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Magnetic CP stars with a large depression in the continuum

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Abstract. Spectropolarimetric observations of 96 CP stars were performed at the 6m telescope with the aim of searching for the presence of stellar magnetic fields. The preliminary selection of candidates, based on the analysis of the continuum depression near λ5200Å, proves very effective. Using recently obtained data, we consider correlations between magnetic field strength, photometrical indices Δa and Z, connected with the continuum depression, and some other parameters of magnetic CP stars with a large depression in the continuum.

Key words: stars: chemically peculiar – stars: magnetic fields – techniques: photometric – techniques: spectroscopic

1. Introduction

Searching for new magnetic stars is rather a difficult problem because the Zeeman effect shows up in ordinary spectra only in individual cases and in most cases it is actually impossible to distinguish a magnetic star from a non-magnetic one, using usual spectral observations. So, for magnetic field measurements one needs either special polarimetrical methods of observations (Zeeman measurements), or a very high spectral resolution, or both.

Apparently, all Ap/Bp stars possess magnetic fields, however, it is unrealistic to perform Zeeman measurements for all 3200 such stars (Renson *et al.*, 1991). At the present time, magnetic field measurements have been made for about 500 Ap/Bp stars; they show a tendency for decreasing numbers of stars with increasing field and the portion of stars with weak fields is large. The lower limit of the field strength which could be detected by the present–day technique is about 10–100 G depending on the methods, brightness of the star etc. For a considerable fraction of Ap/Bp stars for which magnetic field measurements have been made, no fields have been found. It is possible that these objects have magnetic fields, but that they are weaker than the detection limit.

For this reason the search for effective criteria for selection of candidates which could have detectable magnetic fields, for observations with the Zeeman analyser, represents an important problem. In this paper we consider correlations between magnetic field strength and photometrical parameters Δa and Z using recently obtained data. Also some other correlations existing for the magnetic stars will be analyzed.

2. Search for CP stars with strong magnetic fields

In 1980 Cramer and Maeder (1980) published a paper which showed for the first time that there is a correlation between the Z parameter of the Geneva photometrical system and the strength of the surface magnetic field B_s in CP stars. Since the Z parameter describes quantitatively the continuum depression near 5200 Å, one can assert that Cramer and Maeder found for the first time an interrelation between the degree of the continuum anomaly and the magnetic field strength at the surface of CP stars. It follows from this that stars with strong magnetic fields should be searched for among objects with the most strong anomalies of continuum in the region of 5200 Å.

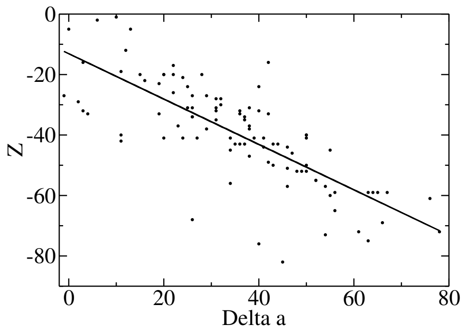

Figure 1. Δa – Z relation.

Based on the list of Cramer and Maeder, in the 1980s the SAO magnetic group performed searches for magnetic stars at the 6 m telescope. These observations were successful – we detected about 20 stars with strong magnetic fields and in another ten stars the presence of the fields was suspected (Glagolevskij *et al.*, 1982; 1985). However, the capabilities of photographic techniques of magnetic field measurements proved to be exhausted, all stars with strong Z parameters accessible to us having now been measured.

Only with the development of new techniques and the application of CCD to observations has a new stage of searching for magnetic stars begun. We took into account not only the results of the Geneva photometry but also results of other observations. In particular, we used extensively the results of the Δa photometrical system (Maitzen, 1976) developed at Vienna observatory and intended specially for the detection of CP stars.

Since the Z parameter of the Geneva system and the index Δa characterize the continuum depression at 5200 Å, a correlation between these parameters should be expected. We selected 98 magnetic CP (mCP) stars for which both these values had been determined. Objects with temperatures from 8000 K to 14 000 K were taken. Results are displayed in Fig. 1. The linear relation between these parameters with correlation coefficient 0.764 is well visible.

Besides the Δa and Z photometry we also performed low–resolution observations of the $\lambda\,5200$ Å region at the SAO 1m telescope and selected some magnetic star candidates using direct observations of spectral anomalies in this region. This method proved effective for cooler stars. Some details of the method are described by Kudryavtsev *et al.* (2006). We are performing searches for magnetic fields with the 6m telescope from 2000. The basic results of 2000–2005 are published by Kudryavtsev *et al.* (2006). Among the new mCP stars there are many interesting objects. For instance, HD 178892 – a cool star with an unusually strong magnetic field with longitudinal component up to 7 kG and magnetic field modulus as strong as 17.5 kG (Ryabchikova *et al.*, 2006). Another example is HD 45583, where longitudinal magnetic field variations show a double wave curve (Kudryavtsev *et al.*, 2008).

3. Some correlations between parameters of mCP stars

From here onwards, we analyze only stars with large magnetic fields and strong anomalies in the energy distribution in the continuum.

3.1. Relationship between magnetic field and photometric indices

We analysed in our paper (Kudryavtsev *et al.*, 2006) correlations between the value of the root mean square magnetic field $\langle B_e \rangle$ and the photometric indices Δa and Z. The results for Δa are presented in Fig. 2. The scatter of points is very large and the correlation coefficients in both cases are less than 0.5.

Nevertheless, almost all stars with $\Delta a > 0\overset{\mathrm{m}}{.}035$ are magnetic. A comparison of stars with $\Delta a > 0\overset{\mathrm{m}}{.}035$ and $\Delta a < 0\overset{\mathrm{m}}{.}035$ shows that for 54 stars with $\Delta a > 0\overset{\mathrm{m}}{.}035$ the average value of the root mean square magnetic field $\overline{\langle B_e \rangle} = 1210 \pm 120\,\mathrm{G}$, whereas for 43 stars with $\Delta a < 0\overset{\mathrm{m}}{.}035$ $\overline{\langle B_e \rangle} = 750 \pm 80\,\mathrm{G}$. A comparison of the mean values by the Student's t–distribution shows that $t = 3.3$, so the possibility that the difference of the mean values in the two samples is accidental is less than 0.1%. Thus some general relation between the index Δa and the magnetic field is appears to exist: the probability of detecting a magnetic field is higher among objects with a large depression in the continuum at 5200 Å.

3.2. $\langle B_e \rangle$ versus relative age

For the following analysis we shall use the ages $\log t$ and fractional ages τ computed by Kochukhov and Bagnulo (2006) for 160 mCP stars. From this sample we select only the stars with a large depression in continuum (i. e. with a large measured Δa, Z or spectroscopically observed anomalies near $\lambda\,5200$ Å). Results for He, Si and Si+ stars and for SrCrEu stars are displayed in Fig. 3.

It is evident that in the case of hotter helium and silicon stars the longitudinal field component decreases with age. The magnetic field $\langle B_e \rangle$ of hot CP stars being at the end of the evolution on the main sequence is 3–4 times as small

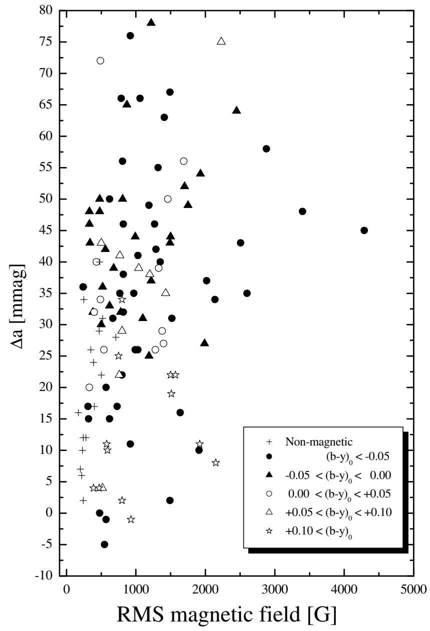

Figure 2. Relationship between the root mean square magnetic field $\langle B_e \rangle$ and index Δa for 5 groups of mCP stars with different values of the magnitude $(b-y)_0$.

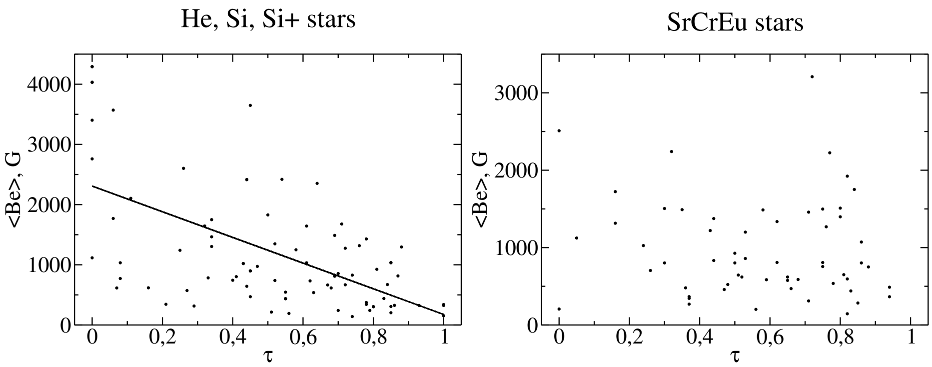

Figure 3. Relationship between relative age τ and magnetic field $\langle B_e \rangle$.

as at its beginning. For this group a comparison of mean field strengths for stars that have not yet stayed a half of their lifetime on the Main Sequence ($\tau < 0.5$) with the stars coming near to the end of evolution ($\tau > 0.5$) shows $\overline{\langle B_e \rangle} = 1570 \pm 200$ and $\overline{\langle B_e \rangle} = 780 \pm 80$ respectively. The Student's distribution gives the value $t = 3.66$, thus the probability of accidental coincidence is less than 0.5%. At the same time, in the case of cooler SrCrEu stars no such dependence is visible.

Table 1. Mean Δa (mmag) values for different ranges of periods and temperatures.

	$T_{\rm eff}$ 8000–9000	$T_{\rm eff}$ 9000–10 000	$T_{\rm eff}$ 10 000–11 000	All ranges, $T_{\rm eff}$ 8000–11 000
$P < 3^{\rm d}\!\!.3$	16	35 ± 3	36 ± 5	35 ± 3
$3^{\rm d}\!\!.3 < P < 30^d$	40 ± 4	44 ± 5	54 ± 7	44 ± 3
$P > 30^d$	55 ± 5	49 ± 15	67	55 ± 4

In a sense, this is the repetition of a result presented by Kochukhov and Bagnulo (2006) for stars with $M > 3\,M_\odot$ and $M < 3\,M_\odot$, as the He, Si and Si+ stars usually have higher masses than the SrCrEu stars. Also, our results are for smaller sample of stars, because we select only the stars with a large depression near $\lambda\,5200$, as it was described above.

3.3. Δa versus period of rotation

We have found that for mCP stars with known periods of rotation the degree of anomalies of the continuum rises with increasing rotational period, if we consider narrow temperature ranges. An analysis was made for three groups of stars: $P < 3^{\rm d}\!\!.3$, $3^{\rm d}\!\!.3 < P < 30^{\rm d}$ and $P > 30^{\rm d}$. The data are presented in Tab. 1. It is obvious that the effect of increasing the Δa index with rotational period is observed in each temperature range and even in averaged values for all the temperature ranges ($T_{\rm eff} = 8000 - 11\,000$ K).

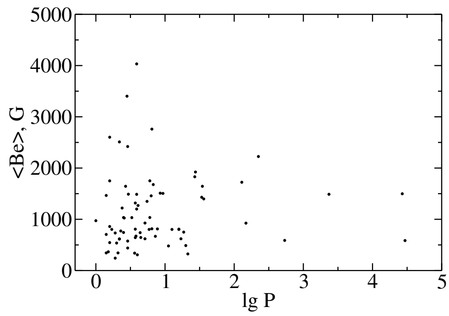

Figure 4. Rotation period versus root mean square magnetic field.

The effect could be explained if we suggest that the appearance of the depression at λ5200Å is connected with the magnetic strengthening of spectral lines. Then with longer periods and deeper spectral lines the sensitivity of the Δa index to a magnetic field should be higher. Also, using the photometric indices for selection of candidates for mCP stars is effective for $T_{\mathrm{eff}} > 8000\,\mathrm{K}$. For lower temperatures the low resolution spectral observations are more preferable.

3.4. $\langle B_e \rangle$ versus period of rotation

The mCP stars with known $\langle B_e \rangle$ and rotation period are presented in Fig. 4. There is no correlation between these values, but one can clearly see that stars with strong magnetic fields are fast rotating stars with period $P < 10^{\mathrm{d}}$.

4. Conclusion

We have analysed the properties of CP stars with strong anomalies in the energy distribution in continuum near $\lambda 5200$Å. It was shown that the existence of such the anomalies is a good indicator of the presence of magnetic field in these objects. The CP stars with the greatest depressions at $\lambda 5200$Å tend to possess the strongest magnetic fields. In the temperature interval of 8000–11 000 K the degree of anomaly of the continuum rises with increasing of the rotational period. One possible explanation of this effect is that the continuum anomalies are connected with the magnetic strengthening of spectral lines, which is more perceptable for slowly rotating stars. It was shown that there is no correlation between magnetic field strength and the rotation of a star. Nevertheless, all the stars with the strongest magnetic fields are fast rotators.

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