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Magnetic Field Measurements of CP Stars from Hydrogen Line Cores *

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Abstract. We present the results of measurements of magnetic fields of chemically peculiar (CP) stars, performed from the shifts between the circularly polarized components of metal and hydrogen lines (the Babcock method). The observations are carried out with an analyzer of circular polarization at the 6–m telescope of the SAO RAS. We found that for the absolute majority of the objects studied (in 22 CP stars out of 23), the magnetic fields, determined from the Zeeman shifts in the hydrogen line cores, are significantly lower than those obtained from metal lines in the same spectra. This disparity varies between the stars. We show that instrumental effects can not produce the above features, and discuss the possible causes of the observed effect. The condition discovered reveals a more complicated structure of magnetic fields of CP stars than a simple dipole, in particular, a reduction of the field strength in the upper atmosphere with the vertical gradient, significantly higher than the dipole.

Key words: stars: magnetic fields – stars: chemically peculiar – stars: atmospheres

1 Introduction

Our recent measurements have shown that the magnetic fields, determined using the classical method (Babcock, 1947) from the shifts between the circularly polarized Zeeman components, appear to be smaller when the measurements are done based on the cores of hydrogen lines than those performed the same way, but from the lines of metals. We published our first results in (Kudryavtsev & Romanyuk, 2009). They show that the differences between the magnetic field values reach 1–2 kG, which is significantly higher than the possible measurement error.

Hydrogen line cores are formed in higher atmospheric layers than the hydrogen line wings and metal lines. Therefore, the effect of a decrease of magnetic field, measured from the hydrogen line cores (as compared with that measured from metals) that we discovered may indicate the existence of a large radial gradient, i.e. a height–wise magnetic field decrease for most of the magnetic CP stars we observed.

The observations were performed at the Main Stellar Spectrograph of 6–m BTA telescope of the Special Astrophysical Observatory of Russian Academy of Sciences (SAO RAS) with the Zeeman analyzer in the spectral region width of about 250 Å centered on the Hβ line, and sometimes on the Hγ line. In all cases we determined the longitudinal component of magnetic field B_e. In each of the Zeeman spectra we measured a sufficiently large (from 50 to 100, depending on the temperature and the star's rotation velocity) number of lines belonging to neutral and ionized metals. Line

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* This paper is based on data obtained at the Russian 6–m telescope

centre positions were determined by fitting the line profile with a Gaussian, both in the case of hydrogen line cores and in the case of metal lines. We do not anticipate any instrumental errors systematically distorting the measurements based on the cores of hydrogen lines. Only in case of very strong magnetic fields, which can show partial splitting of Zeeman components of metal lines, the field obtained from the hydrogen lines, possessing the most simple splitting picture, may turn out to be smaller than the field observed based on the metal lines due to methodological reasons. We shall hereby examine this question in detail.

As the result obtained once more raises the question about the magnetic field topology in CP stars, let us have a detailed look at the results of our measurements and compare them with the data published by other authors.

2 Measurements of Longitudinal Magnetic Field From Hydrogen and Metal Lines

2.1 Search for the Vertical (Radial) Magnetic Field Gradient

2.1.1 Factors Complicating the Task

Before we consider the search for a vertical field gradient, let us denote the factors that can complicate the task: in the first place, this is the topology of magnetic fields and inhomogeneous distribution of elements over the surface.

The observed periodic synchronous magnetic, spectral and photometric variability of CP stars is adequately represented by an oblique rotator model in the form of a rotating star with chemical and thermal inhomogeneities on the surface and a dipole magnetic field. The dipole axis does not coincide with the rotational axis. The oblique rotator model has been successfully applied in several studies carried out in the late 60's and early 70's of the twentieth century by Preston (for example, Preston, 1971) to explain the variability of magnetic CP stars.

A nonuniform distribution of chemical elements on the surfaces of CP stars was confirmed in dozens of works, and subsequently the methods of inhomogeneous surface mapping were developed (e. g. Khokhlova, 1976).

Investigations on the structure of deviations of the magnetic field structure from the dipole structure have a long history as well. The models became more complex — from simple (a noncentral displaced dipole (Landstreet, 1970) to the complex combinations of multipoles of different orders (e. g. Landstreet, 1988).

Later, there were developed magnetic field mapping methods allowing to describe the magnetic fields of any complexity (e. g. Piskunov, 1992, 2000). Kochukhov et al. (2001), Piskunov & Kochukhov (2002) and other authors describe reconstruction programmes of the magnetic field vector on the surface of a star without any preliminary assumptions about its structure, with or without account of the inhomogeneities of chemical composition. Mapping of several stars performed using this method showed that the magnetic field topology of CP stars can be very complex (Kochukhov, 2004).

If vertical inhomogeneities of the field and chemical composition in the atmosphere do exist, then it is extremely difficult to find them in a thin (less than 1% of the stellar diameter) atmosphere, as the horizontal inhomogeneities are appeared much stronger in the spectra and would mask the vertical effect. Currently the one and only way is prosed to study the vertical structure of the field and the distribution of chemical composition — a thorough study of line profiles, formed at different optical depths in the atmospheres of CP stars.

2.1.2 Field Measurements from Metal Lines at Different Formation Depths

A search for a vertical field gradient in magnetic stars was first proposed by Babcock (1949) and Preston (1965) via measuring the Zeeman shifts of the lines formed at different depths in the atmosphere. Yet they did not implement this idea.

The first measurements of magnetic fields from the lines in the spectral regions up to (high layers) and after (deep layers of the atmosphere) the Balmer jump were performed for three stars by Wolff (1978). For the star α^2 CVn, she found a smaller value of the longitudinal field and the amplitude of its variability in the region shorter than the jump, what indicated a 25% decrease of the field in the α^2 CVn upper atmosphere.

Romanyuk (1980) has as well independently found a decrease of the field B_e with height in the atmospheres of CP stars α^2 CVn and 53 Cam from high intensity lines, formed in higher atmospheric layers than the weak lines, showing a larger field.

Later Romanyuk (1986, 1993) made a detailed examination of the α^2 CVn spectrum based on the lines of different elements in the spectral regions before and after the Balmer jump and confirmed the decreasing of its longitudinal magnetic field with height. Especially large differences in the B_e value were found from the lines of rare earth elements. Note that the above results were obtained by measuring the Zeeman shifts between the circularly polarized components of metal lines from the spectra obtained with photographic plates at the 6–m BTA telescope.

First digital detectors worked in the red spectral region. It was only at the end of the twentieth century when the registration with CCD chips in the near–ultraviolet spectral region became possible at the 6–m telescope. We performed Zeeman observations of several magnetic CP stars in the range of 3400 – 4200 Å with the NES echelle spectrograph with high spectral resolution. Using the Babcock method we measured the longitudinal component of the magnetic field B_e. We confirmed our previous result for α^2 CVn: its longitudinal magnetic field decreases with height by about 25% (or 400 – 500 G) in the observed layer of the atmosphere (Romanyuk et al., 2007). Therefore, we estimated that α^2 CVn magnetic field decreases with height with a gradient of a few tenths of G/km. For other stars we did not obtain sufficient data, however, we should note one trend — the longitudinal field B_e decreases with height.

Nesvacil et al. (2004) proposed another method. They did not measure the longitudinal component B_e, but the mean modulus of the magnetic field B_s from the split Zeeman components of spectral lines formed at different depths in the atmosphere in the spectral regions before and after the Balmer jump. The measurements were performed based on high–resolution unpolarized spectra obtained at the ESO's UVES VLT spectrograph. For all the three investigated magnetic stars, HD 965, HD 116114 and HD 137949 the authors obtained an increase of the B_s value with height.

Therefore, conflicting results were obtained, although different stars were investigated. Sufficiently hot stars with strong fields at the BTA, and cold and slow rotators with narrow split lines on the VLT. In addition, we measured the longitudinal component of the field B_e, yet at the VLT the surface field B_s measurements were done.

Note here that the main factor affecting the measurement accuracy of the longitudinal component of the field at the 6–m telescope is a strong transmission decrease of the circular polarization analyzer in the spectral region shorter than the Balmer jump. Consequently, the S/N ratio of the obtained spectra in the $\lambda < 3646$ Å region appeared to be significantly smaller than that in the long–wave region. When measuring the mean modulus of the field, the major distorting factor — an increase of spectral line blending with decreasing wavelength. Since the Lande factors of the lines in general differ quite weakly, an increase of blending does not greatly affect the accuracy of the longitudinal field component measurements.

In both cases the differences in field strength reached noticeable quantities, more than 300 – 500 G, which is larger than the typical measurement errors. We have no reason to doubt the reality of different field values at different depths in the atmospheres of CP stars. In case of a simple dipole field, the strength of the field itself decreases proportionally to the cube of the distance from the dipole centre, i. e. from the centre of the star. Therefore, at a distance of the atmospheric thickness (a few tenths of percent of the diameter) it may decrease by no more than 0.01 from its value (or $30-50$ G for typical magnetic CP stars).

Hence we may conclude that the evidence of the existence of a radial gradient, exceeding the dipole gradient, is obtained. This indicates, in turn, that a field structure much more complicated than a simple dipole is quite widespread.

Recent works discovered the stratification of elements in the atmosphere. Hence, this fact should be taken into account in the analysis of characteristics of the field distribution with height. This issue will be considered further in the discussion of results of our study.

The effect of inhomogeneous horizontal distribution of elements on the results of investigations of the vertical field structure and the stratification of elements is anyhow difficult to assess. The solution can be found, in our opinion, measuring the magnetic fields from hydrogen lines. There is no reason to believe that there is any significant variation in the distribution of hydrogen abundance over the surface. Therefore, investigating the distribution of polarization (or Zeeman shifts) of the hydrogen line core and wings, we may hope to detect the features of the vertical structure of magnetic fields. The cores of hydrogen lines are formed in higher layers of the atmosphere than the usual metal lines. A comparison of measurements obtained from them can as well yield data on the vertical structure of magnetic fields of CP stars.

2.2 Results from the Landstreet Balmer Line Magnetometer

Hydrogen lines are very broad, hence the classical method (Babcock, 1947) could not be used in the photographic studies of stellar magnetism. Measurements of magnetic fields from hydrogen lines were for the first time performed by John Landstreet on the photoelectric Balmer magnetometer he designed (Angel & Landstreet, 1970). This device measured the V–Stokes parameter in the wings of hydrogen lines, mainly Hβ. The 5 Å–wide spectral region at the distance of 5 Å from the hydrogen line core was cut with an interference filter, while the shifts in the spectrum, associated with the differences in radial velocities of different objects, were offset by the tilt of the filter. The longitudinal magnetic field B_e was obtained from the measurements of circular polarization caused by the Zeeman effect in the wings of hydrogen lines.

The formation regions of hydrogen line wings and metal lines must approximately coincide. The calibrations performed showed that in general there is a good agreement with the measurements obtained earlier from metal lines using the photographic method. Nevertheless, the field obtained photoelectrically is not necessarily an identical match with the one obtained photographically due to significant differences in the techniques of observations and reduction, and due to the fact that, unlike metals, hydrogen is distributed uniformly throughout stellar surfaces.

Landstreet and his team studied a number of known magnetic CP stars with an anharmonic photographic curve of the longitudinal field B_e component variability. In most of cases, hydrogen curves of the longitudinal field appeared to be much closer to the sine, yet several stars still showed anharmonicity of B_e curves.

The results were interpreted as follows: hydrogen is distributed uniformly over the surface of the star, and the harmonious sine curve indicates a dipole field. Stars with an anharmonic hydrogen curve possess magnetic fields different from the dipole. Anharmonicity of the “metal” curve is linked both with an inhomogeneous distribution of elements over the surface and with nondipole topology of the field.

The studies of vertical topology via analyzing the distribution of circular polarization in hydrogen lines were not carried out. However, note (as we demonstrate further in Section 4) that although the curves of magnetic fields obtained from hydrogen line wings and metal lines may differ, magnetic field strengths obtained using these two methods do not show systematic differences.

2.3 Measurements with LSD Techniques

By the end of the twentieth century the observations on hydrogen magnetometers were over, the latter being replaced with the CCDs. Classic Zeeman measurements were at first performed on them only from metal lines.

Practice has shown that we can significantly improve the accuracy of magnetic field measurements summing the signals of the V–Stokes parameter from many lines. Although a transition from polarization values to magnetic fields may cause calibration problems and the results may not coincide with those measured using the classical method, the multi–line technique turns out to be very effective for the detection of stellar magnetic fields. It was called LSD, or the Least Squares Deconvolution technique.

This method has been implemented by Donati et al. (1999) on the MUSICOS spectrograph. A large series of observations of the earlier known magnetic stars was carried out on this instrument (Wade et al., 2000), which showed a good agreement with the data obtained by other means.

2.4 Measurements with FORS1

The measurements of circular polarization in hydrogen lines continued on the new magnetometer FORS1 VLT (Bagnulo et al., 2002). Circularly polarized spectra with low ($R = 2000$) resolution in the spectral range 3500 – 5800 Å are observed with this device. The instrument simultaneously registers all the available hydrogen lines from Hβ to the Balmer limit (3646 Å), and metal lines. The device has a very high efficiency, it can provide high accuracy of observations (typical errors — tens of gauss). However, it has its drawbacks, there are problems with calibration and referencing of the obtained values of magnetic fields to the data from previous studies.

3 Comparison of Magnetic Field Measurements Obtained with Different Techniques

Measurement of stellar magnetic fields is a rather complex methodological task. To detect such fine and weak effects, as the radial magnetic field gradient, a detailed study and elimination of various instrumental causes that may affect the accuracy of the results are required.

Analysis of all observations shows that a vast amount of data on the magnetic fields of CP stars was obtained from the measurements of the longitudinal component B_e. From all the proposed and implemented options and methods determining this value, the most successful are the following:

1) measurement of shifts between the circularly polarized components of lines from the spectra, obtained with photographic plates (the so–called photographic method, proposed by Babcock in 1947);

2) measurement of circular polarization in hydrogen line wings (the photoelectric method, Angel & Landstreet, 1970);

3) measurement of shifts between the circularly polarized line components from the spectra obtained with CCD chips (the modified Babcock photographic method, see, e. g. Mathys, 1991; Mathys & Hubrig, 1997; Kudryavtsev et al., 2006);

4) multi–line LSD techniques that appeared relatively recently (Donati et al., 1999; Bagnulo et al., 2002).

In case of the dipole stellar field and a uniformly distributed over the surface chemical composition, the measurement results obtained from lines of different elements and with the use of different methods would be roughly the same. But it is well known that CP stars have chemical compositions inhomogeneously distributed over the surface: the elements are often concentrated in spots or rings around magnetic poles. In view of the foresaid it is of interest to compare the longitudinal field data for the same stars obtained using different methods.

In (Romanyuk et al., in preparation) we compare the measurement results for 28 magnetic stars, for which the rotation periods are known, and for which the curves of the longitudinal field B_e components were identified both from the hydrogen line wings and from metal lines. We have rather reliably found the extrema of B_e curves, and analyzed the degree of mutual conformity of every curve for each star.

The analysis is as follows. The longitudinal field B_e is stronger from hydrogen for 7 stars, stronger from metals for 7 stars as well, equal (within the measurement error) for 12 stars, and for 2 objects we lack sufficient measurement data to make a comparison.

Analyzing these data we can come to two conclusions.

1) for approximately half of all the studied stars there are significant and crucial differences in the longitudinal field strength obtained from metal and hydrogen lines, at that the distribution is equal, 7 stars show a stronger field from metals, and 7 from hydrogen lines. Typically, these are stars with strong fields. For the second half (as a rule, these are stars with weaker fields) within the measurement errors the B_e curves do not differ in amplitude. Certainly, relative accuracy of measurements of such stars is lower and the individual differences are less visible.

2) Although the amplitudes and shapes of "metal" and "hydrogen" B_e curves for individual stars may vary, in general, there are no systematic differences: the fields defined from the lines of metals may be higher, lower or equal to the fields measured from hydrogen lines.

No observational evidence was found that the strength of the longitudinal magnetic field, obtained using the photoelectric method based on the measurements of circular polarization in the wings of hydrogen H_β line (or other lines) is systematically higher or lower than the field strength obtained from the measurements of shifts between the centres of left and right circularly polarized metal lines. The features are observed only in the degree of differences between the B_e curves and sines. As early as in 1977, Borra & Landstreet (1977) noted that systematically the "hydrogen" curves are more harmonious than metal curves, what is associated with homogeneous distribution of hydrogen over the surface.

The conclusions about the absence of systematic differences have an important practical significance: they indicate reliability and good mutual agreement of calibrations made by different authors determining the longitudinal field B_e component using different methods and at various telescopes. This also means that different instrumental effects are correctly taken into account, or else systematic deviations would appear, irrespective of the object observed.

On the other hand, we can see that for approximately half of the stars from Romanyuk et al., in preparation) there are significant differences (both upward and downward) in the field value obtained from metal and hydrogen lines. Apparently, this is a consequence of peculiarities of inhomogeneous distribution of metals over the surface. Individual characteristics of the field topology for each of the stars play a certain role as well, but it is a more complex issue and modelling is needed in order to solve it.

Therefore, a question arises as of how to explain a significant and systematically smaller field value obtained from the hydrogen line cores in comparison with that found from metal lines from the same spectra, previously deduced (Kudryavtsev & Romanyuk, 2009). Based on the analysis above we can argue that such a systematic difference is neither related to instrumental factors, nor to the peculiarities of the distribution of chemical composition over the surfaces of magnetic stars. It remains to assume that the differences we found are linked with the topology of magnetic fields of CP stars, most likely — with the peculiarities of their vertical structure. Hence we are back again with the problem of searching the radial gradient of magnetic fields.

Theoretically, the right thing to do is to choose the following method: to measure the magnetic fields from different parts of hydrogen line profiles. The hydrogen line cores are formed in the stellar atmosphere certainly higher than their wings. As the hydrogen is distributed uniformly over the surface of CP stars, the effect of horizontal inhomogeneities of chemical composition will not be present, and the influence of the field topology will be minimized. By measuring the field in different regions of the hydrogen line profile formed at different optical depths, we could do a vertical section of the field by height in the atmosphere. However in practice this task is very hard to implement. The polarization signal (the V–Stokes parameter) of the Zeeman effect sharply decreases with distance from the hydrogen line core, the situation is complicated by blends of different metal lines.

To date, the greatest number of V–Stokes parameter measurements in the wings of hydrogen lines was obtained on the photoelectric Landstreet's Balmer magnetometer (Angel & Landstreet, 1970). The observations with this instrument were most often performed in the wing of the Hβ line in a 5 Å wide filter centered at the distance of 5 Å from the core of this line. Circular polarization was measured in the most optimal site of the hydrogen line profile. As a rule, for a typical Hβ hydrogen line it could be adopted that the value of V–Stokes parameter equal to 1% corresponds to the magnetic field B_e of 13 kG. The investigations thus made do not concern the topmost layers of the observed atmosphere.

Based on the fact that there are no significant systematic differences in the field strength, deduced from the lines of metals (using both the classical and LSD–method) and found from the observations of circular polarization on hydrogen magnetometers, we attempt to estimate the existence of the radial field gradient higher than the dipole gradient based on a comparison of measurements of the field from the metal lines and hydrogen line cores using the classical "photographic" method proposed by Babcock (1958a,b).

In the following sections we will set out the methodology of observations and data reduction, as well as the results of our observations.

4 Observations and Data Reduction

Our observations have been obtained with the Main Stellar Spectrograph (Panchuk, 1998) of the 6m telescope equipped with an image slicer and a circular polarization analyzer (Chountonov, 2004) and a 2000×2000 pixel CCD with the spectral resolution $R = 15000$. For our observations we used the spectral range 4760 – 5000 Å, which includes 50 – 100 metal lines (mostly Fe and Cr for our stars) and the Hβ line. Several spectra were obtained in the region of other hydrogen lines (Hα, Hγ). The data reduction was performed within the MIDAS context LONG and using our own codes (Kudryavtsev, 2000) developed for the reduction of the Zeeman spectra and measurement of longitudinal magnetic fields.

The technique of our measurements has been already described (see, e. g. Kudryavtsev et al., 2006). Longitudinal magnetic field values were measured from the Zeeman shift between the line positions in the right–hand and left–hand circularly polarized spectra, using standard Babcock's formulae. For the metal lines we used the mean Lande factor $z = 1.23$. With multiple measured lines this is a good approach and will not lead to additional errors. The positions of spectral lines were determined via fitting the profiles with a Gaussian. The same procedure was applied to measure the positions of the Hβ line core. The central part of the line, well–described by the Gaussian profile is adopted as a line core. A typical procedure of the hydrogen line core centre determination is demonstrated in Fig. 1.

The errors σ for metal lines are based on the scatter of individual values and derived using standard statistics expressions. The errors of the Hβ line measurements are derived from the procedure of Gaussian fitting as the biggest error of the line centre finding in pairs of Zeeman spectra.

Note that the measurements from hydrogen and metal lines are done from one and the same spectrum, which minimizes all the possible systematic errors. In Fig. 2 we show a spectral region of the star 53 Cam in right–hand and left–hand circular polarizations, and the Stokes V parameter for this region. One can see that the Stokes V values in metal lines are greater than that in Hβ. Particularly this effect is caused by the fact that metal lines have generally higher Lande factors ($z =$

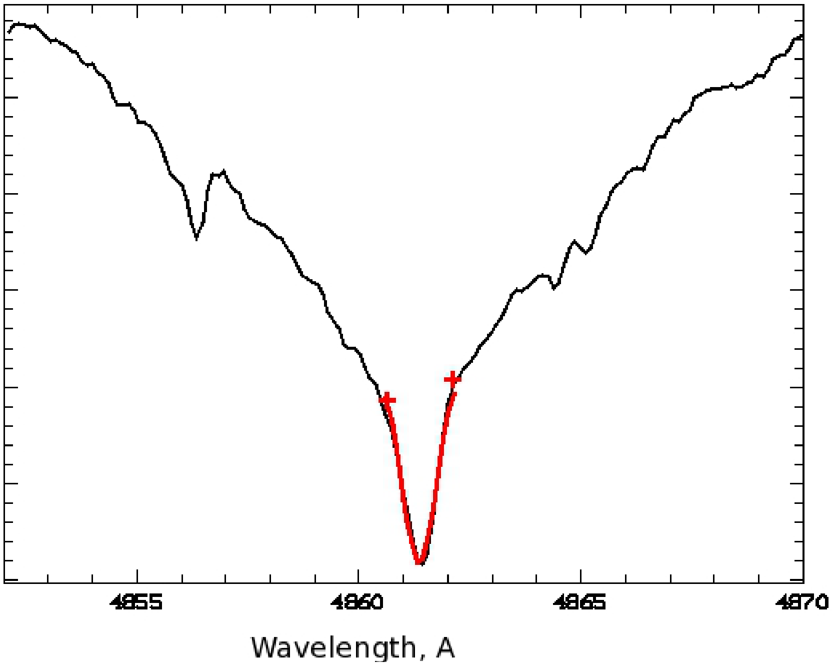

Figure 1: Hydrogen line core centre determination by fitting the line profile with a Gaussian

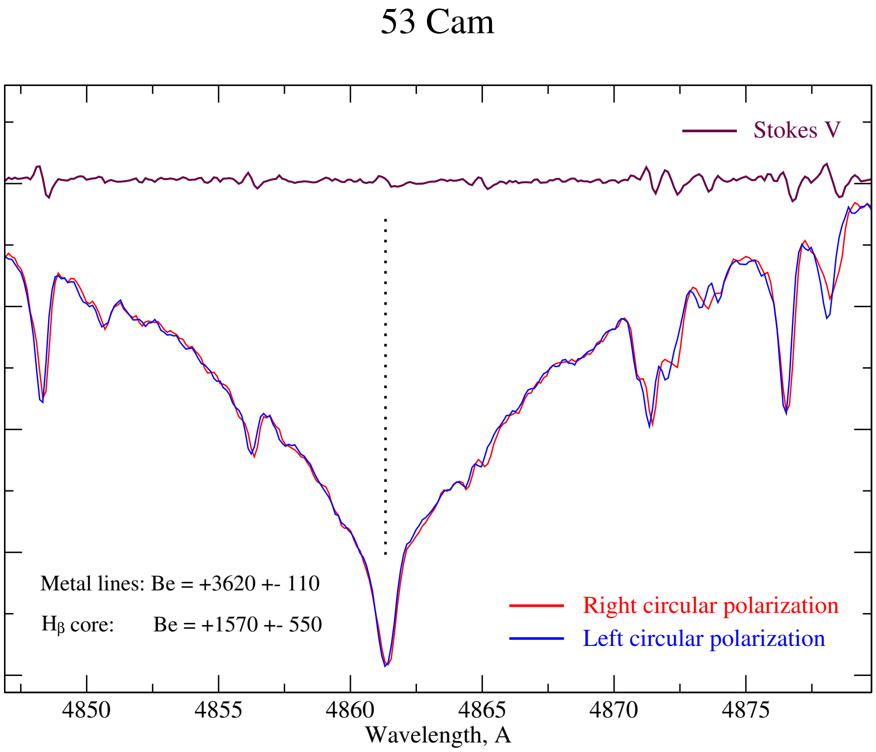

Figure 2: Spectra of the right–hand and left–hand circular polarizations and V–Stokes parameter for the star 53 Cam in the Hβ region

Table 1: Longitudinal magnetic field B_e extrema for 53 Cam

method	B_e (extrema)	$[n]$	Citations
Hβ (V–Stokes)	$-4900/+3900$	[18]	Hill et al. (1998)
metals (photo)	$-4500/+3700$	[12]	Babcock (1958a)
metals (photo)	$-5800/+3400$	[8]	Preston & Stepien (1968)
metals (photo)	$-3200/+4200$	[16]	Glagolevskij et al. (1978)
metals (CCD)	$-5400/+4300$	[30]	our CCD (this paper)
metals (LSD)	$-4600/+3300$	[10]	Wade et al. (2000)

1.23 on average), and therefore are more sensitive to the magnetic field, while Hβ has $z=1.0$. A more significant effect — lower steepness of the hydrogen line profile. But in the Zeeman measurements we correct for the difference in the Lande factors, and the magnetic field is determined from the line centre positions, hence the steepness of the profile may have an impact only on the accuracy of measurements. Nevertheless the measured longitudinal magnetic field B_e shows quite different values for metal lines and for the core of Hβ line.

5 Results of Magnetic Field Gradient Measurements Obtained at 6–m Telescope

5.1 53 Cam Longitudinal Magnetic Field From Metals and Hydrogen

In this section we present the results of magnetic field measurements from the hydrogen line cores and metal lines for 23 magnetic CP stars. We performed more than 30 observations in different phases of rotation period for one of these stars, 53 Cam. Since this object is often used as a magnetic standard and was thoroughly studied using different techniques, let us give it special consideration.

As a first step, we analyze the previously obtained results of measurements of 53 Cam longitudinal magnetic field. Its B_e curves were obtained repeatedly using different techniques. Compare the extrema of these curves in Table 1. The columns represent: the observational technique, extreme values of the longitudinal magnetic field component B_e, number of observations $[n]$ and references.

Wade et al. (2000) compared Babcock's "metal" curve (Babcock, 1958a), the hydrogen curve by Hill et al. (1998) and the "metal" LSD B_e curve they obtained. It is noted that Babcock's photographic metal curve is strongly anharmonic, the hydrogen curve obtained on Landstreet's Balmer magnetometer is almost sinusoidal, and the shape of the curve obtained using the LSD method from metal lines occupies an intermediate position between them: it is anharmonic, but to a smaller extent than Babcock's curve. Our observations performed at the BTA (both photographically and CCD–based), show that our curve for 53 Cam is anharmonic and agrees well with Babcock's curve (Babcock, 1958a).

For greater clarity Fig. 3 shows different curves of the longitudinal field for 53 Cam: open circles — the curve of Hill et al. (1998), triangles — Preston & Stepien (1968), stars — the LSD curve of Wade et al. (2000), filled circles — our curve from metal lines.

Thus, we can conclude that all methods of observation of the longitudinal component yield approximately the same value of 53 Cam longitudinal field. Some differences are observed only in the form of the B_e curves.

More surprising is the fact of significant differences in the field strength, obtained from the cores of hydrogen lines not only in comparison with metals, but with the hydrogen curve of Hill et al. (1998). Consider this question in detail. Our measurements of the magnetic field from metal

Table 2: Longitudinal magnetic field B_e of 53 Cam, measured from metal lines (B_e) and from cores of hydrogen lines $B_e(H)$

JD (2450000+)	Phase	$B_e \pm \sigma$	$B_e(H) \pm \sigma$	spectral range
2189.432	0.865	-4170 ± 280		4400-4640
2544.611	0.114	$+3620 \pm 210$		4400-4640
2624.304	0.042	$+1740 \pm 190$		4400-4640
3395.519	0.122	$+3190 \pm 110$		4400-4640
3717.586	0.246	$+3330 \pm 100$		4400-4640
3784.517	0.584	-1510 ± 130		4400-4640
3786.507	0.832	-4560 ± 160		4400-4640
3812.547	0.076	$+2660 \pm 130$		4400-4640
4016.368	0.469	$+2820 \pm 160$		4400-4640
4040.501	0.475	$+2640 \pm 140$		4400-4640
4041.526	0.603	-2990 ± 180		4400-4640
4110.358	0.178	$+2900 \pm 100$		4400-4640
4162.298	0.649	-3820 ± 150		4400-4640
4401.527	0.453	$+3510 \pm 140$		4400-4640
4488.196	0.250	$+3530 \pm 90$	$+2340 \pm 680$	4760-5000
4521.568	0.408	$+3620 \pm 110$	$+1570 \pm 550$	4760-5000
4522.423	0.514	$+2140 \pm 140$	-200 ± 530	4760-5000
4610.288	0.461	$+3620 \pm 130$	$+1320 \pm 320$	4760-5000
4611.264	0.582	-1560 ± 170	-1090 ± 200	4760-4930
4749.432	0.796	-5020 ± 140	-3130 ± 600	4200-4440
4750.370	0.913	-4180 ± 150		4400-4640
4783.634	0.057	$+1930 \pm 140$	$+510 \pm 380$	4200-4440
4901.338	0.721	-5190 ± 170	-2180 ± 190	4400-4640
4903.304	0.966	-2180 ± 190	-2100 ± 280	4760-5000
4955.303	0.444	$+3690 \pm 100$	$+1980 \pm 160$	4760-5000
5015.242	0.911	-4780 ± 180	-2460 ± 270	4760-5000
5075.536	0.423	$+4280 \pm 130$	$+2480 \pm 180$	4760-5000
5077.529	0.671	-5400 ± 160	-2410 ± 210	4760-5000
5136.332	0.997	-510 ± 160	-930 ± 260	4760-5000
5139.533	0.396	$+3840 \pm 120$	$+2560 \pm 250$	4760-5000
5171.386	0.364	$+3610 \pm 100$		4400-4640
5171.523	0.381	$+3490 \pm 100$	$+2280 \pm 180$	4760-5000
5202.608	0.254	$+3740 \pm 100$	$+2740 \pm 300$	4760-5000

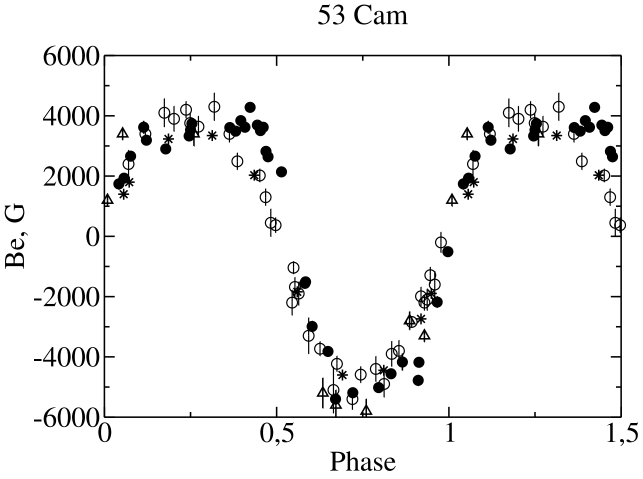

Figure 3: B_e curves for 53 Cam obtained using different techniques. Open circles — Hill et al. (1998), triangles — Preston & Stepien (1968), stars — Wade et al. (2000), filled circles — our measurements from metal lines

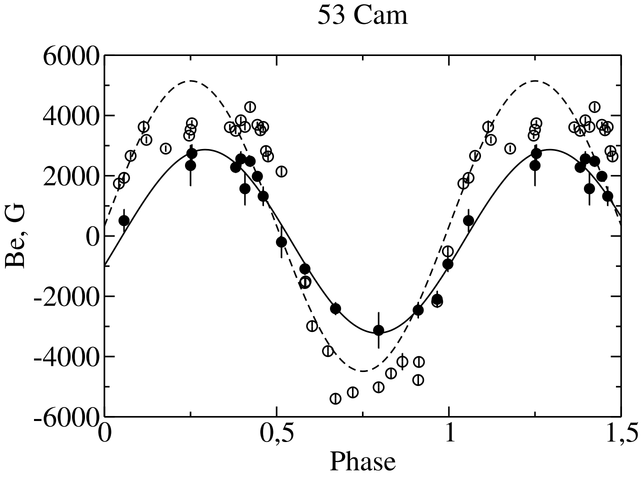

Figure 4: B_e curves for 53 Cam, measured from metal lines (open circles) and from cores of hydrogen lines (filled circles)

lines and from cores of hydrogen lines are demonstrated in Table 2. The phases of the period are computed in accordance with the elements of Hill et al. (1998):

$$\mathrm{JD} = 2448498.186 + 8.02681$$

Note that we measured about 100 metal lines in each Zeeman spectrum of 53 Cam.

Figure 4 demonstrates the B_e curves obtained from hydrogen line cores (filled circles) and metals (open circles). We can see that the longitudinal field obtained from the hydrogen line cores has much smaller extrema (from -3 to $+2.5$ kG) compared with those found from the lines of metals (from -5 to $+4$ kG). Also, one can see a possible phase shift between these two curves with the value of 0.04.

It is also obvious that the B_e curve from hydrogen line cores is more sine than the metal line, and resembles the hydrogen curve of Hill et al. (1998), but with a much smaller amplitude. The differences between the two hydrogen curves obtained from cores and wings of the hydrogen Hβ line are bigger than from the curves, obtained from hydrogen and metals. As hydrogen is distributed

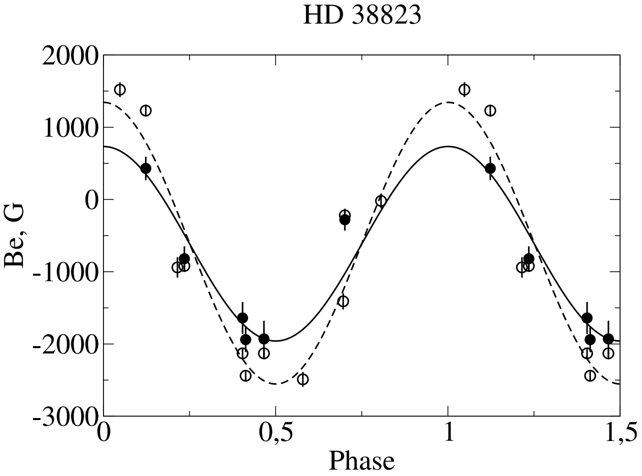

Figure 5: B_e curves for HD 38823, measured from metal lines (open circles) and from the core of Hβ (filled circles)

uniformly over the surface of 53 Cam, the differences in the curves may only be caused by the differences in the size and topology of the field at different layers with height in the atmosphere.

5.2 Longitudinal Magnetic Field of Magnetic Stars from Metals and Hydrogen Line Cores

Table 3 represents the results of magnetic field measurements from metals and the core of a hydrogen line (Hβ in overwhelming majority of cases) for 22 stars. Recently discovered magnetic stars from (Kudryavtsev et al., 2006) were mainly taken for the measurements.

It is obvious that the values of magnetic field B_e, obtained from the measurements of hydrogen line cores are systematically smaller than those measured from metal lines for except of the cases when B_e is close to zero. Only in the star HD 258686 in two measurements out of four done, the core of Hβ showed significantly higher field values than the metal lines.

Let us consider a few stars with known rotation periods for which there is a sufficient number of measurements.

5.2.1 HD 38823

Hensberge et al. (1981) determined the period of the star's rotation as $8\overset{d}{.}635$. They also estimated the range of probable periods from $8\overset{d}{.}596$ to $8\overset{d}{.}674$. In Kudryavtsev et al. (2006) we noted that the magnetic measurements better fit to the period of $8\overset{d}{.}628$, though a small number of measurements did not allow determining the accurate period.

Based on our previous data (Kudryavtsev et al., 2006) and new measurements presented in Table 3, we have determined the star's rotation period as $8\overset{d}{.}676 \pm 0.03$. Figure 5 shows the curves of the magnetic field obtained from the metal lines (open circles) and the Hβ line core (filled circles). The longitudinal magnetic field of HD 38823 changes sign, we can see that the amplitude of the hydrogen curve is smaller than that obtained from metal lines.

5.2.2 HD 45583

From the photometric variability North (1987) defined HD 45583 rotation period as $1\overset{d}{.}177177 \pm 0.000009$. Based on six measurements of the longitudinal magnetic field in (Kudryavtsev et al., 2006) we suspected that the B_e curve shows the presence of a double wave. The unusual shape of

Table 3: Magnetic field B_e from metal lines and hydrogen line cores

Star	JD (2450000+)	$B_e \pm \sigma$ (metals)	$B_e(H) \pm \sigma$ (hydrogen)	S/N
HD 6757	4015.481	$+2450 \pm 110$	$+310 \pm 360$	190
	4783.442	$+2780 \pm 100$	$+1340 \pm 710$	240
HD 16605	4015.493	-1580 ± 90	-540 ± 160	200
HD 19712	4015.508	$+1700 \pm 130$	$+1060 \pm 180$	290
	5075.556	$+1710 \pm 140$	$+1110 \pm 130$	330
HD 27404	4015.558	$+260 \pm 150$	-90 ± 170	210
	5075.569	$+1470 \pm 120$	$+590 \pm 160$	400
HD 29925	4015.514	-1440 ± 100	-1070 ± 250	190
HD 32145	4015.520	$+2450 \pm 260$	$+1380 \pm 250$	260
HD 34719	4015.606	$+1320 \pm 220$	$+680 \pm 240$	330
HD 36955	4015.546	-480 ± 210	$+30 \pm 280$	190
HD 38823	4488.259	-2130 ± 70	-1640 ± 220	250
	4809.350	-2440 ± 60	-1940 ± 170	280
	4903.242	-920 ± 80	-820 ± 170	200
	5136.525	$+1230 \pm 80$	$+430 \pm 160$	220
	5139.499	-2130 ± 80	-1930 ± 250	160
	5202.270	-220 ± 80	-280 ± 150	220
HD 45583	3717.560	$+4440 \pm 480$	$+2700 \pm 420$	260
	4015.573	$+90 \pm 600$	-620 ± 370	310
	4488.274	$+3470 \pm 610$	$+3000 \pm 320$	340
	4809.368	$+2860 \pm 520$	$+1670 \pm 270$	350
	4903.283	-2250 ± 360	-2100 ± 280	320
	5139.533	$+3850 \pm 490$	$+2080 \pm 350$	200
	5202.349	-2400 ± 200	-1650 ± 260	290
HD 49040	4015.585	$+160 \pm 60$	$+170 \pm 320$	200
HD 112413	4903.408	$+1070 \pm 70$	$+620 \pm 150$	700
	4955.313	-980 ± 50	-870 ± 90	2000
	5015.250	-990 ± 50	-850 ± 100	2500
	5171.545	$+1470 \pm 70$	$+1000 \pm 70$	1400
	5202.582	-880 ± 50	-680 ± 70	1870
HD 137909	4955.322	-940 ± 50	-550 ± 120	1000
	5015.256	-300 ± 50	-210 ± 100	1500
	5202.590	$+430 \pm 50$	$+270 \pm 70$	1140

Table 3 continued

Star	JD (2450000+)	$B_e \pm \sigma$ (metals)	$B_e(H) \pm \sigma$ (hydrogen)	S/N
HD 169842	4522.623	$+350 \pm 360$	$+460 \pm 350$	170
HD 170565	4016.194	$+1140 \pm 170$	$+440 \pm 220$	170
HD 178892	2838.390		$+4350 \pm 350$	200
	2840.433		$+6590 \pm 300$	240
	3666.163	$+6980 \pm 240$		230
	3666.191	$+6960 \pm 200$	$+6410 \pm 290$	270
	3667.171	$+6460 \pm 250$		220
	3667.193	$+6960 \pm 270$	$+5910 \pm 310$	220
	4338.312	$+2350 \pm 170$		170
	4488.655	$+4300 \pm 410$	$+2210 \pm 360$	210
	4522.593	$+8010 \pm 340$	$+5080 \pm 410$	190
	4610.394	$+3920 \pm 190$	$+1530 \pm 240$	200
	4669.367	$+1850 \pm 170$	$+1140 \pm 160$	200
	4955.423	$+7700 \pm 380$	$+5390 \pm 410$	350
	5015.335	$+2830 \pm 230$	$+830 \pm 200$	300
	5021.301	$+6490 \pm 290$		140
HD 184471	4488.631	$+880 \pm 50$	$+450 \pm 200$	230
	4521.605	-80 ± 50	-80 ± 320	200
	4522.507	-230 ± 50	$+190 \pm 240$	210
	4610.322	$+250 \pm 50$	$+300 \pm 230$	200
	4669.317	-190 ± 50	-220 ± 180	200
	4955.348	$+810 \pm 50$	$+320 \pm 220$	250
	5015.275	$+320 \pm 50$	$+550 \pm 140$	300
HD 201601	4521.634	-1210 ± 50	-160 ± 150	280
(γ Equ)	4610.430	-1140 ± 50	-500 ± 100	520
	4669.377	-1170 ± 50	-410 ± 110	620
	4754.145	-1170 ± 50	-520 ± 140	550
	4783.162	-850 ± 50	-310 ± 120	650
	4808.119	-1150 ± 50	-340 ± 110	390
	4955.438	-1250 ± 50	-530 ± 100	500
	5015.348	-1220 ± 50	-360 ± 120	900
	5075.465	-1210 ± 50	-400 ± 100	800
	5077.454	-1040 ± 50	-380 ± 90	800
	average	-1140	-390	
HD 258686	4015.600	$+5100 \pm 220$	$+6240 \pm 400$	250
	5136.533	$+6760 \pm 370$	$+5340 \pm 450$	250
	5139.469	$+7170 \pm 350$	$+5440 \pm 300$	220
	5202.304	$+5750 \pm 320$	$+6880 \pm 450$	210

Table 3 continued

Star	JD (2450000+)	$B_e \pm \sigma$ (metals)	$B_e(H) \pm \sigma$ (hydrogen)	S/N
HD 293764	4015.530	$+4780 \pm 170$	$+2990 \pm 440$	190
	4809.396	$+5170 \pm 180$	$+3390 \pm 340$	210
HD 343872	2805.503	$+3950 \pm 170$	$+2300 \pm 240$	160
	3096.500	$+4100 \pm 140$	$+4010 \pm 260$	130
	4016.176	$+560 \pm 90$	-240 ± 330	190
	4522.552	$+4150 \pm 100$	$+3770 \pm 290$	190
	4610.359	$+4490 \pm 100$	$+3800 \pm 270$	200
	4611.333	$+3500 \pm 140$	$+2700 \pm 900$	100
	4669.338	$+1330 \pm 120$	$+130 \pm 220$	220
	4955.379	$+3310 \pm 90$	$+3050 \pm 180$	300
	5015.308	$+4500 \pm 110$	$+4370 \pm 270$	300
HD 349321	2839.308		$+1890 \pm 620$	70
	2840.396		-2150 ± 270	100
	4016.156	$+1920 \pm 100$	$+1320 \pm 280$	300

the longitudinal field component curve was confirmed in the paper by Kudryavtsev et al. (2008) based on a greater number of measurements. To explain it we proposed a model of a complex dipole–quadrupole magnetic field configuration in HD 45583, that describes well the double wave in the curve of B_e variability. The model predicts the surface magnetic field B_s with the strength on the order of 30 kG.

However, a subsequent modeling of the line profiles (Semenko et al., 2008) did not confirm the presence of such a strong surface field, in connection with what a hypothesis was made about a strong inhomogeneity of the distribution of metals over the surface of the star, capable of causing an appearance of a significant secondary minimum on the B_e curve.

In this study, we used both the new measurements presented in Table 3, and our earlier measurements from the papers (Kudryavtsev et al., 2006, 2008). The curve constructed in accordance with the period $1\overset{\mathrm{d}}{.}177177$ of North (1987), gives a significant scatter of points, hence we determined the HD 45583 period, based on the measurements of B_e from metal lines. These measurements are best described by the period of $P = 1\overset{\mathrm{d}}{.}1771 \pm 0.0003$. The corresponding curves are shown in Fig. 6.

The curve constructed from metal lines (open circles), clearly shows the double wave. We have little data to analyze the shape of the curve, constructed from the Hβ core, and hence no conclusion can be made on the presence or lack of a double wave so far. However, some differences from the curve, obtained from the metal lines are already noticeable. For a better visualization, we made a spline through the points measured from the Hβ core (filled circles). We can see that in general the hydrogen curve is more sinusoidal and, perhaps, somewhat shifted in phase relative to the metal curve. In addition, the difference in amplitude of two curves is significant — the hydrogen curve shows lower values of the field. Thus, here the differences of two curves can be attributed to two effects, an inhomogeneous distribution of metals over the surface, and a possible observable field gradient in the stellar atmosphere.

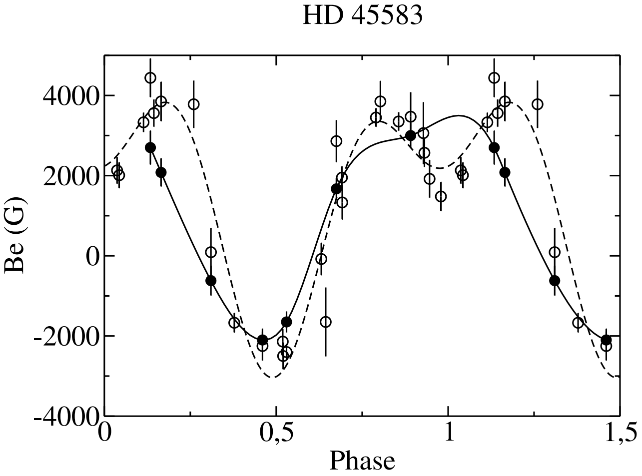

Figure 6: B_e curves for HD 45583, measured from metal lines (open circles) and from the core of Hβ (filled circles)

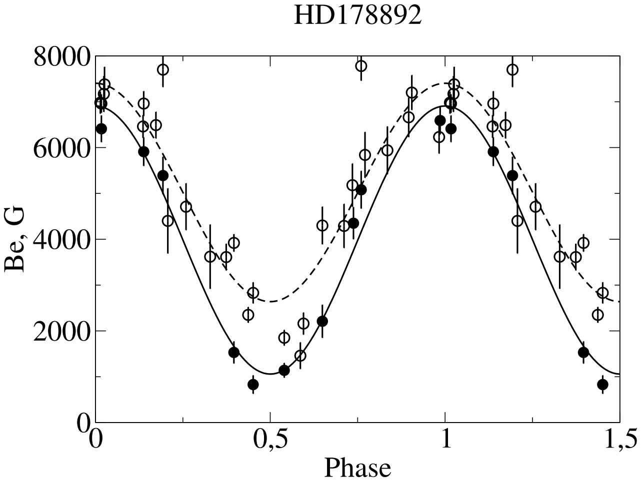

Figure 7: B_e curves for HD 178892, measured from metal lines (open circles) and from cores of hydrogen lines (filled circles)

5.2.3 HD 178892

The star has a very strong magnetic field $B_s = 17.5$ kG (Ryabchikova et al., 2006), partial Zeeman splitting is present in the metal lines. To exclude the influence of this effect on the longitudinal field measurements, we selected only the lines which were symmetrical relative to the line centre and did not reveal the Zeeman splitting. Although this technique includes a subjective factor, we believe that its shortcomings are mainly expressed in a somewhat bigger scatter of points, as well as in some cases in an inconsistency of some measurements with the general appearance of the curve. The overall shape of the curve and the amplitude of variability of the longitudinal magnetic field B_e, however, can be considered as well enough determined. This statement is partially confirmed by the fact that our new measurements show significantly lower B_e values, than the previous studies based on the same observations (Elkin et al., 2003), where the field was determined using an express procedure without a careful selection of spectral lines.

The period of the star $P = 8.2478 \pm 0.0076$ was defined in Ryabchikova et al. (2006) using the All Sky Automated Survey photometry (Pojmanski, 2002). Our measurements of B_e, taking into

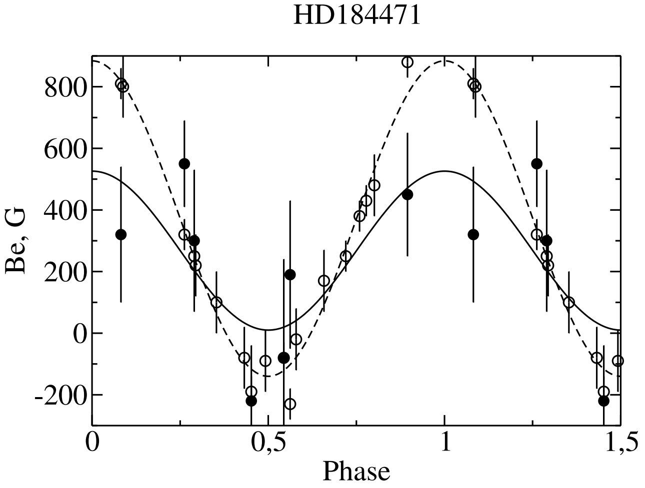

Figure 8: B_e curves for HD 184471, measured from metal lines (open circles) and from the core of Hβ (filled circles)

account new data, best fit the period of $8^{\mathrm{d}}.255 \pm 0.009$. The B_e curve corresponding to this period is demonstrated in Fig. 7. The measurements obtained from the hydrogen line cores are shown by filled circles. The longitudinal magnetic field of HD 178892 does not change its polarity. The figure shows that in this case, the curve obtained from the hydrogen line cores is shifted towards smaller B_e values, compared with the measurements from metal lines.

We can introduce the H/M value — a ratio of the magnetic field values measured from the hydrogen line cores and metals. In most of the stars the Be curve passes through zero, and it is inconvenient to apply the value of H/M as its accuracy and relevance depends on the period phase: the more the B_e field approaches zero, the greater the contribution of the measurement errors. In the case of HD 178892, the star is turned to us by the positive magnetic pole, the B_e curve does not pass through zero, and, as it can be seen from Fig. 7, in the first approximation we can assume the value of H/M constant and equivalent during the rotation period. In this case, the average H/M ratio for all phases for HD 178892 is 0.62 ± 0.08.

5.2.4 HD 184471

HD 184471 has a magnetic field of a relatively small magnitude with a longitudinal component of up to 800 – 900 kG (Kudryavtsev et al., 2006). The star has narrow spectral lines, what allowed measuring its B_e with high accuracy (up to 50 G). Based on the data from (Kudryavtsev et al., 2006) and our new measurements, we determined the stellar rotation period as $P = 50.8 \pm 0.4$. The B_e curve is represented in Fig. 8.

Measurements of metal lines (open circles) show a clear sine variation of B_e values during the period of rotation. The measurements done from the Hβ core are shown by filled circles. The measurements made from the core of one hydrogen line are much less accurate than those performed based on a large number of narrow metal lines. Nevertheless, it is clear that the hydrogen measurements show a smaller amplitude of the magnetic field variability.

5.2.5 HD 201601 (γ Equ)

γ Equ is a bright, very slowly rotating magnetic star with a rotation period of more than 75 years. Thus, the longitudinal component of the field B_e in this star can be considered constant over several years, making γ Equ an extremely convenient standard for magnetic measurements. Currently the longitudinal magnetic field of γ Equ is estimated at about -1000 G. This is confirmed by our multiple measurements (including those presented in this paper) and by data of other authors.

We have made 10 measurements for this star in the regions allowing the studies of both hydrogen and metal line. In all cases the field, measured from the hydrogen line cores, is significantly less than the one measured from metal lines. Mean magnetic field value from metal lines amounts to -1140 G, which is in good agreement with the known value of B_e. From the hydrogen line cores we obtained the mean value $B_e = -390$ G, which is almost three times smaller. Note that in individual measurements the error of σ was less than 50 G for the metal lines and 150 G for the Hβ line.

The average value of the H/M ratio, introduced in the section 5.2.3, is 0.34 ± 0.03. Note that this value is markedly different from that obtained for the star HD 178892, and in γ Equ the difference between the magnetic fields measured from hydrogen and metals is bigger than in the case of HD178892. Note that in contrast to HD 178892, the field of γ Equ is considerably smaller and our spectra with a moderate spectral resolution $R = 15000$ do not reveal any effects of partial Zeeman splitting. From other side HD 178892 has a much stronger magnetic field, that also may affect the value of H/M.

An example of γ Equ clearly shows that our system of magnetic field measurement from metal lines is in good agreement with the generally accepted international standards. At the same time the measurements of the hydrogen line cores in it show considerable differences with the common up–to–date values of B_e, obtained from metal lines.

6 Discussion

We measured magnetic fields of 23 stars concurrently from metal and hydrogen lines. In almost all the cases, when the longitudinal magnetic field B_e is nonzero, the measurements made from the hydrogen line cores show lower values of B_e than the measurements from metal lines. Only for the star HD 258686 in two measurements out of four the hydrogen line showed a significantly stronger field as compared to the metal lines. In those phases of the rotation period, when B_e close to zero, the measurements of metal and hydrogen lines show equal (zero) values of the magnetic field within the measurement errors. This indicates that there is no instrumental distortion which could lead to the differences in the field strength, obtained from metals and hydrogen.

Let us consider the factors that could cause the observed effect.

6.1 Instrumental and Systematical Errors

Magnetic field measurements in stars demand the highest accuracy in spectral line positioning. Even a very small unaccounted factor could result in wrong B_e values. In observations we exclude or correct for all the possible sources of errors. To control the measurements, the stars with zero global magnetic fields are observed, as well as the stars with well–studied magnetic fields (e. g. 53 Cam, γ Equ). These standard field measurements, as it was shown above, are in a good agreement with other studies.

In the phases close to the zero longitudinal magnetic field, both metal and hydrogen lines show the zero field, indicating the absence of any distortion of the spectrum. On the other hand, the ratio of the magnetic field measured in two ways varies for different objects (e. g. H/M ratios for HD 178892 and γ Equ), and, in two cases (HD 258686) even show a reverse picture (the field is stronger from hydrogen) what indicates the absence of the systematic difference between the two methods, which might be caused, for example, by the error in the code or other errors constantly present. The absence of systematic errors is also indicated by different shapes of the curves, obtained via two techniques for the stars HD 45583 and 53 Cam. In both cases the curves obtained from the hydrogen line cores are more sine than the metal curves. In the case of systematic errors the curves would have the same shape and differ only in amplitude.

Therefore, we believe that all the instrumental and possible systematic errors are excluded.

6.2 Partial Zeeman Splitting

Metal lines generally have a more complex picture of Zeeman splitting than the Hβ. For stars with strong fields this may cause an asymmetry or a partial splitting of spectral lines. In these cases our procedure of the line centre determination by fitting a Gaussian may produce an error. However, with the moderate spectral resolution we used, this could be true only for stars with very strong surface magnetic fields. But for most our stars the metal lines are symmetrical for the resolution $R = 15000$ and no partial Zeeman splitting is observed.

This is well–illustrated on the examples of γ Equ and 53 Cam, where our measurements based on metal lines correspond to the data of other researchers. The effects may partially appear in rare cases. We are for example unable to guarantee an absence of errors, associated with partial Zeeman splitting for the measurements of the star HD 178892 with a very large surface field, but this does not affect most of other measurements, presented in this paper.

Therefore, although in rare cases we can not exclude a possible contribution of the effect, for most of measurements the effects of partial Zeeman splitting are insignificant.

6.3 Spots

Ap stars are well known as the objects with inhomogeneous distribution of chemical elements over the surface. This could influence the magnetic field measurements. If the measured lines belong to an element concentrated near the magnetic poles, the measured B_e will be higher than the B_e, obtained from hydrogen lines. Metal lines that we used for measurements are mostly the lines of Fe and Cr. Though these elements could be distributed inhomogeneously, they are adequately present throughout the surface of a star. Moreover, in most cases the spectral variability is not very significant during the rotational period.

As an evidence of a low effect of spots on our measurements, we refer again to the measurements of 53 Cam and γ Equ, where our measurements of metal lines agree well with the measurements of other authors, obtained via measuring the polarization in hydrogen line wings. This example shows that the presence of spots in the chemical composition can not explain the entire set of the obtained measurements, although, as in the case of partial Zeeman splitting, the effects of inhomogeneous chemical composition of the star can affect the effect we observed.

For example, this effect is likely to be present for the star HD 45583, where there is a difference in the shapes of B_e curves. However, based on data from 53 Cam and γ Equ, we can see that the effects of spots affect to a greater extent the shape of the B_e curve, while the amplitudes of our curves and the curves obtained from the hydrogen line wings by other researchers in general coincide. This suggests that the difference in the measurements from metal lines and from the hydrogen line cores can not be fully explained by the presence of spots in the chemical composition.

6.4 Stratification of Chemical Elements

Due to the fact that recent studies found stratification of elements in the atmosphere, it is obvious that this fact must be taken into account when analyzing the characteristics of the field distribution with height. The question of the stratification of elements in the atmospheres of CP stars is not sufficiently clarified. On the one hand, the studies carried out in the early 90s (Romanyuk et al., 2992; Khokhlova & Topilskaya, 1992; Žižňovský & Zverko, 1995) did not find significant stratification of elements. The first study determined the chemical composition of the star α^2 CVn from the lines Fe, Cr and Ti in the areas before and after the Balmer jump, and the other two — for the same star from the lines of 30th Cr II multiplet, located in the wings of the hydrogen line Hβ, but at different distances from its core. The chemical composition was determined using the method of model atmospheres based on the analysis of equivalent line widths. The maximal difference in the abundance of elements found from the lines formed at different heights in the atmosphere did not exceed 0.3 – 0.4 dex.

On the other hand, a very significant (up to 3 orders of magnitude) stratification of elements was found in a big number of studies in recent years for cold CP stars, particularly for the rapidly oscillating Ap stars (roAp stars) (Ryabchikova et al., 2007; Kochukhov et al., 2006; etc.). As for the metal lines, i. e. Fe, Cr, Ti, in some stars a sharp increase of abundance with depth was detected. At the same time, in some roAp stars an increased abundance of rare earth elements was found in the upper atmosphere. These results were obtained based on the analysis of spectral line profiles.

In any case, a presence of stratification of chemical elements can not explain the observed effect other than by the presence of a magnetic field gradient, as in the case of a uniform magnetic field the B_e measurements have to show equal values regardless of the presence or absence of the stratification of chemical elements. On the other hand, in the case of presence of the magnetic field gradient, the effects of the stratified chemical composition must be taken into account to build a reliable picture of the magnetic field distribution with height.

6.5 Gradient of the magnetic field

Another way to explain why the measured longitudinal magnetic fields differ is to suggest that we observe a gradient of the magnetic field in stellar atmosphere. The formation of metal lines and hydrogen line cores takes place in different layers of the stellar atmosphere. Hence if there is a difference in magnetic field strengths between these layers, we must observe different values of the longitudinal magnetic field.

Accepting this explanation we should note that the observed magnetic field gradient is not a usual dipole magnetic field that decreases moving out from the centre of the dipole, as the thickness of the stellar atmosphere is too small for this effect to be observed. Thus, we probably observe a strong deviation from the standard dipole model of the magnetic fields of Ap stars within a rather small radial scale.

If we do not take into account the theoretical aspects, the presence of a magnetic field gradient is the simplest way that can explain the entire set of measurements we obtained, despite the fact that in some cases we do not exclude the influence of such effects as the partial Zeeman splitting, and surface inhomogeneity of the stellar chemical composition.

7 Conclusions

We found that the magnetic fields, determined from the Zeeman shifts in the hydrogen line cores, are significantly lower than those obtained from metal lines in the same spectra.

This can be considered as an evidence of the existence of a radial (vertical) gradient of the magnetic field in the atmospheres of CP stars. Except for one star, HD 258686, in all the 22 remaining cases the magnetic field decreases with height within limits of the atmospheric depth for a magnitude of 30–70%, significantly exceeding the possible variations in the dipole field model. We find no instrumental factors which could cause the found systematic differences in the field strength, obtained from the metal lines and hydrogen line cores. The physical causes, such as an effect of inhomogeneity of chemical composition or a partial Zeeman splitting can not explain the entire set of data obtained.

On the other hand this explanation is facing great difficulties in the theoretical description. Nevertheless, it can be argued that in any case the observed effect indicates significant deviations of the real magnetic field configuration from the simple dipole model.

A thorough analysis of the V–Stokes parameter distribution over the hydrogen line profile in magnetic CP stars has to be done to find the final solution. However, this is a very time consuming and laborious work, where we have to eliminate the effect of polarization of metal lines located in the hydrogen line wings. In addition, at a distance of more than 3–4 Å from the core, the steepness of the hydrogen line profile sharply drops, which leads to a proportional decrease in the signal from the V–Stokes parameter. Consequently, the accuracy of the field measurements will worsen as well. Nevertheless, there exist hopeful prospects for such a work.

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