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On the Magnetic Behaviour of CP Stars with their Age

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Abstract. The relationship between the magnetic field and the evolutionary age has been investigated on the data base of the mean magnetic field strength of 45 chemically peculiar (CP) stars. The analysis shows, that the field of the stars increases after passing the zero-age main sequence (ZAMS) before they reach the luminosity class V - whereas it decreases later on caused by the evolutionary growth of the radius. This result confirms our earlier assumption that the integral magnetic flux in CP stars does not change during their lifetime on the main sequence.

1. Introduction

The study of magnetic fields in chemically peculiar stars, as they move evolutionarily across the main sequence, is of great importance for revealing the properties of magnetic fields and their relation to chemical anomalies. The averaged quadratic (rms) values of the magnetic field have been investigated earlier by Glagolevskij (1988). As the star evolves, the field decreases inversely as the square of the stellar radius, to a first approximation. It is of interest that the relationship reaches a maximum after the star has already departed from the ZAMS, i.e., when the star approaches the band occupied by stars of luminosity class V. At that time this presented a serious problem.

The relationship discussed was plotted for all types of CP stars. Later, Glagolevskij & Chuntonov (1998) tried to construct such relations for the four main types of chemical peculiar stars separately. Despite the evident shortage of data, inferences could be drawn that to a first approximation, the magnetic field in He-rich stars grows during the lifetime of their stay on the main sequence. The field of He-weak and SrCrEu stars at first increases, then reaches a maximum in the band of stars of luminosity class V, and then decreases. Thus, the decrease in field strength with the evolutionary increase of radius is significant, so that an initial increase may be assumed. Chemical anomalies behave exactly in the same manner (Glagolevskij & Chuntonov, 2001). The degree of chemical anomalies at first rises and, having reached a maximum in the middle of the main sequence, begins to diminish.

Table 1. Mean magnetic surface field strength B_s of 49 CP stars related to the relative radius Q_Z on the zero age main sequence (ZAMS)

HD	B_s	Q_Z[G]	$Q_Z[\beta]$	Q_Z	$\triangle$	Reference
2454	3700	1.5	1.6	1.55	0.05	1
5797	1800	1.9	-	1.9	-	2
8441	100	2.1	2.3	2.20	-	1
9996	4800	-	1.4	1.4	-	1
12288	7900	1.9	1.7	1.80	0.10	1
14437	7700	-	1.3	1.3	-	1
18078	3800	2.8	2.4	2.60	0.20	1
22374	500	1.9	-	1.9	-	2
24712	2600	1.1	1.4	1.25	0.15	2
37776	35000	1.1	1.2	1.15	0.05	4
50169	4800	1.8	-	1.8	-	1
55719	6500	1.9	1.8	1.85	0.05	1
59435	3200	0.3	-	1.8	-	1
65339	12800	-	1.3	1.3	-	1
70331	12300	-	1.3	1.3	-	1
72968	2800	-	1.3	1.3	-	3
81009	8400	1.0	1.4	1.20	0.20	1
94660	6200	-	1.6	1.6	-	1
110066	4100	-	1.9	1.9	-	1
111133	3700	-	1.8	1.8	-	2
112185	330	-	2.8	2.8	-	9
112413	2900	1.4	1.1	1.25	0.15	5
115708	3850	1.0	1.0	1.0	0.00	6
116114	5900	1.3	1.6	1.45	0.15	1
116458	4700	-	1.9	1.9	-	1
118022	2900	-	1.7	1.7	-	2
119419	23000	1.2	1.1	1.15	0.05	6
126515	12300	1.3	-	1.3	-	1
134214	3100	0.8	-	0.8	-	1
137909	5500	1.8	1.2	1.50	0.30	1
137949	4700	1.5	1.1	1.30	0.20	1
147010	12000	-	1.1	1.1	-	9
165474	6500	-	1.4	1.4	-	1
166473	7600	-	1.2	1.2	-	1
175362	28000	1.0	1.2	1.1	0.10	7
176232	2100	1.6	1.9	1.75	0.15	2
187474	5000	-	1.5	1.5	-	1
188041	3700	-	1.2	1.2	-	1
191742	1800	2.8	2.1	2.45	0.35	2
192678	4700	-	1.6	1.6	-	2
196502	2000	-	2.5	2.5	-	2
201601	3800	1.0	1.4	1.2	0.20	1
204411	500	-	1.2	1.2	-	2
215441	34000	1.2	1.0	1.1	0.10	8
221568	1800	1.6	-	1.6	-	2

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2. Parameters

A sufficient number of measurements of the mean magnetic field B_s has now been obtained so that we can attempt a new statistical investigation of the functional relation between the magnetic field and the radius of the star. For the representation of the sample of 45 CP stars we use the commonly adopted parameters of the Stromgren photometric system, $uvby\beta$, the relation between the effective temperature $T_{\rm eff}$ and the surface gravity $\log g$, and the relative radii, $R/R_{\rm Z}$, with z indicating the position on the ZAMS in the Hertzsprung-Russell diagram.

In Table 1 stars are listed for which the mean surface magnetic field B_s and the values of the relative radii $R/R_{\rm Z}$ are known (Mathys, 1995). $R_{\rm Z}$ is the star's radius as it was on the ZAMS. The values $Q_{\rm Z}[{\rm G}] = R/R_{\rm Z}[{\rm G}]$ are the relative radii estimated from the absolute magnitudes $M_{\rm V}$ by *Hipparcos* parallaxes (Gomez et al., 1998), and the values of the relative radius $Q_{\rm Z}[\beta] = R/R_{\rm Z}[\beta]$ are derived from the β index. The relative radii are connected with $\log g$ by the relation:

$$\log g(R/R_{\rm Z}) = 0.5(\log g_{\rm Z} - \log g).$$

The application of the relative radii instead of $\log g$ is more descriptive for the star's position on the Hertzsprung-Russell diagram. In order to evaluate the magnitudes $M_{\rm b}$, the effective temperatures were taken from the list of Glagolevskij (2002). The magnitudes $R_{\rm Z}$ were estimated from $M_{\rm b}$ by means of the movement of the star along the evolutionary track on the HR diagram until the main sequence. The location of intersection with the ZAMS corresponds to the luminosity $M_{\rm b}$ of the star. As shown by Glagolevskij (2002), the mean errors of $R/R_{\rm Z}[{\rm G}]$ and $R/R_{\rm Z}[\beta]$ are of the same order $\pm\ 0^m.2$. The bolometric corrections were taken from a paper of Strayzis & Kuriliene (1981). In order to get an idea of the reliability of the estimates of the relative radii, we present a column with $\triangle$ values, which represent the difference between these values and the average ones. It is shown in the paper Glagolevskij (2002) that $\triangle$ strongly depends on the degree of chemical anomalies.

3. The relationship $B_s, R/R_{\rm Z}$

The relationship plotted from the data of Table 1 (Fig. 1) is characterized by the fact that four stars with extreme fields stand out, belonging obviously to different types of peculiarity. Despite the rather large scatter, we see that the magnetic field strength decreases with age. The magnetic field is supposed to appear on the ZAMS, and it undergoes no changes afterwards (Glagolevskij & Chuntonov, 2001). The dissipative decay takes a time of $\tau \sim 10^9$ - 10^{10} years, being essentially longer than the lifetime on the main sequence (Glagolevskij et al., 1987). It turned out to be $B_s = 20R^{-3}$ (solid line in Fig. 1). In order to find out how the observed magnetic field strengths depart from the assumed values, their differences $\triangle B_s$ were computed by the same values of $R/R_{\rm Z}$ as shown in the right panel of Fig. 1. For most of the stars, the field strength increases significantly up to $R/R_{\rm Z} = 1.3$, then the increase terminates and the points arrange themselves near the supposed relationship.

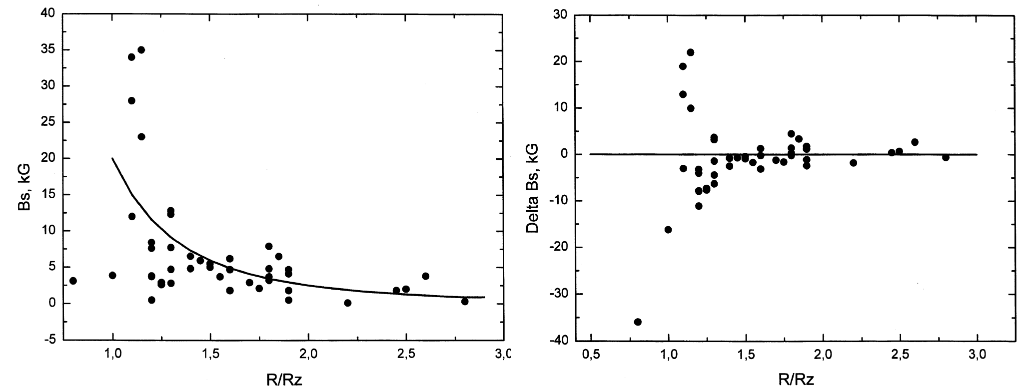

Figure 1. Left panel: the dependence of the mean surface magnetic field B_s on the relative stellar radius R/R_Z (see Table 1). Solid line: the cubic dependence B_s = const*R^{-3}. Right panel: differences between the mean magnetic field strength B_s and the cubic relation $1/R^{-3}$.

4. Conclusion

We made a statistical evaluation of the compiled data of the mean magnetic surface field, B_s, as a function of the relative radius, R/R_Z, of a sample of 45 CP stars. The change of magnetic field strength as the star evolves from the main sequence is most likely to be the result of two opposing tendencies: an initial gradual increase of the field after the star's setting on the ZAMS and a decrease as the result of a constant growth of the radius. This result confirms our earlier assumption (Glagolevskij et al., 1987) that the integral magnetic flow in CP stars does not change during their stay on the main sequence.

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