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New magnetic CP stars

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Abstract.

Observations with the 6 m telescope have revealed 25 new magnetic chemically peculiar stars. We selected candidates by analyzing the depression profile at a wavelength of 5200Å. This technique for selecting candidate magnetic stars is shown to be efficient: we have found magnetic fields in 25 from 40 objects that were selected for observations with the Zeeman analyzer. 11 of the rest 15 objects have wide lines and therefore the accuracy of measuremets is low in these cases, so it is not unlikely that part of these stars are magnetic too. We found several stars with very strong magnetic fields, among them HD 178892 and HD 343872 with the surface magnetic fields not less than 20 kG and 9 kG, respectively.

In spite of the good efficiency of our method for selecting candidates, we have not found any correlation between the intensity of the depression profile and the value of the magnetic field.

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

1 Introduction

At present we know only slightly more than 200 magnetic CP stars (Romanyuk 2000), which is about 3% of the total number of known CP stars (Renson et al. 1991). Such a small number is caused by the fact that investigations of magnetic fields can be carried out only with large telsecopes, where observational time is severely limited. Moreover, before the appearance of CCD detectors it was possible to observe stars with a magnitude of up to 8 only, even with large telescopes.

Now the appearance of new detectors allows us to search for and investigate magnetic fields of stars with magnitudes of up to 11 using the 6 m telescope. Thus, great possibilities for extending the number of magnetic stars are opened. It also allows us to expand the space limits, within which the magnetic stars are observed, and for the first time make a comparative analysis of different characteristics of magnetic stars in relation with the Galaxy structure in the surroundings of the Sun.

The large number of CP stars that is available for Zeeman observations poses two problems. First, we have to choose for the researches such stars, study of which can give new results as soon as possible. Second, we need a criterion which could make it possible to select with a high probability such CP stars which have strong magnetic fields.

First of all, we decided to observe the spatially close stars and stars in open clusters.

It is well known that investigation of stars in clusters can give answers to some questions concerning the evolution of stars. From this point of view it would be extremely interesting to obtain data on characteristics of stellar magnetic fields in clusters of different ages. Now we know approximately 70 magnetic stars which are members of open clusters. But if one considers an individual cluster, then the number of known magnetic stars in it will barely exceed 10 at best. It is clear that no comparative analysis is possible in this case, and the list of magnetic stars needs to be extended.

Investigations of spatially close stars attract our attention as a result of our statistical analysis of the spatial distribution and motions of magnetic CP stars (Kudryavtsev and Romanyuk 2003; Romanyuk and

Kudryavtsev 2001) pointing to some primary orientation of magnetic fields of close stars. However these conclusions are based on an insufficient number of data which must be increased.

Therefore since 2000 we have been searching for new magnetic CP stars basing on the catalogs of Egret and Jaschek (1981), Renson (1992), Kopylov (1987), Niedzielski and Muciek (1988). In this paper we mainly consider the spatially close stars, for this reason candidates for magnetic stars were chosen from the catalogue of CP stars in stellar groups (Egret and Jaschek 1981). We observed mainly SrCrEu stars.

Obtaining Zeeman spectra for all stars would take a lot of observational time at the 6 m telescope, so we need a criterion pointing with some probability to the presence of a strong magnetic field. We used the analysis of the $\lambda5200$ Å depression profile. As early as 1980, Cramer and Maeder (1980) showed that the depth of the $\lambda5200$ Å depression could be an indicator of the presence of a magnetic field. Our method may be considered as some modification of Cramer and Maeder's method, but it differs from it by the fact that we use low resolution spectra but the photometric index. Stars were preliminarily observed with the low resolution spectrograph UAGS at the 1 m telescope of SAO, and after that we selected candidates with the depth of spectral features not less than 10% in the $\lambda5200$ Å region.

The data for a part of new magnetic stars presented in this paper were published earlier (Elkin et al. 2002; Elkin et al. 2003), but now we present another 11 stars for which magnetic field measurements are published for the first time.

2 Observations

The initial selection of candidates was made by analysis of the $\lambda5200$ Å depression profile in low resolution spectra observed with the spectrograpth UAGS at the 1 m telescope of SAO. For the following Zeeman observations we selected stars with a depth of spectral features not less than 10% of the continuum.

The search for magnetic field was performed by measuring its longitudinal component using Zeeman spectra observed with the Main Stellar Spectrograph of the 6 m telescope with analyzers of circular polarization (Naidenov and Chountonov 1976; Chountonov 2000). The spectra were observed at $\lambda4500$ Å with a resolution of about 15000. The Zeeman shift in spectra of magnetic stars is a very subtle effect, therefore we observed not less than three spectra for each star on different dates to exclude any fortuities and also to avoid, where possible, the hit at the phase of zero longitudinal magnetic field.

The data reduction was made in ESO MIDAS using the programs for reduction of Zeeman spectra (Kudryavtsev 2000).

On the whole, a search for magnetic field in 40 candidate stars has been conducted so far. Some data on them are presented in Table 1. The information for spectral class and peculiarity was taken from the catalog of Renson et al. (1991). The stars are divided in two groups: a) stars with detected magnetic field; b) stars the detection of magnetic field in which had no success.

3 Magnetic field measurements

The measurements were made in a classical manner. Zero standards and stars with the well-known magnetic field were observed for the calibration. Measurements of standard stars show a good agreement with previous studies.

Table 2 presents the results of our measurements of the magnetic field B_e for the detected magnetic stars. The measurements of the spectra of the stars in which we failed to detect magnetic field are listed in Table 3.

As one can see from Table 3, the measurements of the majority of "non-magnetic" stars were performed with a large r.m.s. error σ. This is probably due to their fast rotation (period of rotation is unknown) and fact that the lines of the given stars are very broad. Only for 4 sharp-line stars out of 15 stars the measurements were made with the standard accuracy reachable with the MSS of the 6 m telescope. Thus, it is possible that part of the presented stars also have rather strong magnetic fields; however instrument and methods of higher precision are required to detect them.

Four stars with very large extrema of the longitudinal component of the magnetic field: HD 178892 ($B_e = 8490 \pm 380$), HD 293764 ($B_e = 4040 \pm 230$), HD 343872 ($B_e = 4590 \pm 350$), HD 349321 ($B_e = 5560 \pm 310$), attract attention.

Additional observation are presently being made for them with the purpose of determination of the rotational period and construction of models. For HD 178892 and HD 343872 even now it is possible to make a certain analysis which we present below in Section 4.

Table 1: Observed stars

HD/BD	M_V	Sp	Pec	HD/BD	M_V	Sp	Pec
New magnetic stars							
HD 6757	7.7	A0	CrEuSi	HD 178892	8.9	B9	SrCrEu
HD 29925	8.3	B9	Si	HD 189963	9.9	A0	SrCrEu
HD 38823	7.3	A5	SrEu	HD 196691	8.6	A0	Si
HD 39658	8.8	A0	CrEu	HD 209051	8.8	A0	SrCrEu
HD 40711	8.4	A0	SrCrEu	HD 231054	10.0	Ap	SiSr
HD 115606	8.6	A2	Cr	HD 293764	9.5	A2	SrCrEu
HD 134793	7.5	A4	SrEuCr	HD 338226	9.8	A0	Si
HD 142554	9.8	A0	CrEu	HD 343872	9.9	Ap	SrCrEu
HD 158450	8.6	A0	SrCrEu	HD 349321	9.3	A1	Si
HD 168796	7.9	A0	SiCrSr	BD +17°3622	8.8	A2	SrCrEu
HD 169887	9.0	Ap	Si	BD +32°2827	9.9	Ap	SrEuCr
HD 170565	9.1	A3	SrCrEu	BD +35°3616	9.5	F0	SrEu
HD 170973	6.4	A0	SiCrSr				
Stars in which the presence of magnetic field is questionable							
HD 1677	7.3	A2–F0		HD 103498	7.0	A1	CrEuSr
HD 3473	9.0	A2	SiMg	HD 138218	9.8	A2	Sr
HD 4478	9.0	B9	Si	HD 141461	8.5	B9	Si
HD 27505	6.5			HD 158352	5.4	A0	CrEu
HD 31362	6.3			HD 164827	9.3		
HD 34427	8.7	A0	Si	HD 205087	6.7	A0	SrSiCr
HD 37642	8.0	B9	He weak Si	HD 290665	9.4	A0	CrEuSr
HD 68703	6.5	A8					

4 Stars with strong magnetic fields

4.1 HD 178892

During objective–prism observations Bond (1970) found the star to be peculiar. In the SIMBAD database, it is listed as a star in a binary system.

Our observations with the 1 m telescope revealed a prominent feature at a wavelength near 5150 Å. We were able to obtain four Zeeman spectra for this star. It possesses a strong magnetic field whose longitudinal component is not less than 8 kG. At present, we know only one star (HD 215441)[1] with longitudinal component B_e exceeding this value and one star (HD 175362) with a comparable longitudinal component (see the catalog of Romanyuk (2000).

HD 215441 is a hot silicon star ($T_e = 16000$ K), while HD 175362 is a star with anomalous helium lines ($T_e = 17000$ K) (Glagolevskij 1994). Among the numerous and cooler (with T_e of the order of 8000 K) SrCrEu stars, HD 178892 can be a record holder by its magnetic field strength.

Using our measurements of the longitudinal component of the magnetic field B_e, we determined the rotational period as $P = 8.^{\mathrm{d}}27 \pm 0.^{\mathrm{d}}08$. The curve of variation of B_e is displayed in Fig. 4.1. We also attempted to determine the period of rotation using Hipparcos photometry data; however, the star showed no significant light variability. The photometry data fitted with the period $8.^{\mathrm{d}}27$ are shown at the bottom of the Fig.4.1.

Using the B_e variability curve, we estimated lower limits of the dipole field strength on the magnetic pole as $B_d \geq 30$ kG and the surface magnetic field $B_s \geq 19.8$ kG. The corresponding theoretical curve in an approximation of a simple dipolar field is shown in the upper part of Fig. 4.1 with a solid line.

Modeling the profile of the line H_α in HD 178892 showed the best fit to the model with $T_e = 8000$ K, $\lg g = 4.0$. Values of $v \sin i$ measured from different lines range from 20 to 45 km/s depending on the Lande factor. Thus, the influence of magnetic broadening of lines is evident. A star with a temperature $T_e = 8000$ K has a radius of the order of $1.85 R_\odot$ (Kopylov 1967). Then the equatorial rotational velocity at the period of

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[1] As we were preparing this publication Bagnulo et al. (2004) discovered a longitudinal magnetic field of 9 kG in the star NGC 2244–334.

Table 2: Magnetic field measurements for new magnetic stars

JD 2450000+	$B_e \pm \sigma$ (G)	JD 2450000+	$B_e \pm \sigma$ (G)	JD 2450000+	$B_e \pm \sigma$ (G)
HD 6757		HD 169887		HD 293764	
2544.539	+2727 ± 144	2128.492	−2340 ± 290	1806.558	+4040 ± 230
2544.554	+2720 ± 196	2129.358	+540 ± 230	1807.529	+3770 ± 310
2545.465	+2166 ± 249	2130.360	+1210 ± 240	1864.505	+3590 ± 290
2545.488	+3099 ± 258	2807.357	+2019 ± 247		
2625.296	+2960 ± 170			HD 338226	
2626.257	+2848 ± 159	HD 170565		2127.545	+1040 ± 230
2689.170	+2625 ± 144	2805.413	+1583 ± 182	2128.458	+440 ± 180
2690.148	+2456 ± 124	2831.384	+1706 ± 187	2129.433	+1490 ± 170
		2835.403	+1956 ± 134		
HD 29925				HD 343872	
1807.508	-1100 + ±190	HD 170973		1768.504	+3590 ± 300
2129.543	−200 ± 360	2688.645	+634 ± 43	1770.391	+2160 ± 400
2153.521	−810 ± 250	2805.360	−399 ± 46	1798.267	+660 ± 340
2189.458	−890 ± 150	2807.521	−343 ± 47	1799.286	−760 ± 220
				1800.432	−600 ± 300
HD 38823		HD 178892		1802.347	+3860 ± 250
1892.493	−939 ± 138	2459.449	+6320 ± 480	1803.401	+1960 ± 790
2624.440	−2493 ± 96	2459.473	+6260 ± 530	1804.315	+2730 ± 370
2625.452	−1412 ± 113	2625.140	+8150 ± 390	1806.185	+1980 ± 350
2626.411	−23 ± 66	2626.139	+8490 ± 380	1807.185	+1510 ± 190
2689.241	+1523 ± 85	2660.652	+5773 ± 519	1893.122	+2210 ± 350
		2661.645	+5277 ± 500	1952.640	+3580 ± 180
HD 39658		2688.614	+1729 ± 225	1952.655	+2880 ± 290
2624.599	−971 ± 91	2689.577	+4917 ± 457	1953.622	+2950 ± 210
2625.640	−642 ± 214	2805.343	+4940 ± 543	2069.458	+2850 ± 200
2626.310	+1349 ± 123	2807.392	+7767 ± 407	2127.283	+2870 ± 230
2661.537	+1332 ± 182	2812.372	+1665 ± 340	2128.283	+3810 ± 230
2662.543	+101 ± 157	2830.403	+6143 ± 626	2130.435	+2660 ± 210
2689.213	−481 ± 306	2831.435	+7795 ± 474	2805.503	+4179 ± 173
		2832.496	+7752 ± 398	2840.349	+4589 ± 351
HD 40711		2834.431	+6181 ± 520		
1807.554	−230 ± 60	2835.380	+5097 ± 553	HD 349321	
1892.538	+330 ± 110	2838.390	+4780 ± 602	2805.432	−5555 ± 312
2130.553	−630 ± 310	2840.433	+5762 ± 535	2807.418	+1869 ± 334
2153.557	−650 ± 90			2830.380	−4700 ± 279
		HD 189963		2831.409	−1647 ± 455
HD 115606		2457.447	+255 ± 140	2832.471	+1774 ± 318
1952.438	−210 ± 130	2459.421	+212 ± 200	2834.407	+2192 ± 213
2333.454	+680 ± 120	2805.473	+301 ± 73	2835.358	−5153 ± 306
2333.479	+640 ± 110	2830.462	−695 ± 91	2839.308	+1858 ± 948
2417.254	−760 ± 150	2835.455	+355 ± 57	2840.396	−3445 ± 620
HD 134793		HD 196691		BD +17°3622	
2624.642	−140 ± 114	2130.304	−1940 ± 240	1275.555	+1600 ± 160
2660.592	−812 ± 122	2417.500	+2290 ± 360	2069.512	+1510 ± 240
2661.591	+900 ± 83	2454.473	+1920 ± 240	2127.417	+980 ± 130
2689.483	+953 ± 96	2457.419	+630 ± 250		
				BD +32°2827	
HD 142554		HD 209051		2191.208	−770 ± 180
2417.448	+1737 ± 260	2130.456	−3300 ± 580	2417.341	−470 ± 150
2805.274	+1744 ± 245	2191.258	−2580 ± 460	2457.417	+60 ± 130
2807.305	+447 ± 364	2454.498	−2980 ± 730		
2830.311	−771 ± 263	2458.420	−1040 ± 700	BD +35°3616	
				2128.485	+250 ± 150
HD 158450		HD 231054		2626.168	−517 ± 52
2130.269	+240 ± 100	2127.502	+960 ± 250	2805.320	−13 ± 71
2805.373	−528 ± 116	2128.417	+1840 ± 250	2807.448	+310 ± 67
2807.375	−2975 ± 196	2129.395	+2530 ± 270	2835.508	+541 ± 69
2812.415	+812 ± 236	2130.395	+380 ± 170		
HD 168796					
2129.291	−610 ± 110				
2130.291	−290 ± 110				
2190.225	−870 ± 90				
2458.396	+510 ± 110				

Table 3: Measurements for stars in which the presence of magnetic field is questionable

JD 2450000+	$B_e \pm \sigma$ (G)	JD 2450000+	$B_e \pm \sigma$ (G)	JD 2450000+	$B_e \pm \sigma$ (G)
HD 1677		HD 34427		HD 141461	
2544.506	−916 ± 431	2191.474	+1850 ± 1810	2333.563	−1450 ± 1300
2544.521	−471 ± 462	2625.384	+2800 ± 1910	2333.581	−760 ± 1360
2625.232	−275 ± 289	2626.375	−442 ± 1528	2661.610	+513 ± 638
2626.243	+255 ± 305			2662.593	+93 ± 1342
2689.157	+120 ± 513	HD 37642 *			
2690.170	+337 ± 403	2624.419	+2143 ± 890	HD 158352	
		2625.437	+4640 ± 1250	2688.639	+343 ± 772
HD 3473		2626.394	+2630 ± 2302	2689.559	+590 ± 878
2129.485	−70 ± 640			2830.346	+2187 ± 1265
2130.528	+1310 ± 590	HD 68703			
2153.252	−890 ± 970	2333.272	+390 ± 210	HD 164827	
2625.252	+88 ± 380	2544.591	+213 ± 285	2805.392	+1276 ± 450
		2544.600	−325 ± 278	2830.433	+1623 ± 525
HD 4478		2624.507	−219 ± 193	2831.359	−2325 ± 1131
2153.296	+1277 ± 919	2625.657	+176 ± 218	2835.426	−1075 ± 352
2625.276	+533 ± 898	2626.571	+196 ± 180		
2834.468	−1004 ± 719	2661.519	+338 ± 212	HD 205087	
				2805.524	+3 ± 78
HD 27505		HD 103498		2830.537	+239 ± 95
2624.320	−2488 ± 1094	2662.569	−242 ± 56	2831.504	+126 ± 101
2625.338	−78 ± 728	2689.365	−5 ± 85	2832.536	+63 ± 100
2626.331	+2262 ± 1585	2689.391	−25 ± 94		
		2690.398	+8 ± 106	HD 290665	
HD 31362		2830.278	+86 ± 45	2624.388	+7406 ± 2886
2333.293	+79 ± 380	2831.277	−29 ± 36	2625.412	+309 ± 2930
2544.572	+1364 ± 623				
2544.580	+332 ± 335	HD 138218			
2545.411	+213 ± 250	2417.378	−1770 ± 2051		
2545.440	−67 ± 437	2457.328	−3518 ± 1545		
2624.339	+171 ± 188	2660.614	+1391 ± 1084		
2625.347	+411 ± 309				
2626.341	+149 ± 296				

* Magnetic field of HD 37642 was discovered by Borra (1981) using balmer-line polarimeter. Star has very broad lines that made impossible accurate Zeeman spectroscopy.

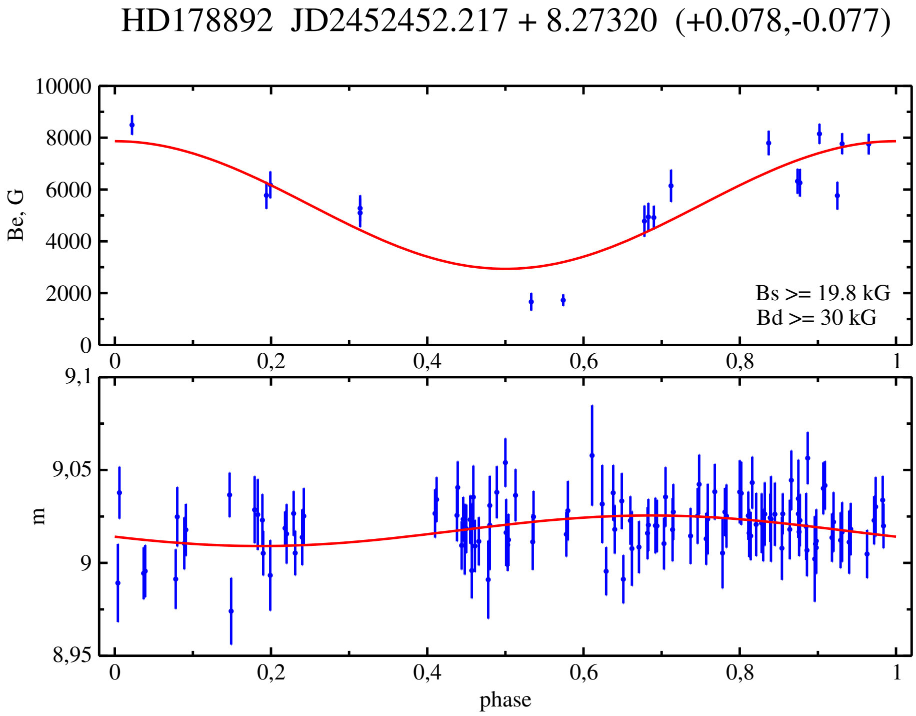

Figure 1: *Longitudinal magnetic field variability and Hipparcos photometry for HD 178892.*

$8^{d}\!.27$ will be of the order of 10 km/s. The instrumental profile of the MSS of the 6 m telescope corresponds to 20 km/s, thus, the entire broadening that we observe is most likely caused by the magnetic field of the star.

4.2 HDE 343872

HDE 343872 was first classified as a Si peculiar star by Bidelman (1983) on the basis of objective–prism spectra. Schneider (1986) included it in the list of CP2 stars to be observed in Stromgren's system to determine its photometric indices, H_β and Δa. Schneider's studies revealed a variable depression at 5200 Å in HDE 343872, which is the largest among all the previously observed CP stars, with Δa from 0.067 to 0.146. Because of the small number of observations, Schneider (1986) was able to estimate the variability period only roughly: from 7 to 9 days.

Subsequently, Kroll (1992) carried out spectroscopic observations of the star. He found $T_e = 10500$ K and $\lg g = 3.1$, suggesting that HDE 343872 is an evolved star. Its spectrum exhibits enhanced chromium and iron lines.

Thus, we had strong grounds for including the CP star HDE 343872 with the largest depression ever observed, which also exhibited the largest periodic variations, in our program of observations with the 6 m telescope to search for and thoroughly study its magnetic field.

We obtained about 20 Zeeman spectra of the star. Using measurements of the longitudinal component of the magnetic field we determined the rotational period of the star as $P = 8^{d}\!.79 \pm 0^{d}\!.02$. To estimate the period, we also attempted to employ Tycho photometry; however, the star showed no considerable variability within the measurement errors. The curve of variability of the magnetic field longitudinal component and Tycho photometry with the period of $8^{d}\!.79$ days are shown in Fig. 4.2.

Preliminary modeling the curve of the longitudinal magnetic field in an approximation of a simple dipole yields lower limits of the dipole strength, $B_d \geq 13.5$ kG, and of the surface magnetic field, $B_s \geq 8.7$ kG. The corresponding theoretical curve of B_e is shown in the upper part of Fig. 4.2 with a solid line.

With such a surface field B_s magnetic broadening can contribute 50% of the total line width, depending on the Lande factor of the line. Values of $v \sin i$ determined from different lines range from 25 to 35 km/s,

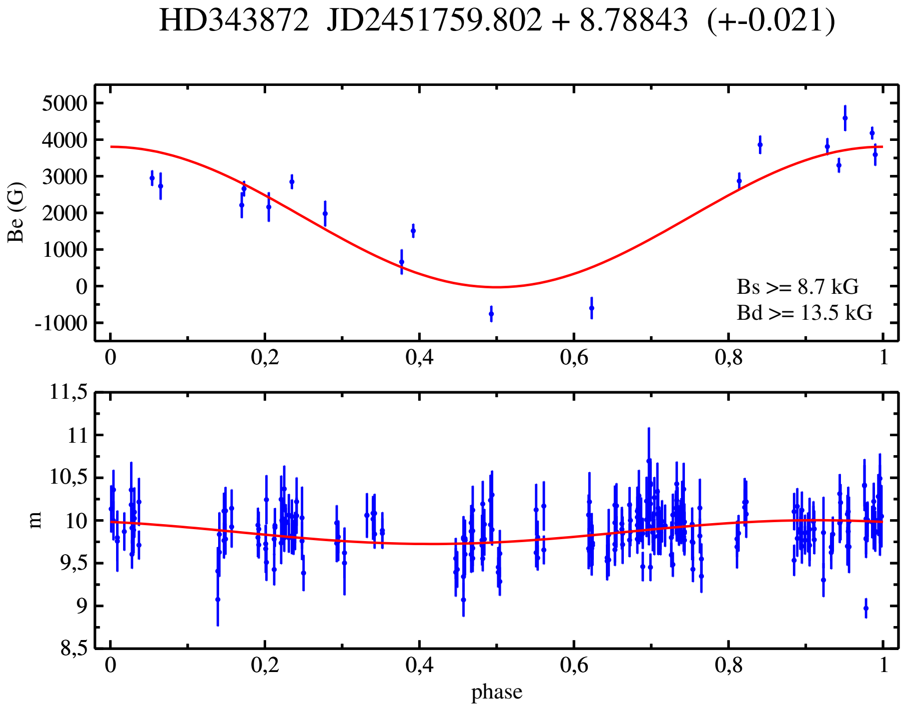

Figure 2: *Longitudinal magnetic field variability and Tycho photometry for HD 343872.*

depending on the Lande factor, which is also evidence of magnetic broadening. The contribution of magnetic broadening cannot be ignored when studying the chemical composition of the stellar atmosphere.

The attempt of modeling hydrogen line profiles showed a result rather curious for a magnetic star — $\log g = 3.0$, which, however, is in excellent agreement with the data of Kroll (1992) mentioned earlier. However, we were unable to define unambiguously the temperature of the star using hydrogen lines. Note also that the modeling of metallic lines represents in this case a task which is far from being trivial.

The star is extremely interesting for further more detailed investigations.

5 Results

So, by the present time, we have observed 40 candidates for magnetic stars, selected on the basis of analyzing the profile of the depression at $\lambda 5200$ Å. In 25 of them (62.5% of the sample) magnetic fields were found, including 4 stars with extremely strong magnetic fields.

Among the rest of the stars 11 out of 15 stars have very broad lines, and that is why the magnetic measurements were made with low accuracy. It is not unlikely that part of them are magnetic as well. If one considers only the stars with narrow lines, then we found fields in 25 (86.2%) from 29 candidates.

Thus, it can be stated that our technique of selecting the candidates turned out to be efficient enough. Nevertheless, it should be taken into account that most of the candidates were of SrCrEu type of peculiarity, and the frequency of occurence of magnetic fields in these stars is very high, which, probably, affected the assessment of the technique presented above.

We attempted to establish a possible relation between the depth of one of the characteristic features on the profile of the depression at $\lambda 5200$ Å and the magnetic field magnitude. Since in the majority of cases we had no curves of variations of the longitudinal field and accurate magnetic field models, we took as the estimate its maximum value, B_{extr}. The relationship between the depth of the detail at $\lambda 5200$ Å and B_{extr} is shown in Fig. 5.

As it can be seen from the figure, we found no correlation between these two values. Although the above-described procedure of estimation of the given relationship is rather rough, we do not expect any qualitative

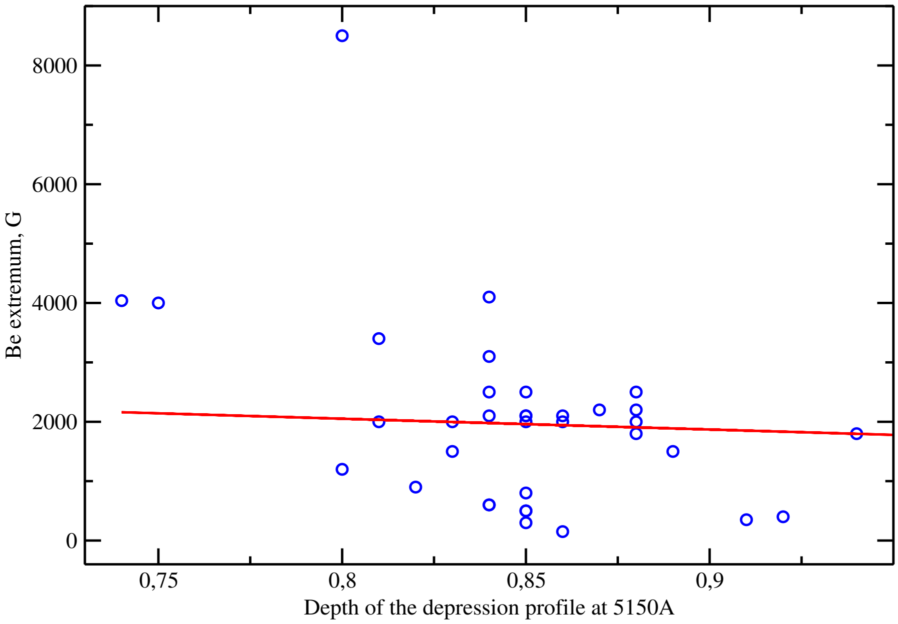

Figure 3: *Relation between the depth of a detail at* $\lambda 5200\,AA$ *depression profile and the observed extremum of the longitudinal magnetic field.*

changes when specifying the magnetic star models. Thus, direct measurements are necessary even in statistical studies of magnetic field of stars.

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