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Magnetic field of CP stars. Observational aspects

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Abstract.

Observed parameters of magnetic CP stars are discussed. The extreme value of the longitudinal component B_{extr} is shown to reflect adequately the real field on the surface of the star B_s, linear relationship between these parameters is found. Magnetic field models are presented for 90 well understood MCP stars, their comparative analysis is made.

It is shown that for 24 stars from the list of Landstreet and Mathys (2000) contributions of octupole component, responsible in the models of these authors for the contrast in the surface magnetic field strength between the magnetic poles and equator, differ depending on the rotational velocity. For 17 single fast rotators the magnetic field increases towards the poles in comparison with dipolar field, while for the slow rotators the indicated contrast is less than the dipolar. Such an effect is not noticed for binary stars.

Relationship between rotational velocity, temperature and magnetic field for different groups of CP stars are found. The photometric indices describing the anomalies of the continuum are shown to increase inside rather narrow temperature intervals with increasing period in each of them. The magnetic field reaches the greatest value in stars with rotational periods from 5 to 10 days.

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

1 Introduction

The General catalog of CP stars (Renson et al. 1991) contains 6700 objects, mainly brighter than 11^m. Half of them are Am stars, the discovery of magnetic field in their atmospheres is questionable yet.

Approximately 3000 CP stars are classified as He-strong, He-weak, Si, Si+, and SrCrEu. It is very likely that all these stars are magnetic, but really magnetic field measurements were made only for a few hundred of them. In general, the frequency of CP stars is about 15% of all Main Sequence stars with spectrall classes from B2 to F0 (Romanyuk and Kudryavtsev 2000).

To search for properties of magnetic field of CP stars, we need to collect all possible data on them. The first catalog of magnetic stars was published by Babcock (1958), it contains the result of his own measurements.

Didelon (1983) collected a catalog of magnetic measurements. It consists of Babcock's catalog and magnetic measurements of other authors (mainly Landstreet and his co-authors) made from 1958 to 1982. Photographic and photoelectric techniques were used.

Over the last two decades a large number of new magnetic measurements have been made. CCD and other digital multichannel devices were used. Earlier it was possible to measure only the simple Zeeman shift (or circular polarization) and then to calculate magnetic field using simple Babcock's (1958) formulae, the modern technique permits searching for the distribution of polarization over the line profile. Different new facilities for field caclulation (e.g. moments method of Mathys (1989) or Zeeman-Doppler Imaging (e.g. Vasilchenko et al. (1996), Piskunov (2001)) were applied.

We collected our measurements and all possible data from literature in a catalog of magnetic CP stars (Romanyuk 2000). Magnetic field strength derived by different techniques may essentially differ. If it was possible, we used the so-called photographic technique for our own field determination for comparison of our and earlier measurements.

Babcock found 67 magnetic stars: his famous catalogue contains 89 stars, after that he found HD 215441, a star with a 35 kG surface field. But no magnetic field of about 20 stars (Am, RR Lyr) was confirmed in later investigations.

After Babcock more than 170 new magnetic CP stars have been found and more than 130 of them were discovered by John Landstreet and his colleagues: (E. Borra, I. Thompson, D. Bohlender, G. Wade and others), by G. Mathys and his colleagues (S. Hubrig and others) and by the SAO group: (Yu.V. Glagolevskij, I.I. Romanyuk, V.D. Bychkov, V.G. Elkin, D.O. Kudryavtsev and others).

Every year 4 new magnetic stars on average were discovered, for the last few years the frequency of discovery has increased. During the past 4 years about 30 new magnetic stars have been found.

The main difficulties are clear: magnetic field can be measured only from high resolution spectra, obtained with large telescopes using a Zeeman analyzer. Zeeman observations are relatively rare because it is very difficult to get a sufficient number of nights, taking into account high pressure for observing time at the largest telescopes.

For effective search for new magnetic stars one needs to find reliable indicators of magnetic field presence. Most of them are connected with anomalies in energy distribution in the continuum. Since the papers of Glagolevskij (1966) and Kodaira (1969) were written, specific depressions of the continuum and Balmer jump have become known. These anomalies can be described using photometric indices Δa (Maitzen 1976), z-parameter of the Geneva system (Cramer and Maeder 1980), the detail in the shape of the depression near 5200 Å and others.

2 Main statistics

Let us consider general properties of magnetic CP stars. We will discuss only 240 stars from our catalog (Romanyuk 2000) with magnetic field actually found.

Now, using modern technique, we can search for magnetic field in stars by 2–3 magnitudes fainter than before. Passing from the 6th to the 9th magnitude stars permits in general increasing the distances to magnetic stars reachable for observations from 100–200 pc to 500–600 pc. We studied before only CP stars from the nearest neighborhood of the Sun, now we can start searching for properties of magnetic stars and their possible relation with the structure of the magnetic field of our part of the Galaxy.

The hottest magnetic star is the He-strong star HD 64740 with $T_e = 24100$ K, absolute magnitude $M_V = -2.4$, and radius $R = 5.8 R_\odot$. The coolest is very peculiar Przibilsky star HD 101065, $T_e = 6075$ K, $B-V = +0.767$.

In general — the coolest are a group of roAp stars, for example, HD 24712: $B-V = +0.323$, $T_e = 7360$ K, $M_V = 2.4$, $R = 1.6 R_\odot$. Practically all CP stars have the B–V color from –0.2 to +0.3,

2.1 $B_e - B_s$ relation

Direct measurement of magnetic field on the star surface is possible only with using split Zeeman components. In practice, this is possible for stars with very sharp lines and strong magnetic fields.

By now the surface field B_s have been measured in about 50 magnetic stars, information on magnetic fields of the other 190 CP stars has been derived from the determinations of the longitudinal field B_e.

It is interesting to see how the value reflects the actual magnetic field on the star's surface. As a value for comparison, we will get the extrema of the longitudinal field B_{extr}. It corresponds to the moment of observation when the longitudinal component of the magnetic field is closest by the field strength to the surface field B_s. It is possible to determine B_{extr} in stars with known rotation period provided that a sufficient number of measurements were performed, and it is possible to fit the B_e curve.

We found in our catalog 39 magnetic CP stars for which it was possible to determine simultaneously B_s and B_{extr}. The result of comparison of these values is presented in Fig. 1.

We have a linear relationship between the values:

$$B_s = 1013 + 3.16 \cdot B_{extr} \quad (G). \tag{1}$$

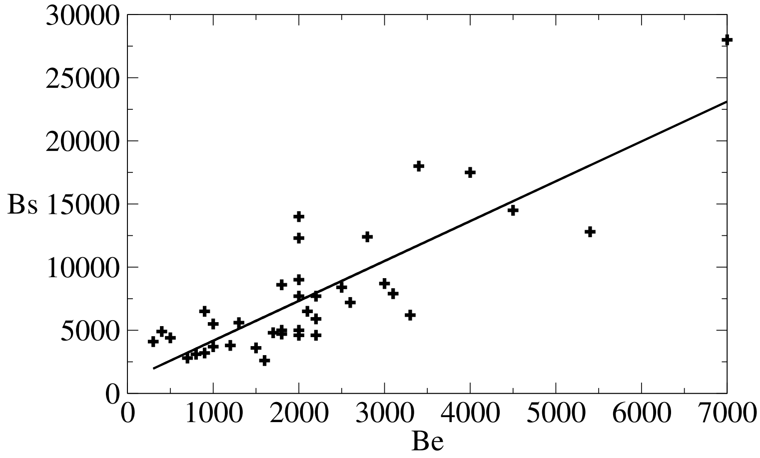

Figure 1. *Relation between the maximum value of the longitudinal field B_{extr} and surface field B_s.*

The correlation cofficient is 0.83.

It is evident that the extrema of the longitudinal component is a good indicator of the real field on the surface and can be used for statistical search for magnetic fields. The high correlation cofficients demonstrate reliability of our conclusion.

2.2 Correlation between the maximum value of the longitudinal field B_{extr} and B_d

On the basis of the information collected in our catalog we listed in (Table 1) the following data: the name of the star, extremum longitudinal field B_{extr}, measured value of the surface field B_s, and calculated from models: B_d (field on the poles of the dipole), B_q (quadrupole) and B_{oct} (octupole); r — $B_e(min)/B_e(max)$; i — angle between the rotation axis and the line of sight; B_p — polar field, can be considered as B_d. B_p is determined in simple models with a central or decentered dipole. More complex models suppose dividing into dipole, quadrupole and octupole components.

Here we are interested in correlation between the magnitudes of B_{extr} and B_d. Three stars (HD 32633, HD 37776, HD 133880) whose field quadrupole component is apparently greater than the dipolar are excluded from consideration. Finally, we have 38 objects for which both B_{extr} and B_d are known.

The empirical relationship between these magnitudes is described by the formula:

$$B_d = 2676 + 3.17297 \cdot B_{extr} \quad (G), \tag{2}$$

the correlation coefficient is 0.945. The very high correlation coefficient points to a complete agreement (with minor scatter) between the actually measured value of the extreme longitudinal field and the model strength of the field at the pole of the dipole.

Moreover, the obliquing factor of the straight line ($k = 3.17$) in formula (2) is practically the same as in the relation $B_e - B_s$ ($k = 3.16$, formula (1)).

This suggests that B_d (the field at the pole of the magnetic dipole) is nearly completely defined by parameters of the curve of B_e.

2.3 Results of modeling

The basic data on the magnetic fields of CP stars were obtained from the measured longitudinal component B_e with the aid of the circular polarization analyzer. However, observations of variability of B_e are insufficient to obtain a single set of parameters even for the geometry of the field being so simple as that of inclined dipole. From observations of B_e one can obtain two significant parameters: maximum and minimum of the longitudinal component or the mean and half-amplitude of the sinusoidal variations. At the same time, the simplest model requires three parameters: angles i and β and the value of the field B_p at the pole of the dipole. Thus, no unique model can be developed without data independent of i.

Table 1. Magnetic field parameters for well-studied MCP stars

Star	B_{ext}	B_s	B_d	B_q	B_{oct}	r	i	β	B_p
HD 2453	−710	3730	−5000	−600	1800	0.45	62	11	–
HD 4778	+1400	–	–	–	–	−0.77	57	79	4800
HD 5737	+500	–	–	–	–	−0.86	90	90	–
HD 9996	−1200	4800	–	–	–	–	–	–	–
HD 10783	+1800	–	–	–	–	–	–	–	10000
HD 11503	−900	–	–	–	–	−0.45	47	68	3000
HD 12288	−3100	7900	−10100	−2800	4200	0.07	119	21	11800
HD 12447	−500	–	–	–	–	−0.80	47	69	2000
HD 14437	−2600	7700	−10300	1600	6300	0.20	115	14	13500
HD 19832	+380	–	–	–	–	−0.90	74	80	1200
HD 22316	−2200	12000?	–	–	–	−0.30	15	–	–
HD 24155	+1660	–	–	–	–	−0.20	80	15	–
HD 24712	+1400			models are very different					
HD 32633	−4300		complex curve of B_e			−0.33	77	24	23000
HD 34452	+1000	–				−0.33	$90-26$	55	
HD 36485	−3800	–	–	–	–	0.80			9000
HD 37017	−2200	–	–	–	–	0.20	42	39	
HD 37776	−2200	60000	2000	−53000	48000	–	–	–	100000
HD 40312	+360	–	–	–	–	−0.67	77	51	1300
HD 49333	+800	–				−0.79	$90-24$	75	
HD 49976	+2200	–	–	–	–	−0.70	42	48	–
HD 50169	+2000	5000	–	–	–	–	–	–	–
HD 51684	−1800	6000	−7300	−2200	2500	0.38	42	18	–
HD 54118						−0.94	–	81	
HD 55719	+2100	6500		crossover=+5955, quadratic field=12041					
HD 58260	+2600	–	–	–	–	–	4	80	8000
HD 59435	+1000	3200	–	–	–	–	–	–	–
HD 61468	−2500	7300	−7400	−4100	−1000	0.38	49	19	
HD 62140	+3200		complex curve B_e			–	90	95	–
HD 64740	−800	–	–	–	–	–	57	12	–
HD 65339	−5400	16000	−16700	−11200	5700	−0.92	50	86	28000
HD 70331	−2800	13000	−15300	26500	−3600	0.93	5	69	–
HD 71866	−2000			complex curve of B_e					
HD 81009	+2500	8400	7400	7200	2200	0.64	48	11	–
HD 92664	−1300	–	–	–	–	0.10	$80-19$	41	–
HD 93507	+2600	7200	10900	−3700	−3400	0.41	55	19	–
HD 94660	−3300	6200	−8400	2700	6900	0.90	47	5	–
HD 96446	−2100	–	–	–	–	0.70	< 3	> 60	–
HD 98088	−1200	8000?		–		–	–	–	–
HD 110066	+300	4000	–	–	–	–	–	–	–
HD 111133	−1500								
HD 112185	+120		–	–	–	–	–	–	250
HD 112381	−3700	–	–	–	–	0.80	–	10	–
HD 112413	+1600		large number of models			−0.80	60	30	–
HD 115708	−1500	–	–	–	–	−0.60	130	77	–
HD 116114	−2200	6000	−9000	1100	600	0.92	56	2	–
HD 116458	−2100	4600	−7600	2600	400	0.68	52	10	

Star	B_{ext}	B_s	B_d	B_q	B_{oct}	r	i	β	B_p
HD 118022	−1800	–	–	–	–	0.90	14	71	5000
HD 119213	+1500	–	–	–	–	−0.12	–	45	–
HD 119419	−4200		unharmonic curve, complex models						
HD 122532	−900		simple sinusoidal curve						
HD 124224	+800	–	–	–	–	−0.50	26	82	4500
HD 125248	+2800	–	–	–	–	−0.80	79	74	9000
HD 125823	−450	–	–	–	–	−0.90	90	>20	–
HD 126515	−2000	12300	−13700	−17700	−5200	−0.69	78	20	–
HD 133029	+3300	–	–	–	–	0.30	22	22	13000
HD 133652	−2100		simple sinusoidal curve						
HD 133880	−4400		quadrupolar component larger than dipolar						
HD 134214	−600	3100	–	–			–	–	–
HD 137509	+2200	large quadratic field $Q_0=29892$, $Q_1=3514$, $Q_2=1978$							
HD 137909	+1000	5500	−8700	−1400	−600	−0.60	15	85	–
HD 137949	+1900	4600	–	–	–	–	–	–	–
HD 142070	+600	4900	4900	1300	2300	−0.27	9	83	–
HD 142301	−4100	–	–	–	–	−0.30	30	80	–
HD 142990	−2500	–	–	–	–	−0.24	30	78	–
HD 144897	+2000	9000	11000	−12900	−4900	0.60	65	12	–
HD 147010	−5000	–	–	–	–	0.60	>25	<65	–
HD 148112	−250	–	–	–	–	0.50	33	37	800
HD 148199	+1400	–	–	–	–	−0.60	–	–	–
HD 152107	+2000	–	–	–	–	0.25	38	14	2900
HD 153882	+3100	–	–	–	–	−0.65	60	80	–
HD 165474	+900	6500	–	–	–	−0.12	–	–	–
HD 166473	−2200	7700	−9400	−5700	1100	−1.00	87	35	–
HD 168733	−1000		quadratic field 3.7 kG						
HD 170000	+640	–	–	–	–	−0.25	81	18	4800
HD 175362	+7000	–	–	–	–	−0.80	27	83	28000
HD 178892	+8500	–	–	–	–	0.20	–	–	–
HD 343872	+4100	–	–	–	–	−0.20	–	–	–
HD 184927	+1800	–	–	–	–	−0.36	25	78	–
HD 187474	+1800	5000	−7700	−1600	1000	−1.00	86	45	–
HD 188041	+1500	3600	5600	−1200	−1000	0.38	70	10	–
HD 192678	+1800	4800	4900	1300	2300	1.0	4	32	6800
HD 196502	−700	–	$H_0=0.12$ kG, $H_1=-0.77$ kG, $H_2=-0.16$ kG						
HD 335238	−3100	8700	–	–	–	–	–	–	–
HD 200311	−1800	8600	12800	3800	800	−0.98	88	24	–
HD 201601	−1100	3800	–	–	–	–	–	–	–
HD 208217	−1800	8000	−13100	6000	−5000	−0.44	15	86	–
HD 215441	+20000	34000	62400	42000	24200	−0.53	30	30	–
HD 217833	−5500		$B_o=-3.78$ kG, $B_1=1.70$ kG , $\varphi=0.74$						
HD 318107	+4000	14300	23700	−23600	8300	0.26	11	78	–

Sometimes, when the radius R of a star (in units of solar radii) and its rotation period P (in days) are measured with sufficient accuracy one can find in an independent manner angle i from the following equation:

$$v_e = \frac{50.6R}{P} \quad (km/s). \tag{3}$$

In practice, it can be done when $v \sin i$ exceeds 10 km/s. If lines are narrow (less than a few km/s), it becomes possible to observe their splitting into $\pi-$ and $\sigma-$components. It is proportional to the local modulus of the field B_s averaged over the entire visible surface. For wider lines, one can detect the effect of broadening of line profiles and deduce qualitatively different parameters.

At the present time, different approaches are employed in modeling magnetic fields of stars. Here we briefly note that it is performed by methods of solution of a direct or inverse problem.

The programs of J. Landstreet can serve as an example of solution of the direct problem: by giving information about angles i and β and values B_d, B_q and B_{oct} in a three-dimensional axially symmetric multipolar expansion and by taking correct account of the contribution of different parts of the visible stellar surface, one can directly calculate integral field moments (B_e, B_s and others) observed as a function of phase. In the paper by Landstreet (1980) it was shown that in order to describe the situation where one magnetic pole is stronger than the other, a quadrupole component is needed in addition to a dipole. Subsequently, the modeling of real profiles of lines (Landstreet 1988; Landstreet et al. 1989) showed that an octopolar component is also required: a simple dipole gives a too great difference in field strength between the poles and equator as compared to observations.

By using this approach, Landstreet and Mathys (2000) made the important inferences suggesting that the inclination angle β between the dipole and rotation axes in slow rotators is small. Bagnulo et al. (2002) confirmed this idea by a larger sample of observed stars and models with a decentered dipole and non-axially symmetric dipole and quadrupole of any orientation.

On the other hand, an alternative modeling found development: on the basis of data on the local value of the magnetic field vector and chemical composition to clarify the magnetic configuration and produce maps of distribution of chemical composition over the surface. To solve this inverse problem, which refers to the class of improperly posed problems, the Doppler-Zeeman mapping method is used. We will note a great contribution made by V. L. Khokhlova and N. E. Piskunov to the development of the mentioned field of research. The results of the latest work of N. E. Piskunov and his colleagues show that there exists considerable deviation from a dipolar field (Kochukhov et al. 2004).

In the present paper a comparative analysis of the magnetic field configuration of fast and slow rotating CP stars is made on the basis of our observations and literature data.

For slow rotators an attempt can be made to find the Zeeman component splitting and thus the surface field B_s modulus together with measurement of the longitudinal field B_e. Given information on the variability of these magnitudes with phase of the rotational period of a star, a model of its magnetic field can be derived. If one manages to determine angle i in an independent manner, it will permit one to construct a unique model of the magnetic field of a CP star wihout knowing the B_s value.

John Landstreet kindly placed at our disposal his program (Landstreet 1988) of modeling magnetic fields, in which data on the curves of the longitudinal and surface magnetic fields are used as initial data. We applied it to estimating the geometry of magnetic fields in slow rotators for the cases where there were no models constructed by other authors.

A completely adequate procedure is based on the inversion of all four Stokes profiles. This is ZDI: Zeeman Doppler Imaging (Piskunov and Kochukhov 2002). However, only some stars were simulated in this way (Kochukhov et al. 2002, Kochukhov et al. 2004). To fulfil such work, high precision data with a good S/N and phase coverage are needed to make a statistically suitable analysis of ZDI data. A similar program has been conducted at the 6 m telescope for the past few years.

We have to wait for the results of this work, and now we will discuss what we have available. The most homogeneous data with a common approach to modeling is the sample of 24 CP stars used by Landstreet and Mathys (2000) to determine common and statistical properties of the magnetic fields of the stars. The geometry of the magnetic field is presented in this paper by superposition of the central dipole and axially symmetric quarupole and octupole.

Table 2. Angular parameters of magnetic dipoles for 15 CP stars

HD	i	β	σi, $\sigma\beta$
24712	140	147	5
62140	90	93	
65339	110	75	
71886	110	95	
98088	85	80	
118022	25	120	
137909	160	100	
115708	130	75	10
192678	170	120	
4778	70	65	15
80316	60	35	
108662	55	120	
152107	15	40	
165474	80	10	20
188041	160	120	

2.4 Comparison of models of magnetic fields of stars derived by different techniques

In literature one can find data on about 90 stars for which magnetic models have been derived, for more than 2/3 of them they are presented in the form of a simple central dipole.

A natural question arises whether the models available are adequate to describe real magnetic fields. As the first step in answering the question, let us examine the difference in models constructed for the same stars by different authors with application of different techniques of observations and reduction. Note that to a certain degree the methods of measuring the longitudinal and surface (B_e and B_s) magnetic fields may be considered as independent. Results obtained by them in observations of broad-band linear polarization are quite independent.

In Table 2 are listed angular parameters of magnetic dipoles of 15 CP stars from the paper by Leroy (1997).

Consider in more details the magnetic stars for which the modeling was performed repeatedly. Standard designations were adopted: i is the angle between the axis of rotation and the line of sight, β is the angle between the magnetic and rotational axes, R is the radius of the star in terms of solar radius, P is the period of rotation (generally in days). Detailed information about each star is presented in our catalog (Romanyuk 2000); here we give only the information concerning the question discussed in the presented paper.

1. HD 4778

   Bohlender (1989) found $v \sin i = 30$ km/s and, given the period, he determined angle $i = 40°$, angle $\beta = 80°$, the field at the pole $B_p = 6$ kG. Based on polarimetry data Leroy (1997) found $i = 70°$, $\beta = 65°$. Wade (1997) found $i = 70°$ using data on spectroscopy. In the paper by Leone et. al. (2000) $i = 57°$, $\beta = 79°$, $H_p = 4.8$ kG. Except for the first data of Bohlender (1989) with the value of i distinquished from the rest of the data, all the remaining data lead to more or less similar parameters of the central dipolar field model and with angles $i = 60 - 70°$ and β from 65° to 80°. We can see that the discrepancy in the values amounts to 10–15 degrees, in the field strength at the pole of the dipole B_p is equal to 20%.

2. HD 12288

   The magnetic model parameters were determined by two different groups, however, they used practically one and the same set of observational data. Leroy (1995) reports that strong interstellar polarization (0.77%!) interferes with measuring intrinsic polarization.

In our paper (Wade et al. 2000) a magnetic model is presented in the form of decentered dipole with parameters: period $P=33.9\pm0.2$ days, $i=119\pm6°$, $\beta=21\pm6°$, $B_p=11.8\pm0.5$ kG, decentring parameter $a=+0.01$, i.e. nearly that of a central dipole.

In the paper by Landstreet and Mathys (2000): $P=34.9$ days, $i=62°$, $\beta=22°$, $B_d=-10100$ G, $B_q=-2800$ G, $B_{oct}=4200$ G. Since angles 0° and 180° are indistinguishable, angles 119° and $180-119=61°$ are indistinguishable either. The parameters of orientation of the dipole coincide to an accuracy of 1°, in spite of the significant contribution of the quadrupolar and octupolar components, which is allowed for in the paper by Landstreet and Mathys (2000) and not considered by Wade et. al. (2000).

3. HD 14437

   In our paper (Wade et al. 2000): $P=26.87$ days, $i=115\pm6°$, $\beta=14\pm4°$, $B_p=13.5$ kG, $a=0.23$, (model of decentered dipole was used).

   Landstreet and Mathys (2000) found: $P=26.87$ days, $\beta=19°$, $i=56°$, $B_d=-10300$ G, $B_q=1600$ G, $B_{oct}=6300$ G.

   As for the previous star, practically the same observational data were used, therefore no great discrepancies in the models could be expected: the angles showing the orientation of the dipole differ by no more that 10°.

4. HD 24712

   From observation of linear polarization (Leroy 1997) in the plane U/I–Q/I we have a pretty diagram (nearly a ring), which can be well interpreted by a classical oblique rotator with $B_s=2.6$ kG and angles $i=140°$, $\beta=147°$.

   It is shown by Leone at al (2000) that the field configuration obtained by different authors is very different. Apparently, when restoring the parameters of the dipole, the inhomogeneity of distribution of elements over the surface should not be disregarded. The field configuration differs from the dipolar so much that simple models are inapplicable.

5. HD 32633

   From results of observations with the Balmer magnetometer (Borra and Landstreet 1980) a model with $i=77°$, $\beta=24°$, $B_p=23$ kG, $R=2.2$ was derived. The curve is largely unharmonic, a secondary maximum shows up at phase 0.6. The photographic curve of B_e is highly variable, the mean value of photometric measurements is more negative, the curve of B_e is more sinusoidal.

   Renson (1984) examined the secondary maximum on a descending, more gently sloping branch of the B_e curve, which is separated from the primary by 0.35. He concludes that there exists a very strong quadrupolar component.

   Leroy (1995) was unable to conduct broad-band observations of linear polarization because of interference of strong (of order 0.5%) interstellar polarization.

   Leone et al. (2000) reported that $v\sin i=23$ km/s, found by Borra and Landstreet (1980), is inconsistent with the stellar radius determined from HIPPARCOS data ($R=2.4R_\odot$). If the data in Borra and Landstreet are correct, the radius must then be not less than 2.9 solar radii. If $R=2.4R_\odot$, then $v\sin i<19$ km/s. Therefore, it is necessary to precisely measure $v\sin i$ for the determination of the inclination of the rotation axis. Since the curve of B_e differs greatly from a sinusoid, the dipolar component of the field is not dominant.

6. HD 37776

   Bohlender (1988) constructed a dipolar-quadrupolar-octupolar model with parameters: $B_d=-2000$ G, $B_q=53000$ G, $B_{oct}=-48000$ G, $i=90°$, $\beta=90°$.

   In our paper (Khokhlova et al. 2000) the subject is treated more thoroughly. In modeling, V.L. Khokhlova adopted angles $i=32°$, $\beta=45°$. To describe the field, a combination of the dipole and quadrupole oriented in an arbitrary manner were applied. None of the constructed models should be considered as satisfactory. Only the presence of a very strong magnetic field (not less than 70 kG) on the surface of the star is beyond a doubt, but its geometry is open to question.

   Bohlender's (1988, 1994) models described well the behaviour of the B_e and B_s curves, but show bad agreement with the results of investigation of Stokes V-parameters obtained in spectral lines.

Khokhlova's model, based on an analysis of parameters of polarization in lines, describes them naturally well; however, it is inconsistent with the longitudinal field curve derived from hydrogen lines (Bohlender 1988).

Leroy (1995), Romanyuk et al. (1992) attempted to measure intrinsic polarization, however, it turned out that in the continuum of the star constant strong (of order of 0.5%) interstellar or circumstellar linear polarization not allowing the intrinsic polarization to be investigated. Apparently, the problem of construction of a realistic model for HD 37776 will not be solved until all Stokes parameters well distributed over the rotational period phase are obtained.

7. HD 62140

The star was studied by different techniques. Bonsack et al. (1974) found $i=43\pm7°$.The magnetic field is of dipole structure with the axis lying nearly in the equatorial plane of rotation.

Leroy (1995) stated that the specific shape of the broad-band linear polarization diagram is difficult to interprete by an oblique rotator model. It needs to be modified. In particular, the variability and polarization of HD 62140 can be very well represented provided that the magnetic signal is not symmetric about the magnetic axis and has some peculiarities in the polar regions. The best model: magnetic lines of force are not closed at the equator, they extend outward, $i=90°$, $\beta=93°$. Leone et al. (2000) used a CCD matrix and obtained Zeeman spectra. A model with $i=90°$, $\beta=95°$ was accepted.

We see a sharp difference between the data of Bonsack et al. (1974), obtained on the basis of photographic observation from metallic lines and the data of broad-band polarization. This is, probably, due to lower accuracy of photographic measurements, and besides, all investigators note that the geometry of the magnetic field of this star is unordinary.

8. HD 65339

Magnetic models for this star have been constructed repeatedly. There are favorable prerequisites for this: measurements of the longitudinal and surface magnetic field and broad-band linear polarization have been made.

In the 1970th the model by Huchra (1972) was used: an oblique rotator with parameters $a = 0.145$, $\beta = 80°$, $i = 50°$, $B_p = 28.4$ kG; however, the model of such a decentered dipole is a bad fit to the B_e curve.

Kemp and Wolstencroft (1974) applied a rotator model with the inclination of the magnetic axis to the rotation axis $\beta=90°$ and rotation axis to the line of sight i within 50–60°. Borra and Landstreet (1977) used a model in the form of decentered dipole with parameters $i=65°$, $\beta=100°$, $B_p=28000$ G, $a=-0.15$. The observations were made with the hydrogen-line magnetometer.

On the basis of spectral observations obtained with a reticon (without an analyzer) Landstreet (1988) investigated the magnetic field and distribution of elements over the surface of 53 Cam. The following model was derived: $B_d = -16300$ G, $B_q = -7300$ G, $B_{oct} = +4900$ G, $i = 64°$ and $\beta = 82°$. Broad-band linear polarization measurements (Leroy 1997) yields $i=110°$, $\beta=75°$.

In the end, Landstreet and Mathys (2000) obtained $B_d = -16700$ G, $B_q = -11200$ G, $B_{oct} = 5700$ G, $i = 50°$, $\beta = 86°$. Thus, one can conclude that independent techniques lead to one and the same field model of HD 65339 = 53 Cam in which angle $i=50$–$60°$, while angle $\beta=75$–$85°$.

We can conclude that within 10°–15° all the models obtained in an independent manner coincide in angles. The magnetic field strength value on the pole depends on the precision of B_e and B_s curves, and, specifically, for 53 Cam coincides to an accuracy of the order of 10%. The discrepancy in the parameters of determining the quadrupole and octupole components is much higher, up to 50%.

A new model based on the use of Doppler-Zeeman mapping of the four Stokes parameters has recently been derived (Kochukhov et al. 2004). Reconstruction of the vector distribution of the fields has been carried out, which showes its complex multipolar structure. The result needs comprehension.

9. HD 112413

This is the best understood magnetic star (α^2 CVn), many models explaining all kinds of its variability have been constructed. However, neither measurements of the split Zeeman component of α^2 CVn nor independent measurements of broad-band linear polarization been made because of the undetectability of the indicated above parameters.

The star was intensively studied by the method of Doppler-Zeeman mapping. We will not analyze here the capability of maps of the distribution of spots of chemical composition, but concentrate only on the obtained magnetic field geometry. Pyper (1969) conducted a detail study of the surface of α^2 CVn using Zeeman spectra, a model was constructed of the magnetic field which is a combination of the field of the dipole and quadrupole whose axis is inclined to the axis of rotation by 50°.

Kodaira and Unno (1969) measured the longitudinal and, for the first time, transversal magnetic field, the inclination angle of the rotation axis to the line of sight $i = 64°$. Borra and Landstreet (1977) observed α^2 CVn with the hydrogen-line magnetometer; no significant unharmony of the longitudinal field curve was revealed. Leroy (1995): linear polarization is very low, practically inmeasurable.

Kochukhov et al. (2002), using the ZDI technique, found that the dipolar component is dominating in the magnetic field of the star, while the quadrupole makes a minimum contribution. The surface distribution of chemical elements: symmetric patterns are formed, which are intimately related to the magnetic geometry. This finding postulated one of the first direct proves of existence of the process of horizontal diffusion.

10. HD 118022

Independent measurements are available. The following parameters were found by Borra (1980) with the hydrogen-line magnetometer: $i = 22°$, $\beta = 245°$, $B_p = +6000$ G, $Q = 0.5$ (parameter that defines the contribution of the quadrupolar component of the field). After additional observations Borra and Landstreet (1980) proposed a new model: $i = 14°$, $\beta = 71°$, $B_p = 5000$ G, $R = 1.5$. In the end, from the results of broad-band observations of linear polarization Leroy (1997) found $i = 25°$, $\beta = 120°$. Finally, we see that the dispersion for the angles is within 10°, the field strength at the poles differs by 20%.

11. HD 126515

Preston (1972) proposed for this star a model of decentered dipole since the measurements of B_e and B_s could not be explained otherwise. A model of dipole shifted by 0.36 radius with respect to the star's centre in the direction opposite to the magnetic moment gives the best representation. Leroy (1995) found strong (in order of 0.2%) interstellar polarization, interfering with studying intrinsic polarization.

Landstreet and Mathys (2000) presented the following parameters: $P = 130$ days, $\beta = 20°$, $i = 78°$, $B_d = -13700$ G, $B_q = -17700$, $B_{oct} = -5200$ G.

12. HD 137909

This is a bright object (β CrB). Numerous measurements were made by independent techniques. Results of photographic measurements of β CrB from metallic lines: the inclination of the dipole axis to the rotation axis was found, $i = 88°$ (Preston and Sturch 1967), a simple dipolar model is not satisfactory enough. According to Stepien (1978), the magnetic axis is located close to the plane of the equator of rotation ($\beta > 70°$).

Photoelectric measurements of circular polarization. Freeman (1978) used the decentered dipole model: $\beta = 87°$, $i = 10°$, $B_p = 4000$ G, $a = 0.1$. Paper by Adelman et al. (1998): $i = 21°$, $\beta = 85°$, $B_p = 4700$ G.

Broad-band linear polarization measurements (Leroy 1997): $i = 160°$, $\beta = 100°$. Landstreet and Mathys (2000) present the following parameters: $P = 18.49$ days, $\beta = 85°$, $i = 15°$, $B_d = -8700$ G, $B_q = -1400$ G, $B_{oct} = -600$ G.

The old photographic observations show greater discrepancy, while the rest of them agree with each other within 10° in angles. There is a great difference in the estimates of the field from the poles of the dipole.

13. HD 152107

Photographic spectra: Wolff and Preston (1978) found $v_e \sin i = 24$ km/s, $i > 35°$, $\beta > 26°$.

Photoelectric measurements of circular polarization from hydrogen lines (Borra and Landstreet 1980): $i = 38°$, $\beta = 14°$, $B_p = 2900$ G. Broad-band linear polarimetry (Leroy 1995): $i = 15°$, $\beta = 40°$.

This star is seen to have serious discrepancies (more than 20°) in determination of angles i and β obtained by different methods.

14. HD 188041

    Leroy (1997) found $i = 160°$, $\beta = 120°$. Landstreet and Mathys (2000) presented the following parameters: $P = 224$ days, $\beta = 10°$, $i = 70°$, $B_d = 5600$ G, $B_q = -1200$ G, $B_{oct} = -100$ G. The results of Leroy can also be presented as $i = 20$, $\beta = 60$, i.e the models coincide in angles within 10°.

15. HD 192678

    We (Wade at al. 1996) propose $B_p = 6.8 \pm 0.2$ kG, $i = 173 \pm 5°$, $\beta = 120 \pm 7°$. Leroy (1997) found $i = 170°$, $\beta = 120°$. Landstreet and Mathys (2000) proposed the following model: $P = 6.42$ days, $\beta = 32°$, $i = 4°$, $B_d = 4900$ G, $B_q = 1300$ G, $B_{oct} = 2300$ G. Close coincidence in angles and field magnitude was obtained.

16. HD 200311

    In our paper (Wade et al., 1997b) we found: $i = 28 \pm 8°$, $\beta = 90 \pm 8°$, $B_d = -12.8 \pm 1.0$ kG. Landstreet and Mathys (2000) give the following parameters: $P = 52.01$ days, $\beta = 24°$, $i = 88°$, $B_d = 12800$ G, $B_q = 3800$ G, $B_{oct} = 800$ G.

    Since the data were obtained in a great measure from the same material, we cannot consider them to be independent.

17. HD 215441

    The famous Babcock's (1960) star with resolved Zeeman components suggesting the surface field $B_s = 34$ kG.

    Borra and Landstreet (1978) found the angle of inclination of the dipole axis to the rotation axis as 30–35°. A model of a symmetric rotator cannot explain satisfactorily the photoelectric curve of the longitudinal field B_e.

    Landstreet et al. (1989) conducted observations with a reticon. The results are in agreement with the model: the magnetic axis is inclined to the rotation axis at an angle of 35°, the latter is inclined to the line of sight at the same angle. The field geometry is represented by superposition of the dipole, quadrupole and octupole with a field strength at the pole of +67, −55 and 30 kG, respectively.

Summing the data obtained for 17 stars, we can draw the following conclusion. Independent measurements show that if the star has the structure in which the dipolar component is dominating, the angles i and β that define the orientation of the dipole in space are determined with an accuracy of about 10–15° and better. Typical discrepancies in field magnitudes at the poles of the dipole are of order of 20% of its value. For stars with essentially non-dipolar field components the accuracies are much worse. For the star HD 37776 no satisfactory model explaining observational data has been constructed at all.

2.5 Statistical study of magnetic models

A paper by Bagnulo et al. (2002) having the above title has recently been out of print. In the paper results of a statistical study of the structure of 34 CP stars are presented. The field geometry is described by superposition of a dipole and an arbitrary oriented quadrupole. Unfortunately, in contrast to the paper by Landstreet and Mathys (2000), Bagnulo et al. do not give a sufficient number of observed parameters of their sample, that is why it is difficult to have our own opinion of the accuracies and reliability of inferences of their paper.

Some results of Bagnulo et al. confirm the older ones: for instance, it was found that for fast rotators angles β are large, and for slow ones they are small, which corresponds to the conclusion drawn by Landstreet and Mathys. It was also found that for short-period stars (with a period less than 10 days) the plane containing two vectors, characterising quadrupole, are nearly always coincident with the plane containing the rotation and magnetic axes. A long-period star is characterized by the fact that the axes of the quadrupole are oriented in such a way that they lie in a plane perpendicular to that indicated above. This is one more proof that there exist differences in the two classes of stars, depending of rotation. However we can be content only with averaged statistical inferences: individual parameters adopted for the modeling of each star are practically absent in paper by Bagnulo et al. (2002).

For this reason, for subsequent work we make use of a sample of 24 CP stars (Landstreet and Mathys 2000). The forms of field distribution over their surfaces are computed in a direct manner. The model parameters are varied until they agree with observations of B_e and B_s. The sinusoidal variations of B_e were found to agree with a simple dipolar global field when the dipole is centered in a star, and its axis is inclined to the rotation axis at the angle β. In this case the dipole axis escribes a cone around the axis of rotation of the star, the inclination of the dipole axis is time variable in this case, and the observer sees a sinusoidal variability of the averaged along the line of sight component.

Assigning information about i, β, B_d, B_q and B_{oct} in three-dimensional axially symmetric multipolar expansion and taking into account the contribution of different parts of the visible surface, one can directly compute different integral moments of the fields B_e and B_s observed as a function of phase. The curves of B_e and B_s must be smooth, without jumps. There must be good phase coverage. As a first approximation, the field value at the pole of the dipole is taken. For the case where only the dipolar component is present, Landstreet and Mathys (2000) established that B_d is by factor 1.5 larger than the maximum value of B_s. One should take into account the darkening towards the limb and the weakening of lines arising because of that.

The necessity for introducing the octupolar component consists in increasing or dropping of contrast of dipole field from pole to equator. It turned out that a great number of observed fields require octupole components because the actual contrast in them differs from that of a simple dipole.

On the basis of modeling Landstreet and Mathys (2000) found that one of the two angles (i or β) is nearly always less than 30° for stars with both long and short periods. Here the authors believe that for slow rotators angle β is small, while for fast rotators it is large.

Since on the basis of the above paper important conclusions concerning the evolution of CP stars are drawn, let us analyze carefully the sample of the stars used in it. For this purpose, we present in Table 3 the necessary data on 24 stars from the list of Landstreet and Mathys: the number of the star from catalog HD, rotational period P, angles β, i, field magnitudes at the poles of the dipole, quadrupole and octupole B_d, B_q and B_{oct}, correspondingly. In addition, we calculated the ratios B_q/B_d and B_{oct}/B_d, characterizing the contribution of the quadrupolar and octupolar components and also presented information on duality if any.

Below we are analyzing the values of B_q/B_d and B_{oct}/B_d for fast and slow rotators. At this stage, we are not concerned with the point of whether this structure is really quadrupolar; a quadrupole merely indicates quantitavely to what extent one pole is stronger than the other. We need also the octupolar structure as an indicator of contrast of the magnetic field B_s between magnetic equator and poles.

Find the mean value of the quantities mentioned for slow and fast rotators.

1. $P<25$ days, 8 stars:

   $\overline{B_q/B_d}=-0.326\pm0.279$, $\overline{B_{oct}/B_d}=+0.180\pm0.100$.

2. $P>25$ days, 16 stars:

   $\overline{B_q/B_d}=+0.123\pm0.146$, $\overline{B_{oct}/B_d}=-0.187\pm0.080$.

It can be seen that slow and fast rotators differ not only in the distribution of angles i and β. Firstly, the signs of the quadrupole and octupole components are generally opposite for one and the same stars. This may possibly be due to the shortage of model representation which should be compensated for, so that the resulting longitudinal fields be not too large. Secondly, the quadrupolar component for fast rotator has the sign opposite to dipolar and makes 1/3 of its value; at the same time for fast rotators the quadrupole and dipole components have the same sign, while the quadrupole component has a magnitude of 12% of the dipole. The difference $\Delta\overline{B_q/B_d}=0.449\pm0.317$, which is about 1.5σ.

For the octupole component the picture is more clear-cut: for fast rotators the contrast of the field is higher than the dipolar, while for slow rotators it is lower. Quantitatively this difference makes $\Delta\overline{B_{oct}/B_d}=0.367\pm0.128=2.9\sigma$.

Thus, we found that the star from the sample of Landstreet and Mathys (2000) show different contrast in magnitude of the surface magnetic field between poles and equator, which is described quantitatively by the octupolar component.

For a more careful analysis of the results, try to find how the contribution of the octupolar component is related to the rotational period. Let us construct a relationship '$\lg P - B_{oct}/B_d$'. We do not present here the general picture because of great scatter of points, although certain signs of the trend are visible. A straight line drawn across them by the least-squares method may be represented as $B_{oct}/B_d=0.250+(-0.173)\cdot\lg P$ (correlation coefficient is 0.46). Consider this question in more detail below.

Let us see whether the duality has an effect on our result. Among the 24 stars from the sample described above, we found data on 7 binaries with orbital periods from 70 days to a few years. We will consider the

Table 3. Parameters of magnetic models for 24 CP stars

HD	P	β	i	B_d	B_q	B_{oct}	bin
Stars with period $P<25$ days							
HD 65339	8.0	86	50	−16700	−11200	5700	6 y
		$B_q/B_d=+0.67,\ B_{oct}/B_d=-0.34$					
HD 70331	1.99	69	5	−15300	26500	−3600	no
		$B_q/B_d=-1.73,\ B_{oct}/B_d=+0.24$					
HD 137909	18.5	85	15	−8700	−1400	−600	10 y
		$B_q/B_d=+0.16,\ B_{oct}/B_d=+0.06$					
HD 142070	3.3	83	9	7300	1100	−800	500 d
		$B_q/B_d=+0.15,\ B_{oct}/B_d=-0.11$					
HD 192678	6.4	32	4	4900	1300	2300	no
		$B_q/B_d=+0.26,\ B_{oct}/B_d=+0.47$					
HD 208217	8.4	86	15	−13100	6000	−5000	no
		$B_q/B_d=-0.45,\ B_{oct}/B_d=+0.38$					
HD 215441	9.9	30	30	62400	−42000	24200	no
		$B_q/B_d=-0.67,\ B_{oct}/B_d=+0.39$					
HD 318107	9.7	78	11	23700	−23600	8300	no
		$B_q/B_d=-1.00,\ B_{oct}/B_d=+0.35$					
Stars with period $P>25$ days							
HD 2453	546	11	62	−5000	−600	1800	no
		$B_q/B_d=+0.12,\ B_{oct}/B_d=-0.36$					
HD 12288	34.8	22	62	−10100	−2800	4200	4 y
		$B_q/B_d=+0.28,\ B_{oct}/B_d=-0.42$					
HD 14437	26.7	19	56	−10300	1600	6300	no
		$B_q/B_d=-0.16,\ B_{oct}/B_d=-0.62$					
HD 51684	370	18	42	−7300	−2200	2500	no
		$B_q/B_d=+0.30,\ B_{oct}/B_d=-0.34$					
HD 61468	322	19	49	−7400	−4100	−1000	no
		$B_q/B_d=+0.55,\ B_{oct}/B_d=+0.14$					
HD 81009	34	11	48	7400	7200	2200	22 y
		$B_q/B_d=+0.97,\ B_{oct}/B_d=+0.30$					
HD 93507	556	19	55	10900	−3700	−3400	no
		$B_q/B_d=-0.34,\ B_{oct}/B_d=-0.31$					
HD 94660	2700	5	47	−8400	2700	6900	no
		$B_q/B_d=-0.32,\ B_{oct}/B_d=-0.82$					
HD 116114	27.6	2	56	−9000	1100	600	no
		$B_q/B_d=-0.12,\ B_{oct}/B_d=-0.07$					
HD 116458	148	10	52	−7600	2600	400	SB1 70 d
		$B_q/B_d=-0.34,\ B_{oct}/B_d=-0.05$					
HD 126515	130	20	78	−13700	−17700	−5200	no
		$B_q/B_d=+1.29,\ B_{oct}/B_d=+0.38$					
HD 144897	48	12	65	11000	−12900	−4900	no
		$B_q/B_d=-1.17,\ B_{oct}/B_d=-0.45$					
HD 166473	4400	35	87	−9400	−5700	1100	no
		$B_q/B_d=+0.61,\ B_{oct}/B_d=-0.12$					
HD 187474	2345:	45	86	−7700	−1600	1000	SB1 2 y
		$B_q/B_d=+0.21,\ B_{oct}/B_d=-0.13$					
HD 188041	224	10	70	5600	−1200	−1000	no
		$B_q/B_d=-0.21,\ B_{oct}/B_d=-0.18$					
HD 200311	52	24	88	12800	3800	800	no
		$B_q/B_d=+0.30,\ B_{oct}/B_d=+0.06$					

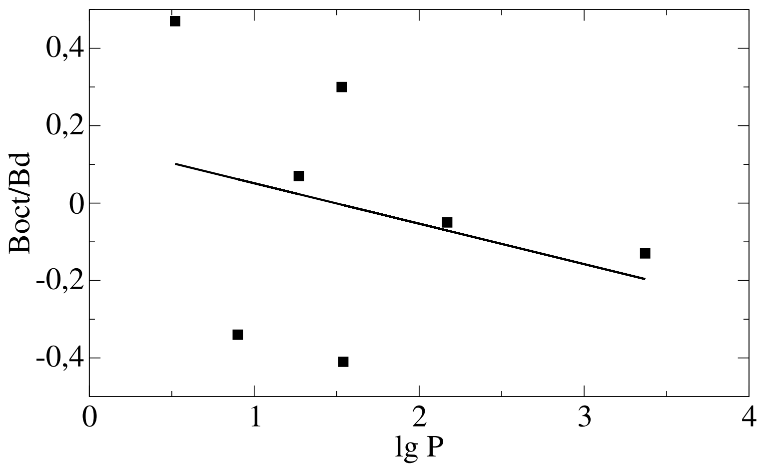

Figure 2. *'B_{oct}/B_d – $\lg P$' for binary magnetic stars. $B_{oct}/B_d = -0.127 + 0.017 \cdot \lg P$, correlation coefficient is 0.07.*

remaining 17 stars to be single because we found no evidence disproving this assumption. Three binary stars are among fast rotators and four of them among slow rotators.

As it was done above, let us analyze the contributions of the quadrupolar and octupolar components separately for fast and slow rotators for binary and single stars.

1. **Binary stars**.

   Fast rotators ($P < 25$ days, 3 stars):

   $\overline{B_q/B_d} = +0.327 \pm 0.172$, $\overline{B_{oct}/B_d} = -0.130 \pm 0.115$.

   Slow rotators ($P > 25$ days, 4 stars):

   $\overline{B_q/B_d} = +0.280 \pm 0.269$, $\overline{B_{oct}/B_d} = -0.075 \pm 0.148$.

   It can be seen that in general there is no difference between magnetic models of fast and slow rotating stars. This is also evidenced by the absence of correlation between period and contribution of the octupole component (see Fig. 2).

   We calculated a straight line $B_{oct}/B_d = -0.127 + 0.017 \cdot \lg P$ with a correlation coefficient of 0.07, i.e. for binary stars no relationship between contribution of the octupolar component and period of rotation of the star was found.

2. **Single stars**.

   Let us consider the remaining 17 stars from the list of Landstreet and Mathys (2000), for which no evidence of duality was found.

   We calculated average values of the contribution of the quadrupole and octupole components for fast and slow rotators.

   Fast rotators (period $P < 25$ days, 5 stars):

   $\overline{B_q/B_d} = -0.718 \pm 0.326$, $\overline{B_{oct}/B_d} = +0.366 \pm 0.037$.

   Slow rotators (period $P > 25$ days, 12 stars):

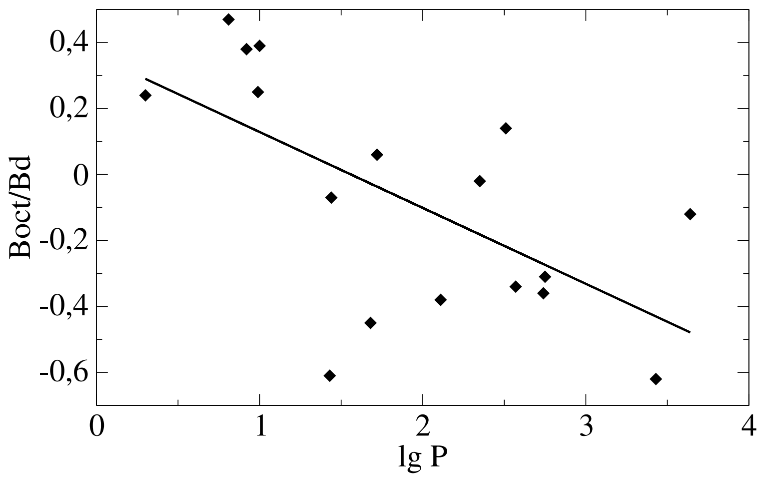

Figure 3. *The relationship 'B_{oct}/B_d–$\lg P$' for single stars. The stright line is drawn with the help of least square method, regression parameters:* $B_{oct}/B_d = 0.428 + (-0.251) \cdot \lg P$*, coefficient of correlation 0.612.*

$\overline{B_q/B_d} = +0.071 \pm 0.177$, $\overline{B_{oct}/B_d} = -0.224 \pm 0.096$.

One can see a large difference both for the contribution of the quadrupolar and octupolar components. Note the small scattering when deriving average values of B_q/B_d and B_{oct}/B_d. The difference for the quadrupole component is: $\Delta \overline{B_q/B_d} = -0.789 \pm 0.370 = 2.1\sigma$.

But a very clear, giant difference is seen when we estimate the contribution of the octupole component: $\Delta \overline{B_{oct}/B_d} = 0.590 \pm 0.103$, which correspond to 5.8σ.

Now let us construct a diagram of the relationship between relative value of the contribution of the octupolar component and logarithm of the rotational period (Fig. 3).

Thus, we can conclude, that the contrast in magnitude of the surface magnetic field between magnetic poles and equator depends on the rotational period. For fast rotators the contrast is higher than dipolar, for slow rotators it is smaller than dipolar. And it is equal to dipolar (on average for 17 single stars) when period $= 51$ days.

As we mentioned above, Landstreet and Mathys (2000) needed octupole component to describe the contrast in B_s curve between magnetic poles and equator. Taking into account, that angle β (following the authors) is large for fast rotators, we can conclude that the magnetic field for fast rotators when the poles are on the equator of rotation becomes stronger in comparison with dipolar.

For slow rotators the magnetic axis and the axis of rotation coincide, and the field does not tend to be stronger than dipolar at the poles, but becomes stronger at the magnetic equator, making the field of the star closer to that of a homogeneously magnetized sphere.

Let us construct similar relations for estimating the contribution of the quadrupole component (B_q/B_d), depending on the rotational period for binary and single stars.

The relationship '$B_q/B_d - \lg P$' for 17 stars is shown in Fig. 4.

It is seen that in this case there exists a correlation between the contribution of the quadrupolar component and the rotation period of the star. The period, at which the contribution of the quadrupole component equals zero is 200 days. However, for binary systems, the same as for octupole, there are not any correlations with the rotational period.

Coming to the end of this Chapter, we can draw the following conclusion. Use of Zeeman spectra with a high signal-to-noise ratio, and also of independent data obtained from observations of linear polarization allows global parameters of magnetic fields of CP stars, such as orientation is space, distribution of inclinations of rotational and magnetic axes to be reliably determined; and also some common laws in the distribution of fields over the surface of CP stars to be found.

This makes it possible to hope that a powerful observational test, which can be used to advantage, fall into the hands of theorists.

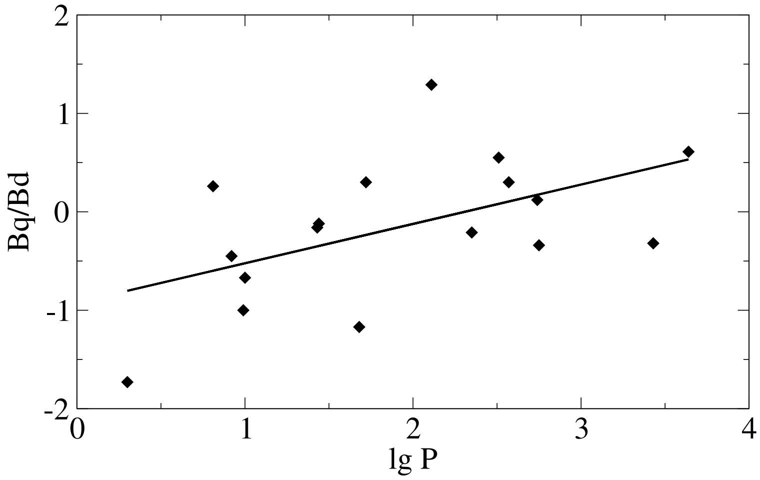

Figure 4. *The relationship 'B_q/B_d – $\lg P$'. Correlation coefficient 0.527, $B_q/B_d = -0.922 + 0.399 \cdot \lg P$.*

Table 4. Distribution of MCP stars according type of peculiarity

Peculiarity	Total number	Fast rotators	Slow rotators	Period is unknown
He–strong	9	7	1	1
He–weak	32	17	9	6
Si	40	20	10	10
Si+	30	12	16	2
SrCrEu	94	24	60	10

3 Analysis of physical properties and parameters of magnetic CP stars

3.1 Groups of magnetic CP stars

Depending on the effective temperature T_e, all magnetic CP stars can be divided into several groups (from the hottest to the coolest) in the following manner: with helium anomalies (He–strong and He–weak), with silicon anomalies (Si and Si+), and the coolest with anomalies of SrCrEu.

A sample of magnetic CP stars according to their peculiarity types is given in Table 4. An analysis was made of two groups of stars: fast and slow rotators. As fast rotators, we chose stars with a rotational period shorter than three days, the rest of the stars are slow rotators.

Thus, the number of CP stars classified by the type of peculiarity is 205, the spectrum of the remaining 35 stars have been poorly studied: in literature we either failed to find detailed information about the peculiarity type, or the data obtained by different authors are contradictory. For 29 of the classified magnetic stars periods of rotation are unknown. It can also be seen from the table that the hotter stars have shorter rotational periods.

Now, we can derive the relationship 'temperature – rotation' for 176 stars with known periods. The results are presented in Fig. 5.

We see a considerable scatter; on the whole, hotter stars have a shorter period, the lower limit (about 0.5 days), however, is the same for all of them.

3.2 Parameters of magnetic CP stars with anomalous helium lines

These are the hottest chemically peculiar stars, their characteristic feature is variable helium lines pointing to non-uniform distribution of this element over the surface. Magnetic field in them was discovered by John Landstreet and his colleagues with the aid of the photoelectric magnetometer. The stars have a small number

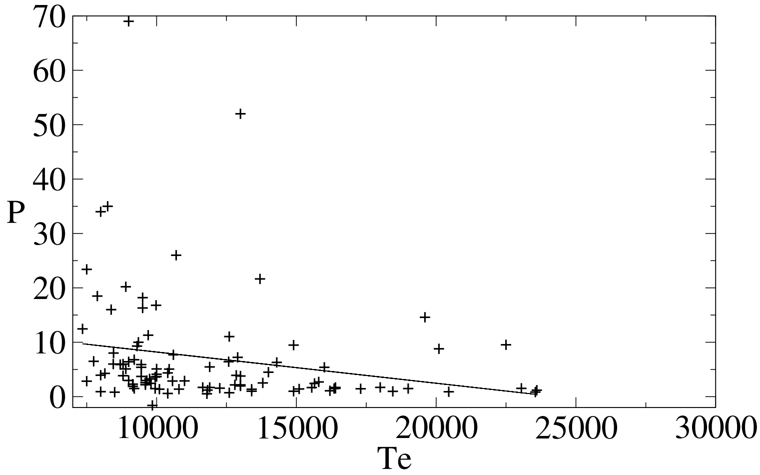

Figure 5. *Relationship 'temperature – period' for magnetic stars (stars with $P > 100$ days are excluded).*

Table 5. Magnetic fields of He–r stars

7 He–r stars	4 stars from OriOB1
$\overline{B_e(min)} = -1530 \pm 514$ G	-2400 ± 456 G
$\overline{B_e(max)} = +916 \pm 700$ G	$+575 \pm 1141$ G
$\overline{\lvert B_e \rvert} = 2508 \pm 321$ G	2875 ± 425 G

of lines in the spectrum; besides, as a rule, they rotate fast, because of this it was impossible to make photographic measurements of magnetic fields.

There are 9 stars with strong helium lines, and 32 stars have weak lines in our catalog. In some cases helium lines are so variable that the star may be referred to both subclasses. Consider He–r and He–wk stars separately.

3.2.1 Helium-rich stars

The group of He–r stars is quite homogeneous, 4 of them belong to the association Orion 1, the data on cluster membership of the rest of the stars are lacking in literature. Rotational periods are known for 8 out of 9 He–r stars: 7 of them are of order of 1 day, and only HD 184927 has a period of 9 days.

The mean value of the period for the 7 stars mentioned is $\overline{P} = 1.287 \pm 0.122$ days, and for 4 stars from the Orion $\overline{P} = 1.334 \pm 0.180$ days.

The small scatter is evidence of homogeneity of the sample from the point of view of rotation.

Let us make a certain analysis of the data on the longitudinal component of the field. Find the mean value of the quantities $\overline{B_e(min)}$ — the mean value in the negative extremum, $\overline{B_e(max)}$ — the same in positive extremum, $\overline{|B_e|}$ — averaging was performed from the moduli of the extrema.

For the 7 He–r stars with known periods and for the 4 members of Ori OB1 these data are presented in Table 5.

It can be seen that for He–r stars the magnetic field in the extremum reaches on average 2.5 kG, for the stars in Orion it amounts to nearly 3 kG. The field of negative polarity (−) is stronger than that of positive polarity: the ratio $\overline{B_e(min)}/\overline{B_e(max)} = -1530/916 = 1.67$. For the 4 stars in Orion the difference is yet larger $-2400/575 = 4.17$.

Conclusions. The stars with strong helium lines represent a small, homogeneous group of MCP stars with T_e of about 20000 , rotational period 1.3 days, magnetic field of the order of 2 kG. It is remarkable that all He–r stars that we have investigated have the longitudinal magnetic field component mainly of negative

Table 6. Some parameters of magnetic He–r stars

HD/BD	P (days)	$B_e(min)/B_e(max)$ (G)	Membership in clusters	T_e	$v \sin i$ (km/s)	Radius ($R/R_\odot$)
HD 36485	1.708	$-3700/-1900$	Ori OB1	18000	32	4.3
HD 37017	0.9012	$-2300/-300$	Ori OB1	20450	150	4.8
HD 37479	1.191	$-1600/+3500$	Ori OB1	23600	150	5.7
HD 37776	1.539	$-2000/+1000$	Ori OB1	23050	80	5.5
HD 58260	1.49	$+2000/+2600$	—	19000	18	4.6
HD 64740	1.33	$-870/+530$	—	24100	160	5.8
HD 66522	—	$-80/+1030$	—	—	30	5.5
HD 96446	0.851	$-2100/-1100$	—	23550	16	—
HD 184927	9.53	$-1200/+3000$	—	22500	10	5.5

Table 7. Some parameters of fast rotating He–wk stars

HD/BD	P (days)	$B_e(min)/B_e(max)$ (G)	membership in clusters	T_e	M_V	Pec
HD 21699	2.49	< 500	α Per	16400	-1.0	Si*
HD 28843	1.3738	$-500/+250$		13400	0.0	Si
HD 35298	1.85	$-2800/+2900$	Ori OB1	14200	–	-
HD 35456	1.7?	$-300/+1080$	Ori OB1	14900	-0.4	-
HD 35502	1.7?	$-2200/-100$	Ori OB1	16400	–	Si ?
HD 36313	0.589	$-1500/+1100$	Ori OB1	10400	–	Si
HD 36526	1.54	$-980/+3480$	Ori OB1	16400	–	Si
HD 36540	2.17	$-400/+1000$	Ori OB1	–	-0.6	-
HD 36668	2.12	$-1590/+1320$	Ori OB1	12800	-0.5	Si
HD 36916	1.565	$-640/-615$	Ori OB1	–	-0.9	SiMn
HD 37140	2.71	$-1050/+400$	Ori OB1	15800	–	SiSr
HD 37642	1.08	$-2980/+2700$	Ori OB1	16200	-0.6	Si
HD 49333	2.1792	$-800/+800$	NGC 2287 ?	–	-0.5	Si ?
HD 142301	1.459	$-4100/+1600$	Sco–Cen	17300	-0.5	Si
HD 142990	0.979	$-2500/+600$	Sco–Cen	18450	–	—
HD 144334	1.495	$-1400/+500$	Sco–Cen	16350	-0.5	—
HD 145501	1.42	$-1480/-1190$	Sco–Cen	15100	–	Si

polarity. This is especially pronounced for the stars in the Orion association. In all the He–r type stars, helium is concentrated at the magnetic poles, the concentration being stronger at the stronger pole, hence at the pole (−) for our 8 stars. Nearly for all the stars magnetic models have been constructed.

The list of He–r stars and their physical parameters are tabulated in Table 6.

Analysis of magnetic field models shows the absence of predominant orientation of the dipole axis to the rotation axis: angles β have both large (80°) and small (about 0°) values.

3.2.2 Helium-weak stars

Our sample contains 32 magnetic stars with weak helium lines. 25 of them are members of different clusters (mainly in Orion and Scorpio-Centaurus). For 26 objects the periods of rotation were determined: 17 stars have short periods, from 0.6 to 3 days; 6 stars from 3 to 10 days and 3 from 11 to 22 days. As in the previous case, let us divide our sample of magnetic He–wk stars into 2 groups: fast (fewer than 3 days) and slow (more than 3 days) rotators.

The sample of fast He–wk rotators is given in Table 7, the sources of data on the period, membership in clusters and effective temperatures are the same as before; the classification by peculiarities 'Pec' is taken from the paper by Glagolevskij and Chunakova (1985a).

In the group of fast rotators all the stars, but for one — HD 28843, are members of clusters. The stars

Table 8. Some parameters of slow rotating He–wk stars

HD/BD	P ()	$B_e(min)/B_e(max)$ ()	membership in clusters	T_e	M_V	Pec
HD 217833	21.8177	$-5500/-2000$?		13700	-2.0	Ti-Sr
HD 5737	21.65	$-400/+500$		13700	-2.0	Ti–Sr
HD 22920	3.95	$+200/+400$		14850	-1.3	Si
HD 37058	14.6	$-800/+1000$?	Ori OB1	19600	–	SrTi
HD 37210	11.05	$-760/+400$	Ori OB1	12600	–	Si
HD 79158	3.835	$-1200/+900$		13000	-0.8	SrTi
HD 125823	8.8177	$-440/+370$	Sco–Cen	20100	-1.4	—
HD 168733	6.354	$-1000/-400$		14300	–	SrTi
HD 175362	3.674	$-5000/+7000$		18000	-0.5	Ti
HD 217833	5.4	$-5500/-2000$?		16000	–	—

Table 9. Mean characteristics of He–wk stars

	17 stars with period < 3 days	9 stars with period > 3 days
$\overline{B-V}$	-0.083 ± 0.018	-0.136 ± 0.012
$\overline{B_e(min)}$	-1576 ± 269	-628 ± 174
$\overline{B_e(max)}$	$+989 \pm 310$	$+452 \pm 172$
$\overline{\lvert B_e(max)\rvert}$	1825 ± 270	1588 ± 696
$\overline{T_e}$	15300 ± 550	15800 ± 940
$\overline{M_V}$	-0.550 ± 0.090	-1.200 ± 0.258

with period larger than 3 days are presented in Table 8.

The number of slow rotators is 9, 3 of them (HD 37058, 37210, 125823) are members of clusters.

Thus, sharp contrast is observed: the fast rotators are mainly members of clusters (16 out of 17 — 94%), while the slow rotators are field stars (only 30% of them are members of clusters). This circumstance has an evolutionary sense.

Below, in Table 9, mean characteristics of He–wk stars from our sample are given. The designations are similar to those of Table 5.

General commentary to the table. Slow rotators prove to be hotter stars ($\Delta(B-V)=-0.053$ and $\Delta T_e=-500$ K) and of higher luminosity ($\Delta M_V=0.65$).

In fast rotators, on average, stronger magnetic fields are observed: $\overline{|B_e(max)|}=1825\pm270$ — the mean value of the moduli of the extreme magnetic fields of fast rotators, and $\overline{|B_e(max)|}=1588\pm696$ — for slow rotators. Attention is attracted by the great scatter caused by 2 stars with a field of 5 kG. If one compares only the stars — members of clusters, the difference will be even more striking (see next Table 10).

On the basis of the above-stated, one can draw the conclusion that fast rotators among He–wk stars nearly all are members of clusters, have stronger magnetic fields and lower temperatures and luminosities than slow rotators. On the whole, magnetic fields of He–wk are by 30% weaker than of those of He–r stars.

Because of inadequate statistics that we used to compare the properties of helium stars in clusters and out of them, it is necessary to involve literature data. It will be recalled here that we have to do with stars for most of which no magnetic field observations were made.

As a source of data, we use the paper of Glagolevskij and Chunakova (1985b). It contains information about 38 He–r stars, 22 of them being field stars and 16 stars are members of 7 clusters and associations (42.1% of the total number). There are data on 83 He–wk stars, 51 of which are members of different clusters and associations (i. e. 61.4%). It will be recalled that from our 32 magnetic He–wk stars 25 (i. e. 78.1%) are

Table 10. Comparison of He–wk slow and fast rotators – members of clusters

	14 stars with a period < 3 days	3 stars with a period > 3 days
$\overline{V}$	6.934 ± 0.337	6.603 ± 1.133
$\overline{B-V}$	-0.079 ± 0.018	-0.127 ± 0.057
$\overline{B_e(min)}$	-1648 ± 278	-667 ± 114
$\overline{B_e(max)}$	$+1038 \pm 327$	$+590 \pm 205$
$\overline{\lvert B_e(max)\rvert}$	1913 ± 272	733 ± 162
$\overline{P}$	1.690 ± 0.139	11.49 ± 1.68
$\overline{T_e}$	15430 ± 570	17430 ± 2420
$\overline{M_V}$	-0.611 ± 0.068	-1.4 **

** M_V was determined only for 1 star

members of different clusters, mainly Orion and Scorpio-Centaurus. Only 27 stars from the list of Glagolevskij and Chunakova have known periods. Among them 15 stars with periods shorter than 3 days, and 12 of them are members of clusters; and 5 stars with periods above 3 days, 2 of them are cluster members.

It should be noted that for more that 15 years that have passed since the the paper cited above was published, rotation periods of many helium stars have been determined and specified for the first time. Nevertheless, basically, the result remains the same: the fast He–wk rotators are members of clusters, while slow rotators avoid them.

One more circumstance attracts attention, which is the case for the sample of magnetic He–wk stars: the field B_e at the negative pole of the dipole is more than twice as strong as the field at the positive pole, both for fast and slow rotators (see below a sample from Table 9).

	Fast rotators	Slow rotators
$\overline{B_e(min)}$	-1576 ± 269	-628 ± 174
$\overline{B_e(max)}$	$+989 \pm 310$	$+452 \pm 172$

The magnetic variability amplitude for fast rotators is 2565 G, while for slow rotators is 1080 G, that is 2.5 times as small. The effect cannot be due to instrumental causes: the magnetic field of fast rotating helium stars is stronger. This statement holds for a vary small sample of stars – members of clusters.

3.3 Magnetic CP stars with silicon anomalies

A group of stars with silicon anomalies in the continuation of the sequence of peculiar stars towards lower temperatures in comparison with helium stars. The stars are divided into two subclasses: 1) stars only with enhanced silicon lines; 2) stars of Si+ type, in which apart from silicon lines, lines of other elements (Cr,Sr,Eu and others) are enhanced.

3.3.1 Stars with enhanced silicon lines

This is a group of stars containing a great number of peculiar stars. Over 300 of them are known at the present time. This is connected with the fact that they can readily be distinquished with the help of low-dispersion spectra, used in the spectral classification, by anomalous enhancement of the lines of the silicon doublet 4128–4130 Å.

We have selected 40 silicon stars in our catalog, therefore, magnetic fields are measured but in about 10% of all the known Si–stars. Magnetic Si–stars are tabulated in Table 11. The designations are standard.

Table 11. Individual parameters of magnetic Si–stars

HD/BD	$B-V$	P (days)	$B_e(min)/B_e(max)$	Δa	Membership in clusters
HD 8855	−0.085	–	−600/ + 270	50	—
HD 12767	−0.156	1.9	−230/ + 290	25	—
HD 19832	−0.106	0.72790	−350/ + 380	15	—
HD 21590	−0.052		−100/ + 1600	34	—
HD 22470	−0.117	1.929	−1100/ + 1200	19	—
HD 24155	−0.058	2.53	−440/ + 1660	26	—
HD 25267	−0.121	1.21	−345/ − 15	26	—
HD 25823	−0.136	7.2274	−100/ + 1200	32	Pleiades
HD 27309	−0.165	1.569	−1200/ − 200	65	Pleiades
HD 29925	−0.08		−1100/ − 200	–	—
HD 34452	−0.198	2.466	−300/ + 1000	61	—
HD 40312	−0.063	3.619	−240/ + 360	28	—
HD 54118	−0.065	3.275	−1600/ + 1600	–	—
HD 64486	−0.048		−1300/ + 600	6	—
HD 70331	−0.05		−2800	–	—
HD 92664	−0.158	1.673	−1300/ − 100	24	IC 2602
HD 93507	+0.028	550	+1600/ + 2600	–	—
HD 94660	−0.103	long	−3300/ − 2100	–	—
HD 103192	−0.083	2.3567	−250/ − 100	–	Sco–Cen ass
HD 112381	−0.095	2.8	−3700/ − 3100	–	Sco–Cen ass
HD 122532	−0.112	3.681	−900/ + 900	–	Sco–Cen ass
HD 124224	−0.118	0.52068	−437/ + 811	17	—
HD 133880	−0.150	0.877	−4400/ + 1920	–	Sco–Cen ass
HD 137193	−0.007	4.9	+230/ + 970	–	Sco–Cen ass
HD 137389	−0.033		–	–	—
HD 142884	−0.008	0.803	950	–	—
HD 143473	+0.089		+4200/ + 5100	–	—
HD 151965	−0.141	1.6084	−3700/ − 550	–	—
HD 169887	0.00		−2340/ + 1210	–	—
HD 170000	−0.093	1.7165	−180/ + 640	28	—
HD 179761	−0.069	1.7	−590/ + 170	–	—
HD 338226	+0.15		+440/ + 1490	–	—
HD 192913	−0.066	16.8	−670/ + 380	37	—
HD 196178	−0.162	1.01	−1500/ − 700	36	—
HD 196691	−0.04		−1940/ + 2290	–	—
HD 215038	−0.036	2.0398	−3000	–	—
HD 215441	+0.031	9.4876	+10000/ + 20000	21	—
HD 221006	−0.175	2.315	+410/ + 990	30	—
HD 223640	−0.138	3.7352	(−)	43	—

The same as for helium stars, let us discuss two samples: stars with periods shorter and longer than 3 days. The fundamental results of this discussion are summarized in Table 12.

Examination of the table leads to a conclusion that the properties of Si–stars are, in a certain sense, opposite to those of He–wk stars when fast and slow rotators are compared. The mean rotational period $\overline{P}=1.718$ days for fast Si rotators is very close to the mean period of fast He–wk rotators, $\overline{P}=1.677$ days.

The fast silicon rotators ($\overline{B-V}=-0.119\pm0.011$ and $\overline{T_e}=13000\pm480$) are hotter than the slow rotators ($\overline{B-V}=-0.040\pm0.022$ and $\overline{T_e}=11500\pm790$) in contrast to He–wk stars in which the situation is opposite. Although, the luminosity of slow rotators ($\overline{M_V}=-0.507\pm0.188$) is higher than that of fast rotators ($\overline{M_V}=0.050\pm0.165$), which is the same as in He–wk stars by an approximately the same value, 0.557 (and 0.650 — for He–wk stars).

The magnetic field magnitudes (extreme value of B_e) are, on average, equal for fast and slow rotators.

Table 12. Mean parameters of magnetic Si stars

	Period < 3 days [20 stars]	Period > 3 days [10 stars]
$\overline{B-V}$	-0.119 ± 0.011	-0.040 ± 0.022
$\overline{P}$	1.718 ± 0.153	
$\overline{B_e(min)}$	-1212 ± 350	-700 ± 400
$\overline{B_e(max)}$	$+188 \pm 267$	$+990 \pm 340$
$\overline{\|B_e(max)\|}$	1459 ± 298	1560 ± 258
$\overline{T_e}$	13000 ± 480	11500 ± 790
$\overline{M_V}$	0.050 ± 0.165	-0.507 ± 0.188
$\overline{\Delta a}$	0.031 ± 0.004	0.032 ± 0.004

However, the same as for He–wk stars, the slow rotators generally show B_e field of negative polarity (the amplitude of variability is from $(-1212{\pm}350)$ G to $(+188{\pm}267)$ G, while for the slow rotators the mean field is slightly more positive, the amplitude of its variability is $(-700{\pm}400)$ G $\div$ $(+990{\pm}340)$ G (see below sample from Table 12).

	Fast rotators	Slow rotators
$\overline{B_e(min)}$, G	-1212 ± 350	-700 ± 400
$\overline{B_e(max)}$, G	$+188 \pm 267$	$+990 \pm 340$

The quantities Δa are, on average, equal for fast and slow rotators.

3.3.2 Magnetic CP stars Si+

This group comprises 30 objects of our sample. On average, these are cooler stars than purely silicon ones. It can be seen from our Table 13 what anomalies are most frequent in their spectra.

Among the stars with known periods, we have found 12 fast rotators and 16 slow ones. In Table 14 some common data on these stars and a comparative analysis of fast and slow rotators are presented.

On the whole, these are cooler stars than Si-stars by about 1–2 thousand degrees. In contrast to Si–stars, the stars Si+ are hotter for slow rotators, however, the temperature difference is not large. The amplitude of variability of the magnetic field and its strength modulus is higher in slow rotators. On average, the field is stronger for cluster member stars for both fast and slow rotators.

The slow Si+ rotators have the greatest value of the parameter Δa among CP stars of all types. The magnetic field of stars Si+ is, in average, by 500 G larger than for Si–stars. The predominance of field of one sign is not noted. The proportion of Si and Si+ stars in clusters is approximately the same, 20%, which is much less than for helium stars.

3.4 Magnetic stars with strontium, chromium and europium anomalies

The coolest and most numerous among the variety of chemically peculiar stars are stars with strontium, chromium and europium anomalies. As a rule, these are slow rotators, possessing narrow and sharp lines. For this reason, they are convenient for magnetic measurements. There are 94 of such stars in our catalog (Romanyuk 2000).

As previously, consider the relationship between parameters of SrCrEu stars and rotational period. For this type stars we will consider those with periods shorter than 3 days to be very fast rotators, from 3 to 30

Table 13. Individual parameters of magnetic stars Si+

HD/BD	pec	$B-V$	P ()	$B_e(min)/B_e(max)$	Δa	cluster
HD 11187	SiCr	+0.260	–	−70/ + 1200	23	—
HD 11503	SiCr	−0.047	1.6092	−900/ + 410	40	Pleiades
HD 12288	CrSi	+0.081	35	−3100/ − 200	55	—
HD 18296	SiSrCrEu	−0.018	2.884	−1000/ + 1350	31	—
HD 22316	CrHgSi	−0.112	2.98	−2200/ + 600	–	—
HD 30466	SiCr	+0.065	1.39	+400/ + 2400	54	—
HD 32633	SiCr	−0.052	6.43	−5700/ + 3500	40	—
HD 68351	SiSr	−0.073	3.2	−50/ + 210	32	—
HD 71866	SiSrEu	+0.090	6.80	−2000/ + 2000	51	—
HD 74521	SiCr	−0.100	7.77	−200/ + 1400	75	Pleiades
HD 90044	SiCrSr	−0.048	4.3790	−800/ + 700	43	—
HD 90569	SiCrEu	−0.043	7.9	−230/ + 400	–	—
HD 112413	SiHgCrEu	−0.115	5.46939	−1400/ + 1600	40	—
HD 119419	Si+	−0.151	2.60	−4200/ + 1800	–	Sco–Cen
HD 133029	SiSr	−0.108	2.89	+1300/ + 3300	57	—
HD 133652	SiCr	−0.076	2.304	−2100/ + 700	–	Sco–Cen
HD 137509	Si+	−0.125	4.49	−1200/ + 2200	–	—
HD 147010	SiSr	+0.156	3.920	−4500/ − 2500	–	Sco–Cen
HD 148199	SiSrCr	+0.083	7.8	−900/ + 1450	–	—
HD 168796	SiCrSr	+0.12		−870/ + 510	–	—
HD 170973	SrSiCr	−0.044	18.2	−400/ + 1000	53	—
HD 173650	SiCrSr	+0.028	9.975	−500/ + 700	23	—
HD 177517	HgSi	−0.015	0.4	−600/ + 200	3	—
HD 231054	SiSr	+0.30		+380/ + 2530	–	—
HD 184905	SiSrCr	−0.034	1.845	–	31	—
HD 200311	SiCrHg	−0.102	52.0	−1800/ + 1800	39	—
HD 205087	SiSrCrEu	−0.092		−200/ + 800	34	—
HD 208095	SiSr	−0.081		−10000?	27	—
HD 209515	SiMn	−0.030	1	−270/ + 560	–	UMa stream
HD 213918	SiSr	−0.046	1.431	> 1000	–	—
HD 224801	SiSrEu	−0.052	3.7398	+250/ + 2200	38	—

days fast rotators, from 30 to 300 days slow rotators, and with periods above 300 days very slow rotators. Let us isolate a specific class of SrCrEu stars — the coolest roAp stars.

Because of the small number of very fast rotating stars and to enhance the statistics, we had to shift the border between the very fast and fast rotators from 3 to 3.3 days.

3.4.1 SrCrEu stars with period shorter than 3.3 days

General information about these stars is presented in Table 15.

The sample numbers 24 stars (SrCrEu — 8, SrCr — 8, Cr — 4, SrEu — 2, Eu — 1). One star, HD 108945, is a member of the cluster Coma, HD 83368 is a roAp star.

The average values of $\overline{B-V} = +0.053 \pm 0.020$, $\overline{B_e(min)} = -986 \pm 212$, $\overline{B_e(max)} = +575 \pm 190$ and $\overline{|B_e(max)|} = 1182 \pm 206$.

For very fast rotators the negative pole is seen to be stronger. The quantity Δa is the same as for silicon stars.

3.4.2 SrCrEu stars with periods from 3.3 to 30 days

The list of fast rotators and basic parameters are given in Table 16.

There are 37 stars in the sample (SrCrEu — 20, SrCr — 9, Cr — 4, Sr — 0, Eu — 1, SrEu — 1, CrEu — 2). On the whole, they differ from faster rotators: 1) in color — the mean $\overline{B-V} = +0.130 \pm 0.023$ against the mean value $+0.053 \pm 0.02$ for stars with periods shorter than 3.3 days; 2) in magnetic field value — the mean $\overline{|B_e(max)|} = 1182 \pm 206$ for very fast and 1839 ± 284 for fast rotators, i.e. varies by a factor of 1.5!

Table 14. Mean parameters of Si+ magnetic stars

	Period < 3 days [12 stars]	Period > 3 days [10 stars]
$\overline{B-V}$	-0.054 ± 0.016	$+0.011 \pm 0.030$
$\overline{P}$	2.043 ± 0.258	
$\overline{B_e(min)}$	-962 ± 491	-1435 ± 423
$\overline{B_e(max)}$	$+1153 \pm 330$	$+1205 \pm 340$
$\overline{\lvert B_e(max)\rvert}$	1782 ± 410	2015 ± 355
$\overline{T_e}$	10560 ± 298	10950 ± 545
$\overline{M_V}$	0.326 ± 0.318	0.300 ± 0.135
$\overline{\Delta a}$	-0.035 ± 0.007	-0.046 ± 0.004

For slower rotators the pole (+) is stronger: $\overline{B_e(min)} = -836 \pm 315$, $\overline{B_e(max)} = +1241 \pm 310$.

In effective temperatures the slower rotators are by 600 degrees cooler, the main distinctions from fast rotators occur for reversive and SrCrEu stars, while in Δa value they are practically the same.

3.4.3 SrCrEu stars with periods longer than 30 days

The slow rotators — stars with periods of more than 30 days — are listed in Table 17.

The table contains a total of 17 stars, 10 of them are very slow rotators with a rotational period of more than 1 year. The mean value of $\overline{B-V} = +0.164$, i. e. the slow rotators are redder than the stars with a period shorter than 30 days.

The magnetic field is stronger than in the fast rotators, but since for a great number of stars magnetic fields have not been found, the magnetic field maxima for them cannot be determined either. From the current average data the fields of the very slow rotators are smaller than those of simply slow rotating stars. The effective temperatures do not differ.

In the slow rotators the mean value of $\overline{\Delta a} = 0.054$ is significantly greater than for the faster rotating stars. If one takes 6 stars with periods over 100 days and exclude the roAp star HD 201601, then $\overline{\Delta a} = 0.062$, this difference makes 5–6σ. Thus, we can state that the slow rotators have the greatest anomalies in the energy distribution in the continuum of the spectrum among SrCrEu stars.

3.5 roAp stars

These are the coolest CP stars with effective temperatures of the order of 7600 K. Oscillations of brightness and radial velocities with a period of 6–20 min are observed. The rotational periods of these stars are most different. The color $\overline{B-V} = +0.30$ corresponds to temperature. Data on the magnetic roAp stars are presented in Table 18.

This sample contains 11 stars: SrCrEu — 7, SrCr — 1, Eu — 1, SrEu — 1, CrEu — 1. As to the magnetic field magnitude, these are intermediate between fast and slow rotators (as stars with very long periods of rotation). Attention is drawn by a very small value of the photometric index Δa. This suggests that it is not operative at low temperatures, or rapid pulstaions are responsible for this.

Table 15. SrCrEu stars with period shorter than 3.3 days

HD/BD	pec	T_e	M_V	P ()	$B_e(min)/B_e(max)$	Δa	comments
HD 4778	SrCrEu	9600	1.2	2.562	$-1100/+1400$	–	
HD 6532	SrCr	–	–	1.9450	-517	3	
HD 12447	Cr	9200	–	1.49	$-510/+430$	30	
HD 15089	SrCr	8600	1.2	1.74	$-65/+350$	–	
HD 49976	SrCr	9650	1.1	2.9767	$-2000/+2200$	45	
HD 55719	SrEu	9150	0.3	2.3	$-1040/+2100$	–	
HD 83368	SrCrEu	–	–	2.852	$-800/+800$	–	roAp
HD 96707	Sr	8000	–	0.928	$-3900/+800$	–	
HD 108945	SrCr	9000	–	2.004	$+20/+440$	28	Coma
HD 116458	SrEu	9950	–	1.48	$-2200/-1300$	54	
HD 119213	CrEu	9800	1.5	2.45	$-500/+1200$	–	
HD 120198	Cr	10100	–	1.3807	$-1300?/+200$	37	
HD 134793	SrCrEu	9800	0.5	2.78	$-530/+450$	32	
HD 135297	SrCrEu	–	0.0	2.8	-1100	42	
HD 140160	SrCr	9100	–	1.596	$-1840/+760$	18	
HD 140728	Cr	10000	–	1.296	$-400/+400?$	31	
HD 148112	SrCrEu	9640	0.2	3.043	$-250/-90$	25	
HD 148898	SrCr	8500	0.5	1.8	$-170/+370$	16	
HD 164258	SrCrEu	8500	–	0.83	$-400/+1100$	–	
HD 164429	SrCrEu	10200	–	0.517	-640	44	
HD 170397	Cr	9600	–	2.191	$-650/+870$	36	
HD 171586	SrCrEu	–	1.1	2.1	$-740?$	36	
HD 220825	CrSr	9600	1.4	1.41	$-400/+200$	38	
HD 221394	SrCr	9100	–	2.86	$-1490/-1100$	–	

4 Searches for rotation relationships

4.1 Statistics

Rotation velocity, together with the mass of the star, is its fundamental parameter. For this reason, we will consider different relationships between parameters of magnetic CP stars (effective temperature T_e, depression indicator at 5200 Å Δa and magnetic field ($|B_e(max)|$, $B_e(min)$, $B_e(max)$)) and rotational velocity. It should be borne in mind that some parameters for instance, Δa, can not be derived for the hottest helium and coolest roAp stars.

Let us treat this point in more details. For Si stars the values of Δa are the same for rapid and slow rotators and make a value of the order of 0.03 (on average). The differences begin to arise from stars with temperatures below 11000 K: Δa increases with increasing period for Si+ and SrCrEu stars.

Let us prove this by using the data of Table 19. In this table is represented a sample of Si+ and SrCrEu stars (roAp stars are excluded) with known periods and Δa values. Division into 6 groups was performed depending on the rotational period. The mean values of the parameters are presented.

It can be seen from the Table 19 that the index Δa increases with decreasing temperature of the star and its rotational velocity. In the interval of periods up to 3.3 days the temperature of the star of our sample is the same and approximately equals 9800 K, and the index $\Delta a = 0.035$. The magnetic field strength are also equal: $\overline{|B_e(max)|}$ is about 1100 G. In the interval of periods from 10 to 30 days are situated the coolest stars with temperatures of the order 8500 , this is by 800 K lower then in stars rotating with a period of a week. However, the index Δa dropped for them to 0.038, while the magnetic field $\overline{|B_e(max)|}$ is equal to 1250 G.

For stars with a period more than a month the temperature does not decrease, but even somewhat increases. In the slowest rotators the index Δa is noticed to rise sharply up to 0.066. It is possible that this index reaches a maximum at temperatures of the order of 9000 . The magnetic field of the stars with a period from a month to a year rises again to nearly 2000 G.

Then it decreases again in stars with a period longer that 1 year, however it should be borne in mind that these are poorly investigated stars and the field extrema in them can not be found yet.

To clarify what has a greater effect on the magnetic field and the quantity Δa, the rotational velocity

Table 16. SrCrEu stars with periods from 3.3 to 30 days

HD/BD	pec	T_e	M_V	P ()	$B_e(min)/B_e(max)$	Δa	comments
HD 3980	SrCrEu	8000	1.5	3.952	$-1200/+1300$	38	
HD 10783	SrCr	10000	0.2	4.133	$-100/+1800$	47	
HD 14437	SrCrEu	10700	0.4	26	$-2000/-800$	–	
HD 15144	SrCr	8400	1.7	16	$-1100/-530$	25	
HD 24712	SrCrEu	7350	2.4	12.46	$+200/+1600$	2	roAp
HD 25354	SrCrEu	8900	1.4	3.901	$-350/-20$	–	
HD 25354	SrCrEu	8900	1.4	3.901	$-350/-20$	–	
HD 42616	SrCrEu	9000	0.6	17	$-440/+840$	–	
HD 51418	SrCrEu	9450	–	5.438	$-200/+750$	43	
HD 62140	SrEu	8150	1.9	4.287	$-2200/+3200$	28	
HD 65339	SrCrEu	8460	–	8.027	$-5400/+4200$	57	
HD 72968	SrCr	9700	–	11.3	$-700/+500$	52	
HD 98088	SrCr	8700	0.5	5.90513	$-1200/+1000$	35	
HD 108662	SrCr	10000	0.9	5.07	$-1150/+550$	52	
HD 111133	SrCrEu	9500	–	16.307	$-1500/-500$	51	
HD 112185	Cr	8900	–	5.089	$-50/+150$	25	
HD 115708	SrCrEu	10450	1.8	5.076	$-1500/+900$	0	
HD 118022	SrCr	9450	–	3.722	$-1800/-200$	41	
HD 125248	CrEu	9300	–	9.295	$-2500/+2800$	44	
HD 128898	Eu	7900	2.1	4.479	$-400/0$	–	roAp
HD 137909	SrCrEu	7800	1.1	18.487	$-900/+1000$	31	
HD 137949	SrCrEu	7500	1.7	7.2	$+980/+1920$	32	roAp
HD 142070	SrCrEu	–	0.8	3.37	$-200/+400$	-	
HD 149911	CrEu	8450	-0.1	6	$-2100/+450$	34	
HD 151525	Cr	9600	-0.7	4.12	–	14	
HD 152107	SrCr	8800	1.1	3.857	$+500/+2000$	37	
BD +32°2827	SrCrEu	–	0	> 3	$-770/+50$	–	
HD 153882	Cr	8800	0.1	6.0089	$-1800/+3100$	42	
HD 165474	SrCrEu	7500	0.7	23.4	$-100/+900$	10	
HD 176232	SrCr	7750	1.4	6.5	$-315/+440$	10	roAp
HD 178892	SrCrEu	–	–	~ 7	$+6260/+8490$	–	
HD 343872	SrCrEu	–	–	~ 9	$-760/+4160$	–	
HD 192678	Cr	9000	–	6.42	$+1000/+1800$	71	
HD 196502	SrCrEu	8900	–	20.275	$-700/-200$	45	
HD 335238	SrCrEu	–	0.0	11.2	$-3000/+1200$	–	
HD 208217	SrCrEu	–	1.2	8.445	–	–	
HD 209051	SrCrEu	–	–	—	$-3300/-1000$	–	
HD 216533	SrCr	8450	0.3	17.2	$-1000/+100$	39	

Table 17. SrCrEu stars with periods longer than 30 days

HD/BD	pec	T_e	M_V	P ()	$B_e(min)/B_e(max)$	Δa	.
HD 965	Sr	–	1.2	long	$-400/0$	–	
HD 2453	SrCrEu	8500	0.7	547	$-1000/-300$	63	
HD 8441	SrCrEu	9000	-0.1	69	$-700/+400$	24	
HD 9996	CrEu	9670	0.68	8000	$-1700/+400$	–	
HD 18078	SrCr	7500	-0.7	long	$-500/+1200$	55	
BD $-03°987$	SrCrEu	–	–	long	$+3590/+4040$	–	
HD 59435	SrCrEu	–	-0.4	long	–	–	
HD 81009	SrCrEu	8000	1.2	34.0	$-100/+2500$	40	
HD 110066	CrEu	9800	–	long	$-55/+300$	78	
HD 116114	SrCrEu	–	1.0	long	$-2200/-1900$	–	
HD 126515	CrSr	9300	1.1	130	$-2000/+2000$	45	
HD 134214	SrCrEu	–	2.3	248	$-800/-200$	–	roAp
HD 144897	EuCr	–	–	48	$+2000$	–	
HD 187474	CrEu	10350	–	2345	$-1800/+1800$	67	
HD 188041	SrCrEu	8650	–	224	$-200/+1500$	63	
HD 201601	CrEu	7600	2.3	long	$-1100/+600$	8	roAp
HD 221568	SrCrEu	–	0.1	159	1000	–	

Table 18. roAp stars

HD/BD	pec	T_e	M_V	P (days)	$B_e(min)/B_e(max)$	Δa
HD 6532	SrCr	–	–	1.9450	-517	3
HD 19918	SrCrEu	–	–		-848	–
HD 24712	SrCrEu	7350	2.4	12.46	$+200/+1600$	2
HD 83368	SrCrEu	–	–	2.852	$-800/+800$	–
HD 119027	SrEu	–			–	–
HD 128898	Eu	7900	2.1	4.479	$-400/0$	–
HD 134214	SrCrEu	–	2.3	248	$-800/-200$	–
HD 137949	SrCrEu	7500	1.7	7.2	$+980/+1920$	32
HD 166473	SrCrEu	–			$-2200/-2000$	–
HD 176232	SrCr	7750	1.4	6.5	$-315/+440$	10
HDE 343872	SrCrEu	–	–		$-760/+3860$	–
HD 201601	CrEu	7600	2.3	long	$-1100/+600$	8

Table 19. Mean parameters of cool stars as a function of rotation

Period	Number of stars	$\overline{T_e} \pm \sigma$, K	$\overline{\Delta a}$	$\overline{\lvert B_e(max)\rvert}$, G	$\overline{B_e(min)}$, G	$\overline{B_e(max)}$, G
$P < 1.5$ days	8	9981 ± 163	0.036 ± 0.006	1115 ± 328	-715 ± 310	$+362 \pm 408$
$1.5 < P < 3.3$ days	14	9750 ± 200	0.034 ± 0.003	1107 ± 296	-552 ± 275	$+933 \pm 302$
$3.3 < P < 10$ days	24	9282 ± 488	0.044 ± 0.005	2100 ± 290	-1340 ± 338	$+1716 \pm 267$
$10 < P < 30$ days	11	8500 ± 300	0.038 ± 0.005	1249 ± 209	-1076 ± 250	$+319 \pm 219$
$30 < P < 300$ days	6	8640 ± 238	0.044 ± 0.006	1933 ± 337	-1317 ± 483	$+1333 \pm 419$
$P > 300$ days	4	9040 ± 640	0.066 ± 0.005	1075 ± 309	-839 ± 274	$+750 \pm 466$

Table 20. Dependence of magnetic fields on temperature and rotation

Interval T_e	Number of stars	$\overline{T_e}$	$\overline{\Delta a}$	$\overline{\lvert B_e(max)\rvert}$	$\overline{B_e(min)}$	$\overline{B_e(max)}$
			$P < 3.3$ days			
$10000 - 11000$ K	9	10340 ± 125	0.036 ± 0.005	1376 ± 505	-235 ± 333	$+1151 \pm 475$
$9000 - 10000$ K	10	9540 ± 100	0.035 ± 0.003	1014 ± 243	-926 ± 250	$+437 \pm 274$
			$3.3 < P < 30$ days			
> 11000 K	3	12520 ± 340	0.039 ± 0.001	3166 ± 1278	-2283 ± 1773	$+2433 \pm 560$
$10000 - 11000$ K	4	10200 ± 130	0.054 ± 0.007	1287 ± 210	-562 ± 249	$+1112 \pm 294$
$9000 - 10000$ K	10	9400 ± 60	0.044 ± 0.005	1450 ± 241	-955 ± 362	$+983 \pm 352$
$8000 - 9000$ K	12	8580 ± 90	0.040 ± 0.004	1920 ± 410	-1270 ± 470	$+1380 \pm 436$
			$P > 30$ days			
$9000 - 10000$ K	3	9370 ± 230	0.049 ± 0.015	1000 ± 513	-918 ± 572	$+900 \pm 550$
$8000 - 9000$ K	4	8350 ± 140	0.055 ± 0.005	2025 ± 475	-1100 ± 696	$+875 \pm 681$

or temperature, let us construct an analog of previous Table 19, but at different temperatures. The result of averaging are given in Table 20. The designations are the same.

We conclude that in narrow temperature intervals the quantity Δa depends on the rotational period of the star: the longer the period, the larger Δa. This is confirmed for each of the three temperature intervals 1000 wide that we choose.

An inference can be made that the photometric index, related to the depression depth at 5200 Å depends on temperature and rotational velocity. When making analysis in rather narrow temperature intervals, removing thus the dependence on temperature, obtain that the quantity Δa increases with increasing period of rotation. This consistent pattern shows up in the temperature intervals from 8000 to 11000 for Si+ and SrCrEu stars.

4.2 Stars with the strongest magnetic fields

Our investigations suggest that the longitudinal magnetic field value for stars whose rotational periods are within an interval from 5 to 10 days reaches its maximum. To analyze this problem, we choose stars with the strongest magnetic fields, the longitudinal component of which is above 3 kG. We included in the list also HD 37776 — a champion star as to the magnetic field strength, although it is not suitable according to formal criteria — B_e at maximum does not exceed 2 kG. They are listed in Table 21. In the collumns of this table are given: name of the star, extrema of the magnetic field B_e, effective temperatures T_e, color $B-V$, rotational period (in days), index Δa and peculiarity type.

Thus, there are 26 stars with $B_{extr} > 3$ kG in our list.

Let us analyze some points. It can be seen from the table that only 2 stars have periods longer than 10 days, in both cases (HD 12288 and HD 94660) the longitudinal field B_e being a little stronger than 3 kG in extremum.

6 of 8 stars presented in the table, having anomalous helium lines, are members of clusters and have rotational periods within 1–1.5 days. The two remaining stars, HD 184927 ($P = 9.53$ days) and HD 217833 ($P = 5.4$ days), are not cluster members and have long periods.

By the greatest number (11 objects) in Table 21 are represented the stars with anomalous silicon lines. They have periods from 1 to 35 days, only 3 of them are in the interval 5–10 days. 5 stars with anomalies of SrCrEu and $_{xtr}$, exceeding 3 kG, are distributed in periods in the following manner: 3 of them have periods of about 8 days, 1 — 6 days and 1 — 4 days. The stars of this type with P shorter than 4 days and longer than 10 days have fields no stronger than 2.5 kG.

Note that the first measurements of the longitudinal component of the magnetic field with the Zeeman analyzer for 8 stars out of 26 with the strongest magnetic field have been measured for the first time with the 6 m telescope, which is 31% of the total number.

5 Conclusions

We have made a statistical analysis of magnetic CP stars and tried to find diiferent interrelations between magnetic field magnitude and other physical characteristics. In the previous paragraph it was shown that together with the temperature, in analyzing anomalous characteristics of magnetic stars, one should take

Table 21. Stars with the strongest longitudinal fields

Star	$B_e(min)/(max)$	T_e	$B-V$		Δa	pec
HD 12288	$-3100/-200$	8250	+0.081	35	55	Si+
HD 32633	$-5700/+3500$	12580	−0.052	6.43	40	Si+
HD 36485	$-3700/-1900$	18000	−0.200	1.708	—	He–strong
HD 36526	$-980/+3480$	16400	−0.110	1.54	—	He–weak
HD 37479	$-1600/+3500$	23600	−0.240	1.191	—	He–strong
HD 37642	$-2980/+2700$	16200	−0.122	1.08	—	He–strong
HD 37776	$-2000/+1000$	23050	−0.139	1.537	—	He–strong
HD 62140	$-2200/+3200$	8150	+0.262	4.287	28	SrEu
HD 65339	$-5400/+4200$	8460	+0.158	8.027	57	SrCrEu
HD 66318	-4500		+0.014			
HD 94660	$-3300/-2100$	10800	−0.103	long		Si
HD 96707	$-3900/+800$	8000	+0.219	0.928		Sr
HD 112381	$-3700/-3100$		−0.095	2.8		Si
HD 133029	$+1300/+3300$	11000	−0.108	2.89	57	Si+
HD 133880	$-4400/+1920$		−0.150	0.877		Si
HD 142301	$-4100/+1600$	17300	−0.069	1.459	—	He–weak
HD 143473	$+4200/+5100$		+0.089			Si
HD 147010	$-4500/-2500$	12850	+0.156	3.920		Si+
HD 151965	$-3700/-550$		−0.141	1.6084		Si
HD 153882	$-1800/+3100$	8800	+0.031	6.0089	42	SrCrEu
HD 178892	$+1900/+8000$		+0.300	8.235		SrCrEu
HD 184927	$-1200/+3000$	22500	−0.160	9.53		He–strong
HD 215441	$+10000/+20000$	14900	+0.031	9.4876	21	Si
HD 217833	$-5500/-2000$	16000	−0.130	5.4		He–wk
HD 343872	$-800/+4000$		+0.08	8.87	146v	SrCrEu
HD 349321	$-5500/+2000$		−0.04	5.5		Si+

into account their rotation too. We have obtained the following results: as a rule, the scale of anomalies (for instance, the index Δa) increases with rotational period.

We confirm the results of Landstreet and Mathys (2000) that the magnetic structure of slow and fast rotators differs. In addition to the conclusion drawn by Landstreet and Mathys, we found that the contrast in surface magnetic field between the magnetic poles and equator for fast rotators is higher than dipolar, while for slow rotators it is lower than dipolar.

For the statistical estimations, it is useful to consider reversive magnetic stars (in which the longitudinal component B_e changes sign) and non-reversive (in which B_e is predominantly of one sign). The detailed determination can be found in our paper (Kudryavtsev and Romanyuk 2000). Here we only note that in reversive stars the observer can see both the magnetic poles and the equator, while in non-reversive ones the poles are mainly seen.

If there are systematic differences in the distribution of elements over the surface depending on magnetic latitude, the chemical composition of reversive and non-reversive stars of equal temperature may be different. Let us look at the stars of our sample — from the hottest to the coolest ones — from this point of view.

1. Stars with anomalous helium lines.

   Nearly all He–r stars are non-reversive. He–wk stars with fast rotation are chiefly non-reversive either (9 non-reversive and 7 reversive), while with a period longer than 3 days they are mainly reversive (2 non-reversive and 6 reversive).

   Almost all fast rotators are members of young open clusters (Orion and Scorpio-Centaurus) and at the same time non-reversive stars. This may imply that magnetic configurations of stars — members of the two clusters and their spatial orientations are the same, which points to their collective origin and probably relic origin of their fields.

   All the He–r stars have periods shorter than 10 days, therefore, one may expect larger angles β (although it is not proved) and sharper curves of field variations. None of the He–wk stars has a period greater

Table 22. Number of non-reversive and reversive stars with silicon anomalies

Pec	Period P (days)	Non-reversive	Reversive
Si	< 3	12	5
Si	> 3	5	4
Si+	< 3	7	2
Si+	> 3	4	9

Table 23. Number of non-reversive and reversive stars with SrCrEu anomalies

Period P (days)	Non-reversive	Reversive	$B - V$
< 3.3	9	8	$+0.053 \pm 0.020$
3.3–30	22	12	$+0.130 \pm 0.023$
> 30	8	4	$+0.164 \pm 0.022$

than 30 days, 3 have a period over 10 days. They posses the weakest fields. It seems that for this type stars the longest period is 7 days. At larger periods $_{extr}$ values are not large.

2. Stars with anomalous silicon lines.

   It has long been known that helium and silicon in hot CP stars vary in antiphase, which means that they are distributed in an essentially different manner over the surface: in the majority of cases the regions of concentration of helium and silicon do not overlap.

   As we show above, some common parameters in helium and silicon stars do differ. However, the same law holds, that for helium stars: the fast rotators are mainly non-reversive, while the slow rotators are reversive (see Table 22).

   Another conclusion can be drawn: silicon in CP stars concentrates most frequently in the region of the magnetic poles, that is why it is well pronounced in the spectra of non-reversive magnetic stars predominantly visible from the poles. Si+ stars are also visible from the magnetic equator, because of this, we can observe neither anomalies of silicon, nor of other chemical elements.

   On the whole, for fast rotators we have 19 non-reversive and 7 reversive, while for slow rotators 9 non-reversive and 13 reversive magnetic stars with anomalous silicon lines. On the average, the field is larger for cluster-member stars both for fast and slow rotators.

3. Stars with anomalous lines of strontium, chromium and europium.

   These objects do not show such sharp differences between slow and fast rotators as the stars of previous types. The data on them are collected in Table 23.

   With increasing period the reddening is observed to increase.

In the end, the analysis of 26 stars with the strongest longitudinal field ($B_{extr} > 3$ kG) shows that 20 of them are non-reversive, 5 are reversive, and for the remaining one star insufficient number of observations were made. It can be seen that the non-reversive stars are, on the whole, hotter, among them are 7 helium stars, 11 silicon ones and only 2 cool SrCrEu stars. For 13 non-reversive stars temperatures are found: 11 of them have $T_e > 10000$ K. Things are different for the reversive stars: 3 out of 5 objects are cool SrCrEu stars, 1 helium and 1 silicon star. 3 stars from 5 have temperatures below 10000 .

Thus, the stars visible mainly from the magnetic poles have stronger magnetic fields B_e (which can be explained on the whole), are hotter, the relative number of fast rotators among them is essentially larger.

This phenomenon is yet to be explained. In our opinion, a certain role may be played by the observational selection effects (the stars visible from the poles are easier to detect). Apparently the atmosphere of the star in the region of magnetic poles is, on the whole, hotter than in the magnetic equator region.

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