Vertical structure of magnetic field in the CP star α^2 CVn

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We observed the magnetic field of the CP star 2 Cvn with the 6m telescope on echelle-spectrometer (spectral resolution R=50000, spectral range 3400-4100 A) using the CCD device and the zeeman analyzer. We find that the longitudinal magnetic field Be measured from lines with wavelength shorter than the Balmer jump (3646 A) systematically are by 25% weaker in all phases of rotation period in comparison with measurements make in the region with > 3646 A. Because in general lines with > 3646 A formed at deeper level than lines with < 3646 A we get additional evidence for increasing of Be with depth in the atmosphere of 2 Cvn.

Introduction

Preston [6] was the first who proposed to search for the radial (vertical) gradient of magnetic field of CP stars using lines formed at different depth of their atmospheres. He used lines with different intensity and found the magnetic field for the CP star 53 Cam to increase with decreasing intensity of lines in their spectrum.

We [7] confirmed Preston's result and found additional evidence for existing of radial gradient of magnetic field in the CP stars 53 Cam and 2 CVn.

Wolff [12] was the first to measure zeeman spectra for 3 stars obtained in spectral range with the wavelength shorter than the Balmer jump (3646 A). Lines with < 3646 A formed in essentially higher layers of atmosphere than lines in most commonly used spectral range with > 3646 A. The main result of Wolff is as follows: for star 2 CVn a small decrease of the longitudinal magnetic field strength in higher layers of atmosphere have been found. For other magnetic star CrB, the magnetic field strength is the same in the ranges before and after the Balmer jump.

We improved the technique and made a series of observation in 1980s using the 6-m telescope and photographic plates with the achromatic zeeman analyzer working in spectral range 3000-7000 A [8,9,10]. It was shown in these papers that the longitudinal component of magnetic field in CP star 2 CVn has smaller value and amplitude of variations in complete agreement with Wolff's result, while in other star CrB such effect is not observed. Because found differences were very small, their reliability were open to discussion due to possible distortion caused by non-linearity of photographic emulsion sensitivity. On this reason, 15 years later we decided to carry out new series of observation using modern technical possibilities.

Observations and data reduction

We included in the program of observation with the 6-m telescope some bright magnetic CP stars to search for the radial gradient of their magnetic fields. To date, sufficient number of data were obtained only for one star, 2 CVn = HD 112413. This is the brightest magnetic star, the longitudinal component of its magnetic field was measured many times and published in dozens of papers. Their summarising led to the following conclusion: the longitudinal component of the magnetic field Be measured by lines of metals in usual spectral range change from -1600 to +1800 G, the Be curve is anharmonic, the positive extremum is more narrow and sharp than negative. Measurements made using the Balmer line magnetometer and hydrogen lines [2] show a practically sinusoidal curve Be with a slightly lower amplitude of variation. Period of all variations (photometric, spectral and magnetic) is the period of rotation and can be described by elements of Farnswort [3]:

JD=2419869.72 + 5.46939 E (days).

Our new observations were conducted with the echelle-spectrometer NES and CCD 2000x2000 elements in the years 2000-2003. The description of procedure and details of observation can be found in papers [5,11]. We obtained zeeman spectra in the wide region 3400-4100 A with a resolution of 50000. The S/N ratio at 3600 A was 50, while at 3900 A it was about 200; the differences are due to a drop of CCD matrix sensitivity and zeeman analyzer transparency in the short-wave region of the spectrum. This leads to a lower measurement accuracy in the region shorter than the Balmer jump.

The reduction of observations was made in ESO MIDAS using the programs for zeeman spectra reduction (Kudryavtsev, [4]).

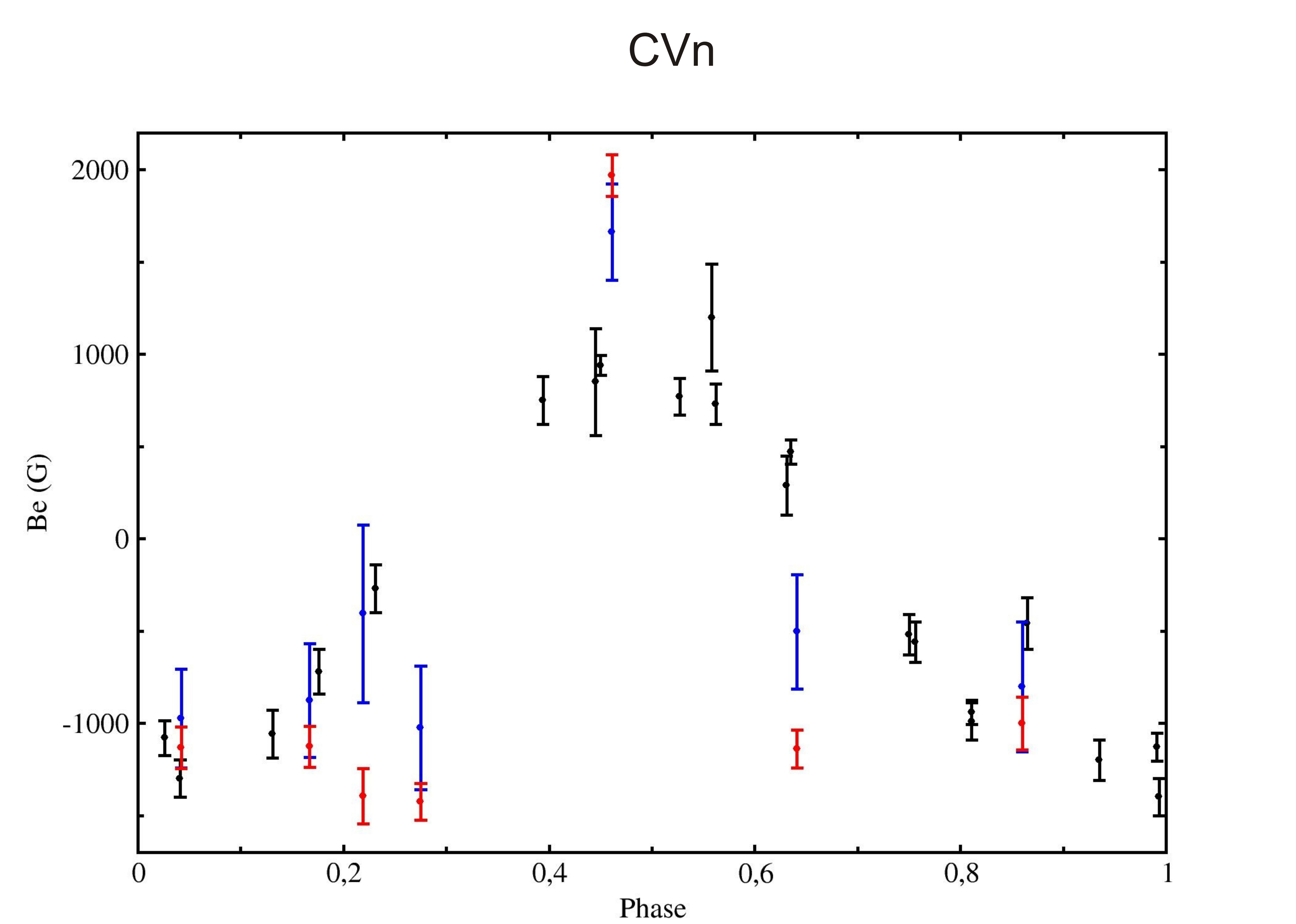

Fig.1 Magnetic field of the CP star 2 Cvn. Black dots - measurements by Borra and Landsteet (1977) with balmer-line magnetometer, Red dots - our CCD measurements using lines of metals in the spectral region with > 3646 A. Blue dots - our CCD measurements using lines of metals in the spectral region with < 3646 A.

Discussion of results

The results of our observations are presented in Table 1 and Fig.1. In Table are given: JD- julian dates of observation, the phase of the period, the longitudinal magnetic field Be and mean-square error sigma in the spectral range before and after the Balmer jump. [n]-number of measured lines for each spectrum.

They confirm the well-known fact that measurements from metallic lines in the usual spectral region (red dots) produce an unharmonic curve of the longitudinal magnetic field Be with a larger amplitude of variability than the field curve obtained from hydrogen lines (black dots).

The measurements in the region shorter than 3646 A (blue dots) show that the field strength in the upper atmospheric layer is much closer to that derived from hydrogen lines in both the amplitude of variability and the shape of the curve.

Table 1

Magnetic field in 2 CVn before and after the Balmer jump

JD (245000+)	phase	Be +- ,G < 3646		[n]	Be +- , G >3646		[n]
1385.258	0.167	-880	310	[25]	-1130	110	[59]
1591.415	0.860	-800	350	[110]	-1000	140	[68]
1592.404	0.042	-980	270	[74]	-1130	110	[78]
1593.386	0.219	-410	480	[76]	-1390	150	[74]
2594.583	0.275	-1020	330	[71]	-1420	100	[327]
2595.600	0.461	+1660	260	[47]	+1970	110	[290]
2596.588	0.641	-500	310	[37]	-1140	100	[283]

At the phases of extrema of Be, the field magnitude from lines formed in deeper layers of the atmosphere is by about 25% larger than in upper layers. This confirms our previous result obtained from photographic plates.

We think that the differences between the photographic and photoelectric curves of the longitudinal field are associated not only with methodological causes [1]. Firstly, hydrogen in contrast to metals, is uniformly distributed over the surface of the star 2 CVn. Secondly, the measurements with photoelectric magnetometer were performed in the hydrogen line wing, but close to its core, where the signal of circular polarization reaches its maximum value. The hydrogen line cores form in the higher layers of the atmosphere than their wings. That is why , the differences in hydrogen and metallic curves of Be may also be due to the fact that the field are different in different depth.

The lines in the region shorter than Balmer jump form at approximately the same depth as the cores of hydrogen lines, therefore the magnetic field measured from the resembles the field measured from hydrogen.

Thus, we have obtained additional information about the increase and complication of the structure of the magnetic field of the star 2 Cvn with depth in atmosphere. For future observations it is necessary to select stars whose hydrogen and metallic curves are greatly different.

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