ON THE MAGNETIC VARIABILITY OF PULSATING STARS.

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Abstract. The variations of the effective magnetic field strength of the magnetic stars α^2 CVn, β CrB and of the pulsating stars RR Lyr and V 474 Mon are studied on the base of the spectrograms oftained at the 6-m telescope. The variation with the phase of the $0^d.567$ pulsating period was found in RR Lyr. Our results together with the Babcock's observations in the 1950s show that the mean field depends on the phase of the $40^d.9$ Blazhko period, presumably because the rotational and the magnetic axes are not coinciding. For V 474 Mon, is not possible to clear up the character of such variation.

Key Words : Stars: Pulsating, Stars: Magnetic Stars: Individual (RR Lyr, V 474 Mon)

Introduction. At the beginning of 1950th, Horece Babcock started to carry out the extended program of the observations of the stellar magnetic fields with the aid of the circular-polarization analyzer with a calcite crystal. The Babcock's (1958) catalogue contained the results on 89 stars with the significant magnetic fields and included 70 peculiar stars (Ap), 7 stars with the lines of metals (Am), and 12 - of other types, including few pulsating stars (Babcock, 1958). Several measurements of the magnetic field of two classical cepheid variables - FF Aql and η Aql and 22 measurements of the magnetic field of the pulsating star RR Lyr were published there. The Cepheid-variable FF Agl and η Aql shows maximum negative field corresponding - 250 + 38 Gauss and 85 + 85 Gauss.

The magnetic field of RR Lyr reversed its polarity from time to time; the maximum positive strength was + 1170 Gauss and the maximum negative strength - 1580 Gauss. Contrary to Babcock (1958), Preston (1967) found no magnetic field of RR Lyr in 1963-1964 within the observational errors.

Later Detre and Szeidl (1973) have suggested, that the discrepancy between these observations may arise due to the 4-yr period of the star, thus Babcock (1958) had registered the magnetic maximum, and Preston (1967) - the magnetic minimum. Balazs-Detre (1959) also suggested the variations of the magnetic field with a 41-day period of the Blazhko effect, which may be a rotational period of the star. At the same time, a long-time variability of the magnetic field with a 4-yr period may occur similar to the solar magnetic cycle.

The premise for suggestion these authors the fact Babcock's (1958) measurements had carried out maximum of 4-yr cycle. The extreme field values correspond the maximum and minimum of 41-st period amplitude.

The observations of the Zeeman shift for several type of cepheid variable (Weiss et al., 1980) showed some positive results. According these data, three δ Cep-type stars: β Dor, W Sgr, η Aql and one W Vir-type star κ Pav showed the variations of the effective magnetic field with an amplitude up to 500 Gauss. The variation of magnetic field strength occurred with the phase of the stellar pulsation.

The attempts to measure the magnetic field of the group of δ Scu-type stars were failed due to the high rotational velocities. However, some stars of this type have a modulation period , small rotation velocities and are suitable for the measurements of the Zeeman shift.

Observations. The spectrograms of some pulsating stars were obtained at camera 2 of the main stellar spectrograph of the 6-m telescope during 1978 - 1984. The magnetic stars α^2 CVn and β CrB were observed as well, as the magnetic field standards, and were used for checking the measurement technique.

The basic objects of the observations were RR Lyr and V474 Mon. RR Lyr is the prototype of the pulsating horizontal-branch stars that occur so often in the globular clusters. Both photometrically and spectroscopically, it is one of the most thoroughly studied pulsating variables. Prolonged photometric monitoring has yielded a basic $0^d.566867$ period of the light variation; a secondary $40^d.8$ period, the Blazhko effect; and auxiliary 123^d and 4-yr periods as well. V474 Mon (HD 40535) is a variable star of the δ Sct-type with the primary period of the light variation ($0^d.1361260$) and the secondary period ($7^d.746$) (Romanov, Fedotov, 1979). The star has special features interesting for the researcher of the pulsating stars. The ratio of the secondary period to the basic one for V474 Mon resembles that observed in RR Lyr-type stars. The star exhibits the unusually large modulation of the photometric amplitude with the secondary period (Millis, 1973) and the multiperiodicity (Shobrock and Stobie, 1974). Unfortunately, the number of the spectral observations is not sufficient to investigate the radial velocities. The measurements of magnetic field strength for V474 Mon has been not carried out. For these observations, we used the achromatic analyzer of the circular-polarization with a Fresnel rhomb as the phase shifter, and a calcite crystal. The height of the spectra on the photographic plate was nearly 0.3 mm. Since 1982, the Kodak 103a-O emulsion was hypersensitized by hydrogen to shorten the exposures, using the method developed at the Odessa Observatory (Bondarenko, 1984). This method allows to increase the image density threefold, without any significant increase of the fog density. The time interval between the successive spectrograms varied from 5 to 60 min, depending on the photometric phase and the sky conditions. The spectra span the 3900-5000 A wavelength interval. The Zeeman shifts between the σ-components of the spectral lines were measured with a comparator having an oscilloscope display for setting on the lines (Udovichenko,

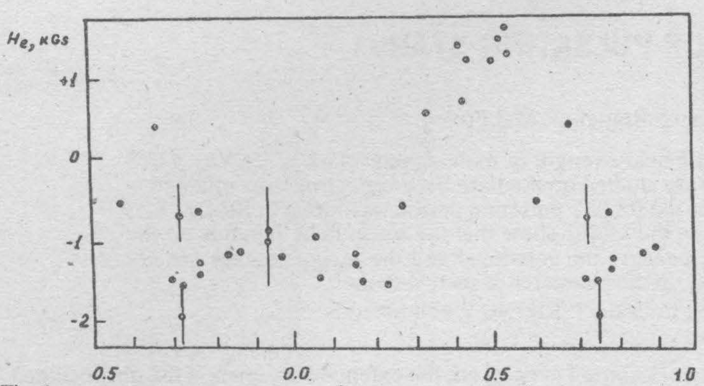

Fig. 1 Magnetic data for α^2 CVn. Filled circles - are the observations of Babcock (1963), Preston and Sturch (1967), and Glagolevsky et al. (1978); open circles - are our observation.

Romanov, 1985). The shifts were determined for all the lines and converted into the effective magnetic field strengths by the expression

$$H_e = 52.7 \left(\frac{4500}{\lambda}\right)^2 F \frac{\Delta S}{Z},$$

where λ - is the wavelength in Angstroms, F [A/mm] - is the dispersion, Δ S - is the line shift in microns and z - is the Zeeman-splitting factor. The probable errors of the measurements for each plate varied from 100 to 500 Gauss, depending on the number of the measured lines and the density of the spectrogram. The values of the Lande g-factor for the lines between 3900 and 4600 A were adopted from Babcock (1962) and Romanyuk (1984).

<u>**Results.**</u> a) α^2 CVn, β CrB

Our data on the magnetic field of these stars are compared with that of other authors. The magnetic field strength variations for α^2 CVn are shown at Fig.1 (Babcock ,1963, Preston and Sturch, 1967, Glagolevsky at al. 1978) and are denoted by the filled circles. Our measurements are denoted by the open circles. The magnetic field strength variations for β CrB are shown at Fig.2 (Preston and Sturch,1967; Wollf and Bonsack, 1972) and denoted by the similar symbols. These figures show, that the values of the magnetic field strength for α^2 CVn and β CrB agree with those obtained by the other authors at all phases.

The phases were computed according to the ephemeris:

JD 2434217$^d_.$50 + 18$^d_.$487 E for β CrB (Preston and Sturch, 1967);

JD 2419869$^d_.$720 + 5$^d_.$46939 E for α^2 CVn (Farnsworth, 1932).

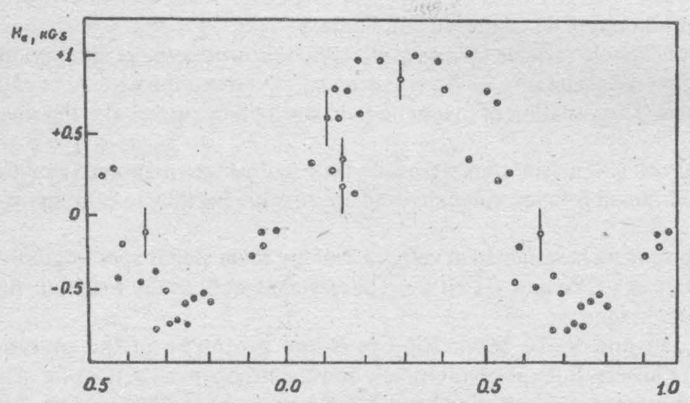

Fig. 2 Magnetic data for β CrB. Filled circles -are the observations of Preston and Sturch (1967), Wolf and Bonsack (1972); open circles - are our observations.

b) RR Lyr.

The individual curves of the magnetic field variations, obtained during the different observational sets, are shown separately at Figs.3-6 . The vertical bars correspond to the probable error of the measurement of the mean field strength, for each plate. In August, 1978 (Fig.3) the amplitude of the field variation was 1 kGauss; the maximum negative field occurred at phase 0.5. In September, 1982 (Fig.4), the polarity was positive and the field strength varied with a 1.5-kGauss amplitude; the maximum positive field was observed at phase 0.0. In July, 1983 (Fig.5) the field had again become negative, and the amplitude was about 1 kGauss. In October, 1984 (Fig.6) the field strength practically not varied (from -400 to +400 gauss) and was comparable with the observational errors. The phases of the basic pulsation period were computed according to the ephemeris:

HJD Max =2442995$^d_.$405 + 0$^d_.$566867 E (Firmanyuk,1984).

It may be fruitful to search for the dependence of the magnetic field on the phase of the secondary period (the Blazhko effect) and to compare the results with Babcock's observations. In order to establish the Blazhko phases, we have assembled all photoelectric observations of RR Lyr, and have computed the elements separately for the epoch of Babcock's observations, and for 1978-1983:

Max HJD = 2414856$^d_.$408 + 40$^d_.$945 N, for 1947-1961,

Max HJD = 2437551$^d_.$316 + 40$^d_.$885 N, for 1963-1983.

The magnetic field variation for RR Lyr with the phase of the Blazhko effect are shown at Fig.7. The figure illustrates, how the magnetic field of RR Lyr depends on the Blazhko-effect phase. Please note, that when all the observations of the past 30 yr are brought together, the average field strength does tend to vary with the 41^d period of the Blazhko effect. This result may

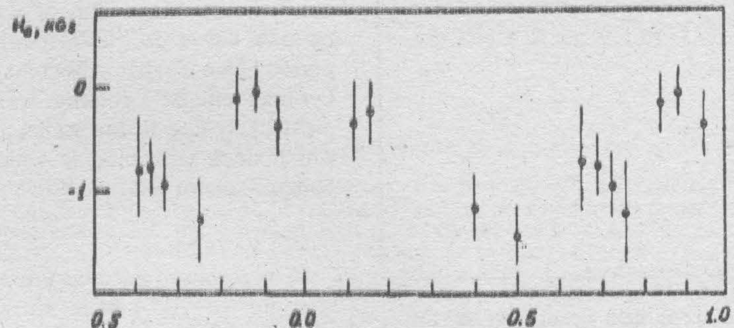

Fig. 3 Variation of the effective magnetic field strength of RR Lyr with phase of the main period (August 20-21, 1978).

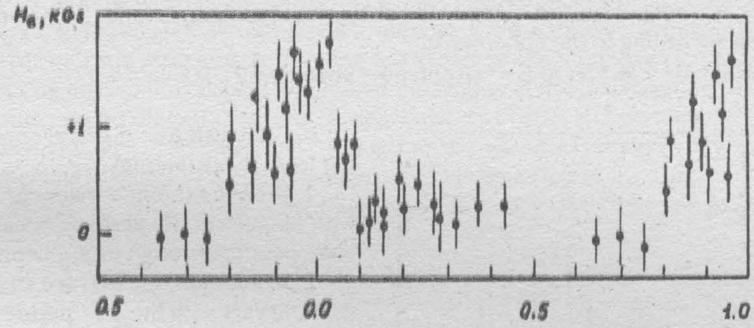

Fig. 4 Variation of the effective magnetic field strength of RR Lyr with phase of the main period (September 25-28, 1982).

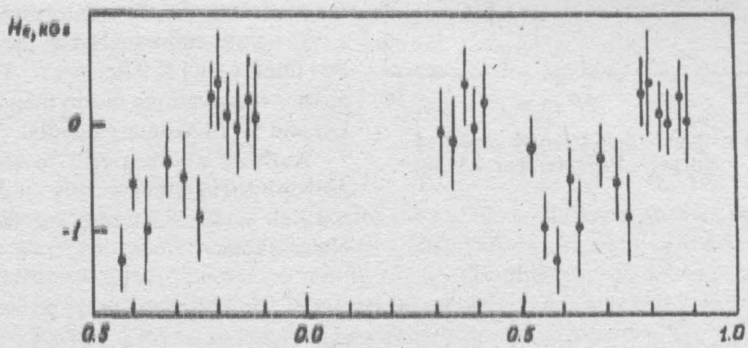

Fig. 5 Variation of the effective magnetic field strength of RR Lyr with phase of the main period (July 18 and 20, 1983).

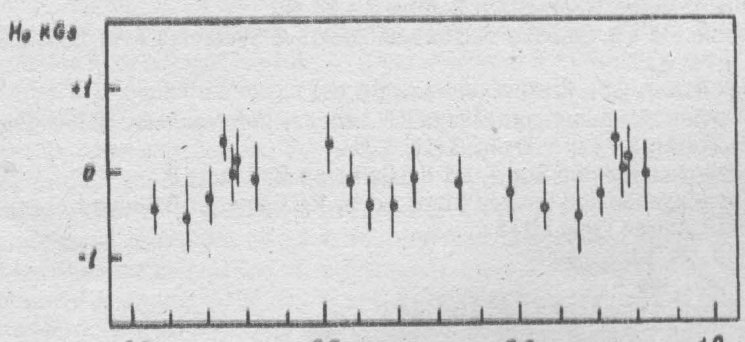

Fig. 6 Variation of the effective magnetic field strength of RR Lyr with phase of the main period (October 10-13, 1984).

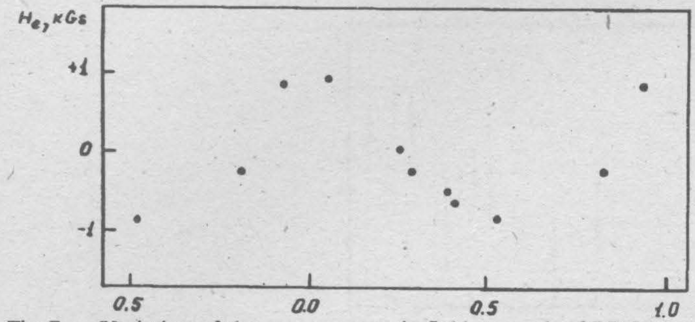

Fig. 7 Variation of the mean magnetic field strength of RR Lyr with phase of the Blazhko effect.

confirm the suggestion of Balazs-Detre and L.Detre (1962), based on the Babcock's observations, that the period of the Blazhko-effect may be manifested by the RR Lyr magnetic field polarity. This 41^d field variability is most likely due to the stellar rotation around the axis, which does not coincide with the magnetic axis (the oblique-rotator model).

c) V474 Mon.

The results of the measurements of the magnetic field strength for V474 Mon are shown at the Fig.8. The scatter of data may be probably caused by the observational errors as well as by the influence of the non-radial waves onto the absorption lines. The Fig.8 shows, that value of the magnetic field strength varies in phase with period of the stellar pulsation. However, it is not possible to clear up the character of such variations . The phases of the fundamental pulsation period were calculated according to the ephemeris:

$$\text{Max HJD} = 2441661^{d}.1668 + 0^{d}.13612600\,E \quad \text{(Romanov, Fedotov,1979).}$$

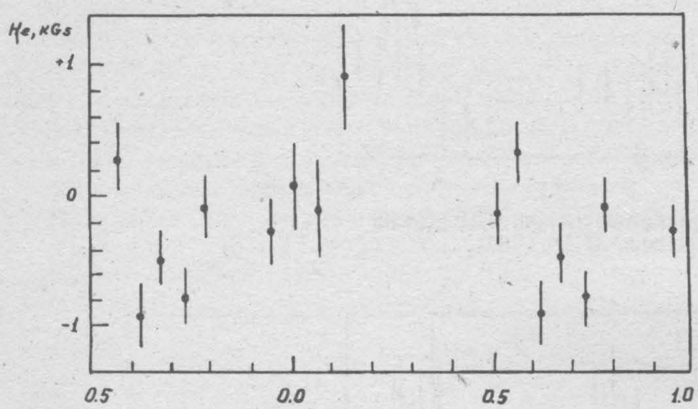

Fig. 8 Variation of the effective magnetic field strength of V 474 Mon with phase of the main period (September 25-28, 1982).

4. Conclusions. Several conclusions may be pointed out from these findings:

1. RR Lyr exhibits a magnetic field variability in phase with its pulsations, perhaps because of the compression wave passing through its atmosphere.

2. In addition, the average strength and the polarity of the field vary with the 41^d period of the Blazhko effect.

3. This longer-term Blazhko variability of the magnetic field presumably indicates that the star is rotating with a 41^d period around an axis, inclined to the magnetic axis. Such an interpretation is supported by the v sin i values estimated from the 4481 Mg II and 4476 Fe I lines: $v \sin i \leq 9$ km\sec. To solve this problem, the further observations of the magnetic field strength of RR Lyr and V474 Mon are needed.

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