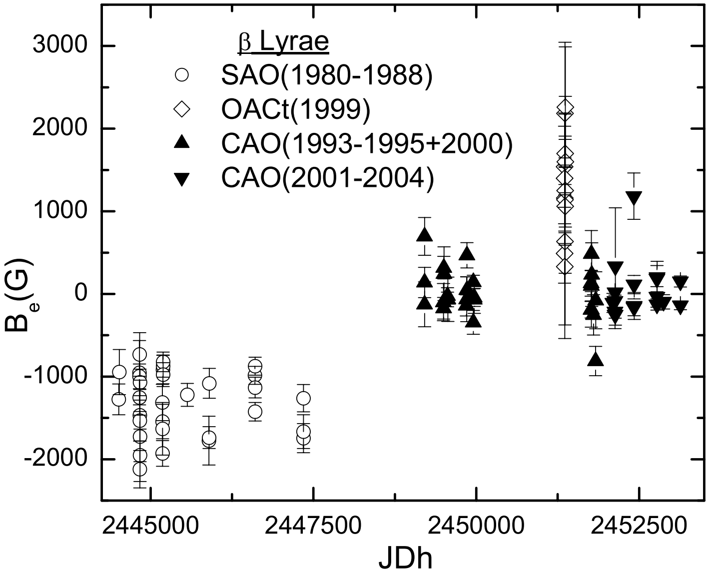

Figure 1. Magnetic field of β Lyrae.

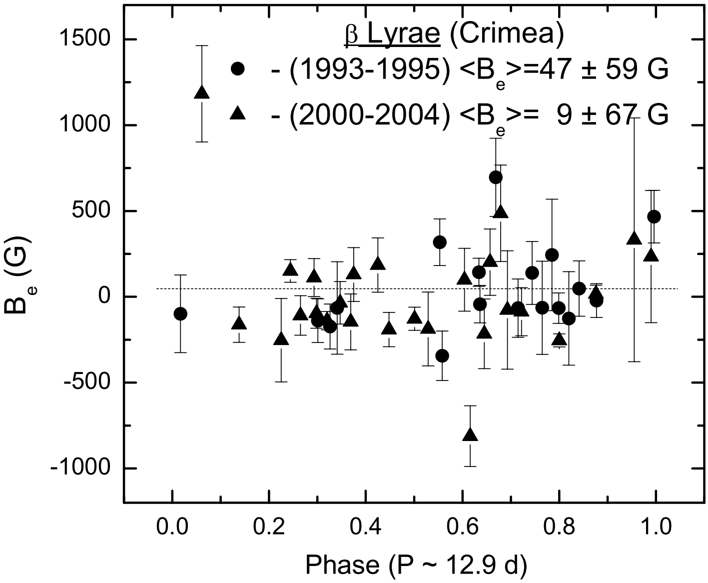

Figure 2. B_e versus the orbital period phases.

possibly, corresponds to the difference between the axial and orbital rotations ($T^{-1} = P_{\rm orb}^{-1} - P_{\rm rot}^{-1}$) and is synchronized with the period of the tidal wave. The secondary short and long periods as well as the orbital period are slowly changing in time. Therefore they should produce a family of periodicities and resonances (Skulsky 2000, 2001).

We phased data of the uniform sample of Crimean observations with periods 283 d and 338 d. Significant periodicity in both cases is absent. Figure 3 shows the effective magnetic field of β Lyrae versus phases of a period equal to 338.6 d (Van Hamme *et al.* 1995, Peel 1997). Marks on a picture have the same denotation as on Figure 1. We took

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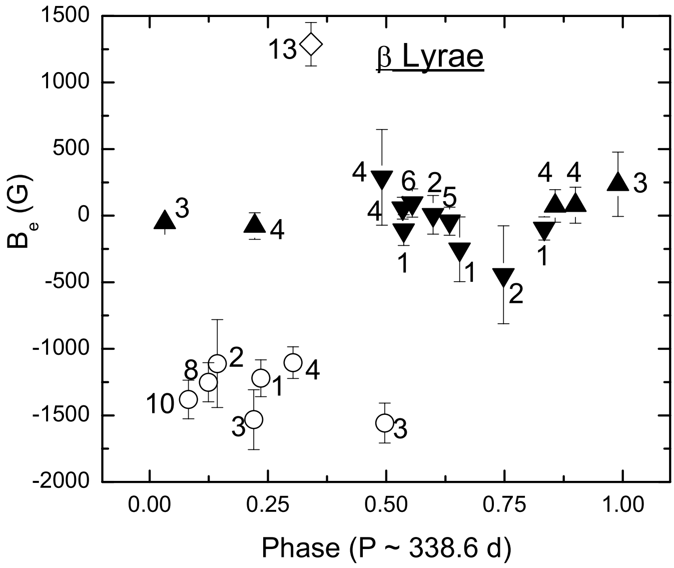

Figure 3. $B_{\rm e}$ versus the 338.6 d period.

into account, that the orbital period grows in 18.9 seconds per year. Arabic numerals are the number of nights. The zero-phase time corresponds to the ephemeris of Van Hamme *et al.* 1995: JD = 2446840.1 d. Our uniform sample is small for a robust analysis of long-time periodicities. Thus, additional observations are needed.

Moreover, we made a frequency analysis of photographic magnetic field measurements for 1980-1988. For this sample the best period equals to 13.43 d. If 13.43 d is the period of axis rotation of the primary component, we can evaluate the 352 d period as due to a beating of two closely spaced frequencies of both orbital motion and axis rotation. But we do not see these periodicities in the observations of others.

Despite a careful selection of spectral lines for the Crimean measurements, since 1993 we have only 5 nights with significant values of the magnetic field. Therefore, we used an internal possibility to determine the presence or absence of significant stochastic and time dependent spurious Stokes signatures (Plachinda 2004). The results of such testing of the derived significant values of the magnetic field are shown in the Table. The first column contains the Heliocentric Julian Date. The second column gives the effective magnetic field $B_{\rm e}$ and its observed error. In the column 3 we give ratio of $k = B_{\rm e}/\sigma$. The forth column contains $B_{\rm test}$ and its error $\sigma_{\rm test}$ and in the column 5 we give ratio of $k_{\rm test} = B_{\rm test}/\sigma_{\rm test}$. One can see that for all 5 dates the ratio $k = B_{\rm e}/\sigma > 3$ and $k_{\rm test} = B_{\rm test}/\sigma_{\rm test} < 3$. Therefore, the statistics assure use that the derived magnetic field values are reliable.

Table 1. Test of "Spurious field"

	HJD (+2400000.000)	$B_{\rm e} \pm \sigma$ (Gauss)	k	$B_{\rm test} \pm \sigma_{\rm test}$ (Gauss)	$k_{\rm test}$
1	49206.342	696 ± 228	**3.1**	73 ± 362	**0.2**
2	49857.488	467 ± 153	**3.1**	-10 ± 273	**0.0**
3	51832.285	-812 ± 177	**4.6**	-139 ± 175	**0.8**
4	52132.287	-254 ± 38	**6.7**	122 ± 73	**1.7**
5	52420.344	1348 ± 253	**5.3**	-411 ± 339	**0.1**

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3. Conclusions

β Lyrae shows complicated and intricate time-dependent behavior of the magnetic field, character of which is not understood yet.

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