Bull. Spec. Astrophys. Obs., 58, 2005, 17-22

Variation of magnetic field of CP stars with age

Yu.V. Glagolevskij[a], **E. Gerth**[b]

[a] Special Astrophysical Observatory of the Russian AS, Nizhnij Arkhyz 369167, Russia, e-mail: glagol@sao.ru
[b] D-14471 Potsdam, Gontardstr. 130, Germany, e-mail: Ewald-Gerth@t-online.de

Received March 23, 2004; accepted June 2, 2004.

Using available data on the mean surface Bs magnetic fields of SrCrEu type CP stars, the change of Bs with age has been studied. Earlier assumptions are confirmed that the mean surface magnetic field of CP stars Bs changes in inverse proportion to the cube of evolutionary increasing radius, as it must be in the case of a dipolar field configuration. If additional sources of dissipation existed, the surface field would decrease faster. As time estimations of pure ohmic dissipation of the magnetic field give values much greater than the lifetime of stars on the main sequence, the presence of the cubic relation does not conflict with the assumption that the full magnetic flow will not change during the whole time the star stays on the main sequence, that the magnetic field decreases only owing to ohmic dissipation, and there are no other sources of its destruction such as differential rotation, meridional circulation, turbulence and others. Compared to the lifetime of SrCrEu type stars on the main sequence, the time of appearance of the field near ZAMS (**Z**ero **A**ge **M**ain **S**equence) is very short. Extrapolation of the mean relation of magnetic field change with age on ZAMS gives a mean field value of $Bs \approx 18$ kG.

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

1. Introduction

The study of the behavior of magnetic fields of chemically peculiar stars during their evolutionary movement across the main sequence band is of great importance for revealing the evolutionary features, in particular, conditions of conservation of magnetic fields and chemical anomalies with time. In (Glagolevskij 1988) we made an attempt to study the field change with time using root mean square values of effective magnetic field $< Be >= [\sum(Be_i^2 - \sigma_i^2)/n]^{1/2}$, first introduced in (Brown et al. 1981). It turned out, that in a first approximation the field decreases approximately as the square of evolutionary changing radius, although dipole field (to a first approximation the structure of magnetic fields of CP stars is dipole) must change in inverse proportion to the cubic radius. This result had to be checked. It is interesting that the mentioned relation gets its maximum after the stars are already away from initial main sequence and are close to the band, occupied by the stars of luminosity class V. The same relation 'magnetic field $< Be >$ – age' was constructed for CP stars of all types. Later, in (Glagolevskij, Chountonov 1998) we attempted to construct such relations for the main four types of CP stars separately. Despite the obvious shortage of data, to a first approximation, we could state that magnetic field of He-rich stars increases during the whole time they are on the main sequence, and starts to drop only at the end. The field of He-weak stars first increases, close to the band occupied by the stars of luminosity class V reaches its maximum and then decreases. The field of Si and SrCrEu type stars is also seen to decrease, but no initial increase and maximum are noticeable. Thus, the field decrease at radius evolutionary increase is surely apparent for stars of all types, so the initial increase may be assumed. Apparently, chemical anomalies behave in the same way (Glagolevskij, Chountonov 2001; Leushin et al. 2000). At first the degree of chemical anomalies increases, having achieved maximum in the middle of the main sequence band, and then it begins to decrease. The $< Be >$ magnetic field root mean square values only approximately characterize the magnitude of the star magnetic field, mainly because they depend on the star orientation relative to the observer. In such an investigation it would be best to use the mean surface magnetic field Bs. By now a great number of Bs measurements have been accumulated, and in this paper we try to use them for more accurate definition of the relation being studied.

2. Parameters

In Table 2 are presented the stars for which the values of the mean surface magnetic fields *Bs* and relative *R/Rz* radii values are known. *R* is the star radius at present, and *Rz* is its radius while it was on the initial main sequence (ZAMS). *R/Rz*(G) are relative radii, estimated by absolute values from (Gomez et al. 1998), which were defined by Hipparcos parallaxes. We defined the values of $R/Rz(\beta)$ using the multicolor photometry parameter β. Relative radii are connected to *lgg* by the following relation

$$lg(R/Rz) = 0.5(lgg(\mathrm{ZAMS}) - lgg),$$

it is obtained from two known formulae

$$lgg = lgm + 4lgT_e + 0.4M_b - 12.49,$$

$$lgR/R_\odot = 8.46 - 2lgT_e - 0.2M_b,$$

where for the Sun T_e= 5780 K, lg g= 4.44, M_b = +4.72, m is the star mass, M_b is its bolometric magnitude.

The usage of relative radii instead of *lgg* gives a more obvious idea regarding the star location on Hertzsprung-Russel diagram and a more accurate relation for the star radius.

To estimate absolute values of M_b the effective temperatures were taken from the catalog by Glagolevskij (2002). For some stars there are no temperatures in this catalog, therefore we estimated them over again by the same calibration, they are given in Table 1. Values *Rz* were estimated from M_b and by means of star initial position shift along the evolutional track on Hertzsprung-Russel diagram down to ZAMS. The point of intersection with ZAMS corresponds to M_b of the star on it. As is shown in (Glagolevskij 2002), the mean errors of *R/Rz*(G) and $R/Rz(\beta)$ values are of the same order, $\pm0\overset{m}{.}2$. Bolometric corrections were taken from (Strayzis, Kuriliene 1981). In the upper part of the main sequence band there exists some uncertainty in the star position relative to the track, but such stars are very few and their impact on the relation is very insignificant. To get a rough idea about the reliability of relative radii estimates in two different ways, we introduced a column in Table 2 containing values of Δ, which are deviations of both values from the mean value. It is clear that mainly they are not large. It is shown in (Glagolevskij 2002) that Δ notably depends on the degree of chemical anomalies. An important point is that mean surface magnetic fields Bs are basically known only for SrCrEu type stars (Table 2). Therefore, all further conclusions will concern only stars of the mentioned type.

Table 1: *Magnetic stars temperatures*

HD	Te, K	HD	Te, K
29578	10100	134214	11200
59435	9900	142070	9800
61468	10200	165474	10000
70331	14300	166473	11300
75445	10500	335238	9800
93507	81010	200311	13500
116114	9900	208217	10700
116458	10100	216018	7400*
119419	11000		

*) Hubrig et al. (2000)

3. Dependence of Bs on R/Rz

The dependence plotted from Table 2 data is presented in Fig. 1A. It is characterized by the fact that near ZAMS a significant dispersion of points is observed, and three stars having extremely strong fields are sharply distinguished. These stars — HD 119419, 175362, 215441 — are of different types of peculiarity. One can see also decrease of the field with age, although scatter of points is rather wide and we can consider only a tendency to gradual taper of the field. As mentioned above, and it is seen in the figure, magnetic field, probably, appears on surface close to the place where stars approach ZAMS after Herbig Ae/Be evolution stage. If the total flux undergoes no losses, but for ohmic dissipation (Glagolevskij, Chountonov 2001), then the mean surface magnetic field must decrease with time as a result of radius evolutionary increase in proportion to R^{-3}, if it has a dipole structure.

Under the conditions of such an ionization degree as inside stars, the ohmic dissipation time is $\tau \sim 10^9$–10^{10} years, i.e. significantly longer than the lifetime on the main sequence (Glagolevskij et al. 1987).

We have fitted the assumed cubic relation so that it is as close as possible to the observed values. It turned out to be the following: $B_s(\mathrm{mean}) = 18{\cdot}R^{-3}$, and in Fig. 1A it is drawn with a solid line. To find out how the observed values deviate from the guess ones, their differences were calculated: $\Delta Bs = Bs - Bs(\mathrm{mean})$ for the same *R/Rz,* which are presented in Fig. 1B. Three extreme stars are situated detachedly. On average, the points are located symmetrically along the median line. Thus, we can suppose that there is no contradiction with the assumption that Bs is proportional to R^{-3}. At first, this assumption is in conflict with location of the three extreme stars and group of stars below the median

Table 2: *Parameters of stars with known mean surface magnetic field Bs*

HD	Bs	R/Rz(G)	$R/Rz(\beta)$	R/Rz(mean)	Δ	Source of Bs	Type
2453	3700	1.5	1.6	1.55	0.05	1	SrCrEu
5797	1800	1.9	-	1.9	-	2	SrCrEu
8441	100	2.1	2.3	2.20	0.10	2	SrCrEu
9996	4800	-	1.4	1.4	-	1	SrCrEu
12288	7900	1.9	1.7	1.80	0.10	1	SrCrEu
14437	7700	-	1.3	1.3	-	1	SrCrEu
18078	3800	2.8	2.4	2.60	0.20	1	SrCrEu
22374	500	1.9	-	1.9	-	2	SrCrEu
24712	2600	1.1	1.4	1.25	0.15	2	SrCrEu
29578	2700	1.6	-	1.6	-	1	SrCrEu
50169	4800	1.8	-	1.8	-	1	SrCrEu
55719	6500	1.9	1.8	1.85	0.05	1	SrCrEu
59435	3200	-	1.7	1.7	-	1	SrCrEu
61468	7100	1.2	-	1.2	-	1	SrCrEu
65339	12800	-	1.3	1.3	-	1	SrCrEu
70331	12300	-	1.1	1.1	-	1	Si
72968	2800	-	1.3	1.3	-	3	SrCrEu
75445	2990	1.2	-	1.2	-	1	SrCrEu
81009	8400	1.0	1.4	1.20	0.20	1	SrCrEu
93507	7250	1.8	-	1.8	-	1	Si+
94660	6200	-	1.6	1.6	-	1	Si+
110066	4100	-	1.1	1.1	-	1	SrCrEu
111133	3700	-	1.8	1.8	-	2	SrCrEu
112185	330	-	1.5	1.5	-	9	SrCrEu
112413	2900	1.4	1.1	1.25	0.15	5	SrCrEu
115708	3850	1.3	1.2	1.25	0.05	6	SrCrEu
116114	5900	1.3	1.6	1.45	0.15	1	SrCrEu
116458	4700	-	1.9	1.9	-	1	Si
118022	2900	-	1.7	1.7	-	2	SrCrEu
119419	23000	1.2	1.1	1.15	0.05	6	Si+
126515	12300	1.3	-	1.3	-	1	SrCrEu
134214	3100	-	0.8	0.8	-	1	SrCrEu
137909	5500	1.8	1.2	1.50	0.30	1	He-w
137949	4700	1.5	1.1	1.30	0.20	1	SrCrEu
142070	4930	-	1.7	1.7	-	1	SrCrEu
147010	12000	1.0	1.0	1.0	0.00	9	Si+
165474	6500	-	1.4	1.4	-	1	SrCrEu
166473	7600	-	1.2	1.2	-	1	SrCrEu
175362	28000	1.0	1.2	1.1	0.10	7	He-w
176232	2100	1.6	1.9	1.75	0.15	2	SrCrEu
187474	5000	-	1.5	1.5	-	1	Si+
188041	3700	-	1.2	1.2	-	1	SrCrEu
191742	1800	2.8	2.1	2.45	0.35	2	SrCrEu
192678	4700	-	1.6	1.6	-	2	SrCrEu
196502	2000	-	2.5	2.5	-	2	SrCrEu
335238	9880	1.8	-	1.8	-	1	SrCrEu
200311	8760	1.3	1.4	1.35	0.05	1	Si+
201601	3800	1.0	1.4	1.2	0.20	1	SrCrEu
204411	500	-	1.2	1.2	-	2	Si
208217	7900	1.4	-	1.4	-	1	Si
215441	34000	1.2	1.0	1.1	0.10	8	Si
216018	5660	1.3	-	1.3	-	1	SrCrEu
221568	1800	1.6	-	1.6	-	2	SrCrEu

References to Bs

1. Mathys et al. (1997)
2. Preston (1971)
3. Romanyuk (2000)
4. Glagolevskij, Gerth (2001)
5. Glagolevskij et al. (1985)
6. Glagolevskij (2001)
7. Mathys (1997)
8. Borra, Landstreet (1978)
9. Glagolevskij (1998)

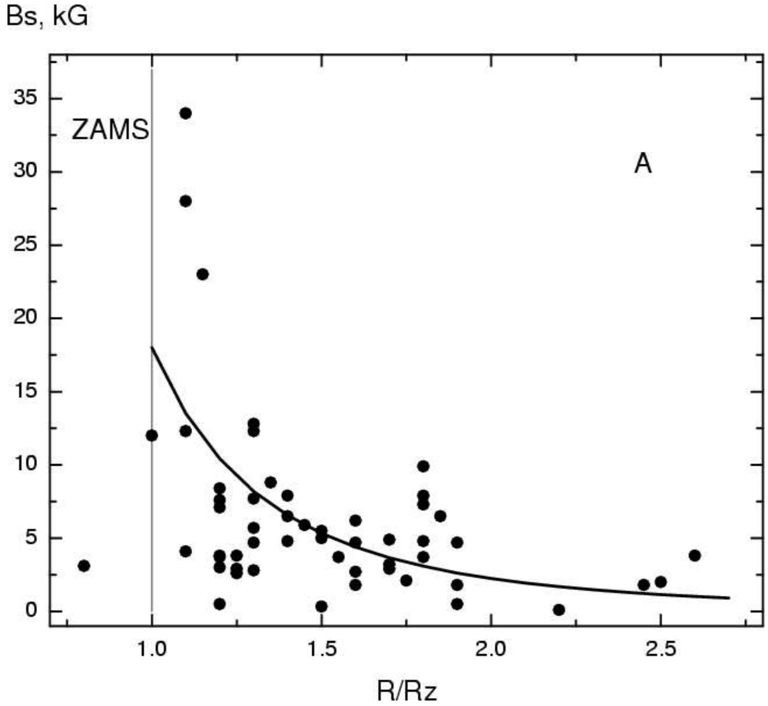

Figure 1: *A — relation between the mean surface magnetic field of CP stars and their relative radius R/Rz.*

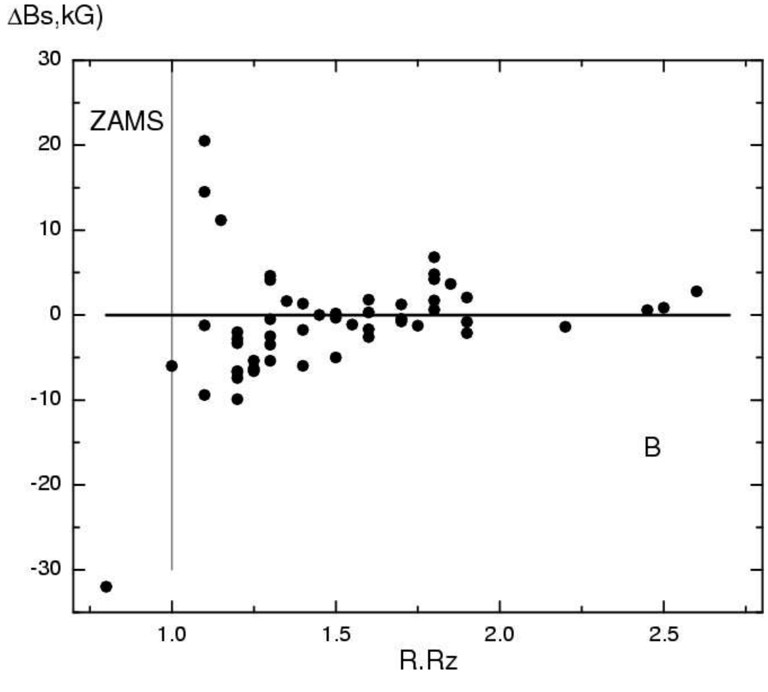

Figure 1: *B – relation between the deviations $\Delta Bs = Bs - Bs(mean)$ and the relative radii R/Rz.*

line. For clarification of this contradiction we plotted a relationship between Bs/Bs(mean) and R/Rz (Fig. 1C). It is obvious that the relative dispersion of points is the same within all the range. Consequently, strong fields of stars located near ZAMS are not an exception. It is seen from Table 2 that these relations are plotted basically for SrCrEu type stars, so conclusions of this paper are related to these stars mainly. In our papers (Glagolevskij, Chountonov 1998, Leushin et al. 2000) it is shown that surface field decrease with

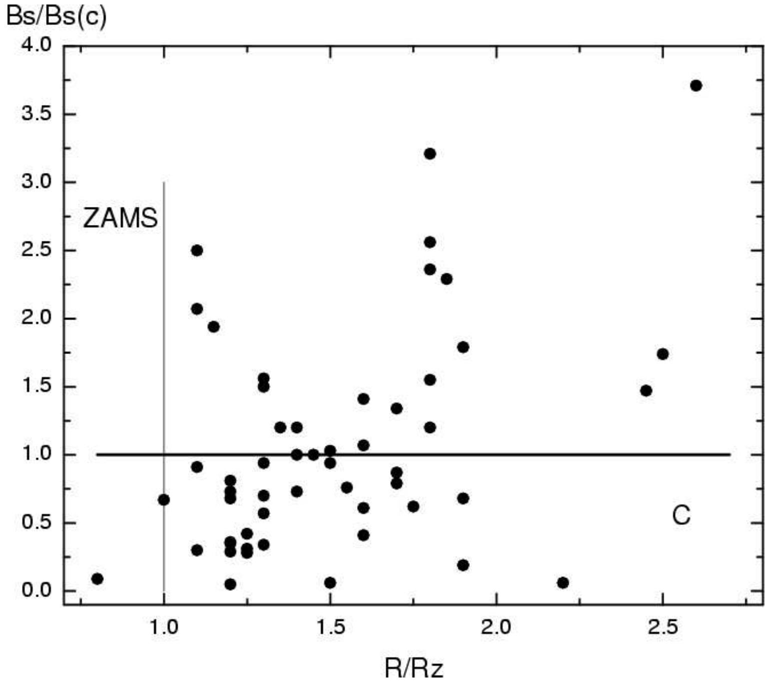

Figure 1: *C – relation between the relative values $Bs/B(mean)$ and the relative radii R/Rz.*

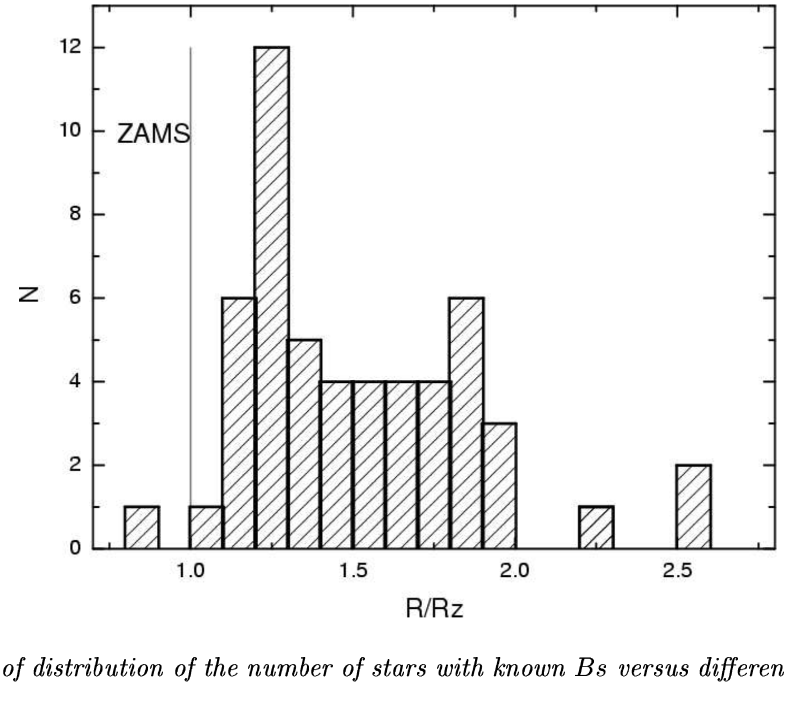

Figure 2: *Histogram of distribution of the number of stars with known Bs versus different relative radii R/Rz.*

age takes place also for stars of other types and that field growth for the He-r and He-w type stars close to ZAMS surely takes place. For the SrCrEu type stars the field growth phase is not observable because of a very short time (presumably 10^6 years) in comparison with the lifetime on the main sequence. That is why it is unnoticeable.

Thus, the change of the magnetic field of CP stars during their evolution on the main sequence, obviously, occurs as a result of radius evolutionary increase. Unfortunately, in consequence of the observational selection there are very few stars near $R/Rz > 2.5$. Stars are considered to be of CP type only when anomalies are strongly pronounced. While locating near ZAMS, when the field and anomalies are weak and still growing, such CP stars are difficult to classify, and the study of this period is inconvenient.

Extrapolation of the obtained mean cubic relation on ZAMS shows that the mean magnetic field of magnetic stars on the initial main sequence must be $B_s \approx 18$ kG on average. This property needs further discussion. As it has already been mentioned, the change of the mean squared field $< Be >$ with age (Glagolevskij 1988) takes place in inverse proportion to the star squared radius. The distinction from the relation for Bs probably occurs because the mean squared field depends on the star orientation relative to the observer, and relation is "blurred" because of the great scattering of points. The check-up of other $Bs \sim R^{-2}$ and $Bs \sim R^{-4}$ dependences show their strong asymmetry (Figs. 1B and 1C). This testifies that the relationships of this kind do not conform to the observational data.

4. Conclusion

The usage of more accurate material than before, allowed obtaining data, confirming the preliminary conclusion made earlier (Glagolevskij 1988) that mean surface magnetic field of CP stars decreases in inverse proportion to the cubic radius, as it is expected in case of dipole field configuration. Since the estimation of duration of pure ohmic dissipation of magnetic field gives values much higher than the lifetime of stars on the main sequence, then the existence of cubic relation does not contradict the assumption that the total magnetic flux does not change during the whole time while the star is on the main sequence and that the magnetic field decreases only as a result of ohmic dissipation, and there are no other sources of its destruction such as differential rotation, meridian circulation, turbulence, etc. In case additional dissipation sources existed, the surface field would decrease faster. The star atmosphere is so stable that conditions of chemical elements diffusion, resulting in chemical anomalies, occur.

Because of the data shortage, we could not obtain clear information regarding magnetic field behavior near the initial main sequence. The left boundary of the considered relations is quite sharply defined, which is evidence that the magnetic field appears during a short time in comparison with the lifetime on the main sequence. This can also be well seen on the histogram of the number of stars versus R/Rz, presented in Fig. 2.

Extrapolation of Bs mean relation to zero age line shows that during the period of approach of magnetic stars to the main sequence, the star magnetic field has an average value of 18 kG.

Acknowledgements. The paper is carried out with support of "Astronomy" grant.

References

Borra E.F., Landstreet J.D., 1978, ApJ, **222**, 226

Brown D.N., Landstreet J.D., Thompson I., 1981, Comm. 23-d Coll., Liege, 195

Glagolevskij Yu.V., Piskunov N.E., Khokhlova V.L., 1985, Pis'ma Astron. Zh., **11**, 371

Glagolevskij Yu.V., Klochkova V.G., Kopylov I.M, 1987, AJ, **64**, 360

Glagolevskij Yu.V., 1988, in: "Magnetic stars", eds.: Yu.V. Glagolevskij, I.I.Romanyuk, Leningrad, Nauka, 206

Glagolevskij Yu.V., Chountonov G.A., 1998, Bull. Spec. Astrophys. Obs., **45**, 105

Glagolevskij Yu.V., 1998, Bull. Spec. Astrophys. Obs., **46**, 123

Glagolevskij Yu.V., 2001, Astrophysics, **44**, 121

Glagolevskij Yu.V., Chountonov G.A., 2001, Bull. Spec. Astrophys. Obs., **51**, 88

Glagolevskij Yu.V., Gerth E., 2001, in: "Magnetic fields across the HR diagram", ASP Conf. Ser., eds: Mathys G., Solanki S.K., Wickramasinghe D.T., **248**, 337

Glagolevskij Yu.V., 2002, Bull. Spec. Astrophys. Obs., **53**, 33

Gomez A.E., Luri X., Grenier S., Figureas F., North P., Royer F., Torra J., Mennessier M.O., 1998, A&A, **336**, 953

Hubrig S.,North P., Mathys G., 2000, ApJ, **539**, 352

Leushin V.V., Glagolevskij Yu.V., North P., 2000, in: "Magnetic fields of chemically peculiar and related stars", eds.: Yu.V.Glagolevskij, I.I.Romanyuk, Moscow, 2000, 173.

Mathys G., Hubrig S., Landstreet J.D., Lanz T., Manfroid J., 1997, A&AS, **123**, 353

Mathys G., 1997, A&AS, **124**, 475

Preston G., 1971, ApJ, **164**, 309

Romanyuk I.I., 2000, in: "Magnetic fields of chemically peculiar and related stars", eds.: Glagolevskij Yu.V., Romanyuk I.I., Moscow, 18

Strayzis V.L., Kuriliene G., 1981, Astrophys. Space Sci., **80**, 353