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On the magnetic field of 52 Her

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Abstract.
The measurements of the magnetic field of 52 Her accumulated by the present time are characterized by extremely high dispersion of results. In this paper we make attempt to simulate the magnetic field measured by different authors under the assumption of the central dipole. It is shown that this model too badly describes the phase curves. The quadrupole model yields better results. It is assumed that the instability of measurement results is most likely due to the complex quadrupolar structure of the magnetic field and very broad spectral lines (0.4 Å). The modeling showed that the dispersion of measured field strengths can not be explained by the star precession. To finely solve the problem of the field structure, new measurements with new techniques are needed.

Key words: stars: chemically peculiar – stars: magnetic fields – stars: individual: 52 Her

1. Introduction

52 Her (HD 152107, HR 6254) is a magnetic chemically peculiar star of SrCrEu type, its apparent stellar magnitude m = 4.83, spectral class Sp = A3. The measurements of its magnetic field made by different authors in different periods of time are noted for the extraordinary and systematic differences.

The magnetic field of the star was first measured by Babcock (1958). He found that the star has an average effective field Be, being always of positive polarity, but an accurate measurement of the field turned out to be difficult because of the wide spectral lines (w = 0.4 Å). Very weak photometric and spectral variability was noted in the paper by Wolff and Preston (1978). Only the line K (Ca II, $\lambda 3933$) undergoes pronounced variations, from which the authors estimated the period of rotation P = $3^d.8575$. Subsequently attempts were made (Bychkov, Shtol 1992), to ascribe to the star other periods, including a longer one, which seemed to be unlikely for the following reasons.

The star has the temperature $T_e = 8700$ K (Glagolevskij 1994), the rotational velocity $\nu sin_i =$ 24 km/s (Wolff, Preston 1978), and the bolometric magnitude M_b =0.95 (Glagolevskij, 2002).Then its radius in fractions of the solar radius proves to be as follows:

$\lg R/R_\odot = 8.46\text{-}2\lg T_e - 0.2M_b = 2.4R_\odot$.

By the known formula, the rotational velocity at the equator $\nu = 50.6R/P = 31.5$ km/s, and from $\nu sini = 24$ km/s we have the inclination angle of the star to the line of sight $i = 50°$. In the paper by Wolff and Preston (1978) the estimate $i \geq 35°$ is given, and the angle between the dipole axis and the rotation axis is $\beta \leq 26°$. From the parameters obtained, one can readily derive the range of possible periods. By substituting different periods into the formula $\nu = 50.6R/P$ and computing the angle i from $\nu sini = 24$ km/s obtain that even at $P > 5^d$ the angle $i = 90°$. Thus, the possible period is $P < 5^d$. The quantity $P = 3\overset{d}{.}8575$ is not at variance with this condition.

To improve the accuracy of the results, additional measurements were needed. After the measurements of Babcock (1958) and Wolff and Preston (1978) measurements appeared in the papers by Borra, Landstreet (1980) and Gerth (1990), the former being made from the hydrogen line. Therefore, in a first approximation they must be free from the influence of the inhomogeneity of the distribution of chemical elements over the surface.

The measurements of Gerth are the most numerous, and they were made during many years at different telescopes, including the 6 m telescope BTA, with a moderate, about 10 Å/mm, dispersion. The measurements of all the authors were obtained with photographic techniques.

The present paper is concerned with the task of modeling the magnetic field of 52 Her from the data of different authors and comparison of model calculations to find out what kind of variations in the model may occur because of the observed differences in the measurement results.

Table 1: *Parameters of the magnetic field models of 52 Her in approximation of central dipole obtained from the measurements made by different authors*

No	Sign	i	λ	δ	B_p, kG	β	Measurements
1)		> 35°	-	-	-	< 26°	Wolff, Preston (1978)
2)	+	50	70°	55°	1.62	35	Borra, Landstreet (1980)
	−	-50	250	-55	-1.62		
3)	+	50	0	75	2.92	15	Wolff, Preston-1 (1978)
	−		180	-75	-2.92		
4)	+	50	20	50	1.78	40	Wolff, Preston-2 (1978)
	−		200	-50	-1.78		
5)	+	50	15	40	3.10	50	Gerth (1990)
	−		195	-40	-3.10		
6)	+	50	$\mathbf{26} \pm 13$	$\mathbf{50} \pm 8$	$\mathbf{2.35} \pm 0.38$	$\mathbf{33} \pm 6$	Average
	−		$\mathbf{206} \pm 15$	$\mathbf{-50} \pm 8$	$\mathbf{-2.35} \pm 0.38$		

2. The model from the data of Borra and Landstreet

Unfortunately, the measurements made by Borra and Landstreet are too few, and therefore the reliability of the model is not high. Usually, in the cases where two observed phase relationships are available: $B_e(P)$ for the average effective magnetic field and $B_s(P)$ for the average surface magnetic field, the inclination angle of the star i is determined automatically in modeling. In the given case there is no phase relationship for the field B_s. For this reason the inclination angle of the star i is found from $\nu sini$. Above, we estimated the angle as $i = 50°$. To construct the model, we used a method of "magnetic charges" that we developed, which is described in detail in the paper by Gerth, Glagolevskij (2000). The best fit of the model and observed phase relations $B_e(P)$ on the assumption of the central dipole is achieved with the parameters obtained from data of Borra and Landstreet (1980) (Table 1, in which λ, δ are the coordinates of "magnetic charges" (longitude and latitude), B_p is the field strength at the poles, β is the angle between the dipole axis and the star rotation axis). The first line of Table 1 gives the parameters derived by Wolf and Preston (2000), the last one — the mean values of the parameters and their root-mean square errors. Our modeling results listed in the table will be discussed below.

In Fig. 1 are displayed the observed (dots) and model (solid curve) phase relationships. Because of the small number of measurements, the derived model should be considered as a first approximation.

3. The first model from the data of Wolff and Preston

We constructed this model from the Lick Observatory data (Wolff, Preston 1978). On the average, they differ by +800 G from the measures of the same authors on Mauna Kea and from those of Borra and Landstreet (1980) despite the closeness in years. The cause of such a great difference is not clear. As in the previous case, we used the central dipole model. The results of comparison of the observed and simulated phase relationship are displayed in Fig.2. The dots in the figure denote not the original measurement data but the values averaged over the measurements by the method of moving average over 5 points. This was done because the dispersion of the measurements was very high. The model was derived using the parameters shown in the 3rd line of Table 1. The difference in the B_e measurements from the data of Borra and Landstreet by the average of +800 G caused an increase in the field by 1300 G at the poles. The angle β turned out to be twice as small.

It is interesting that the field is observed to increase at phases $P = 0 - 0.1$ and $0.6 - 0.7$, which will be discussed together with the results of Gerth (1990) later.

Another difference between the given model and the previous one consist in that the extremes fall at phases 0 and 0.5 but not at 0.2 and 0.7 (however, this may result from the unreliability of the previous model because of the small number of measurements).

4. The second model based on the data of Wolff and Preston

Consider model 2 constructed from the data obtained by Wolff, Preston (1978) on Mauna Kea. The number of measurements is not sufficient, the scatter of point is large, that is why, the reliability of the model is not high. The mean value of B_e is equal to the mean value from the data of Borra and Landstreet (1980) as distinct from the previous case. The result of modeling is exhibited in Fig. 3, the designations

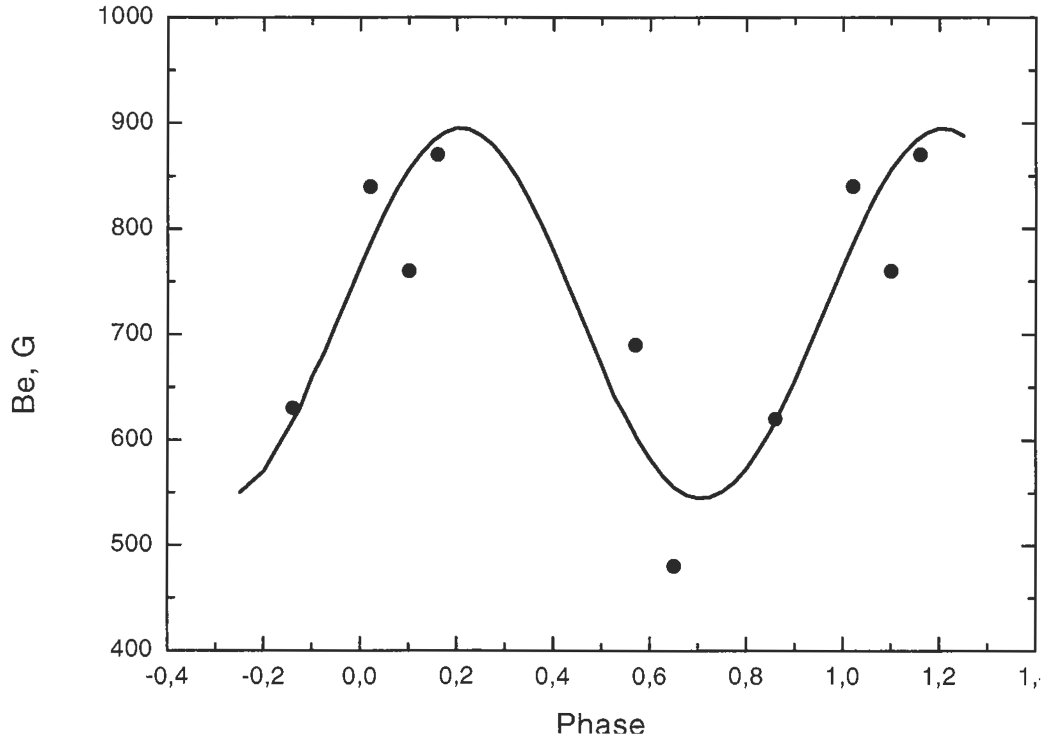


Figure 1: *The observed* B_e *strength (dots) from the data of Borra and Landstreet (1980) and the model relationship under the assumption of the central dipole model.*

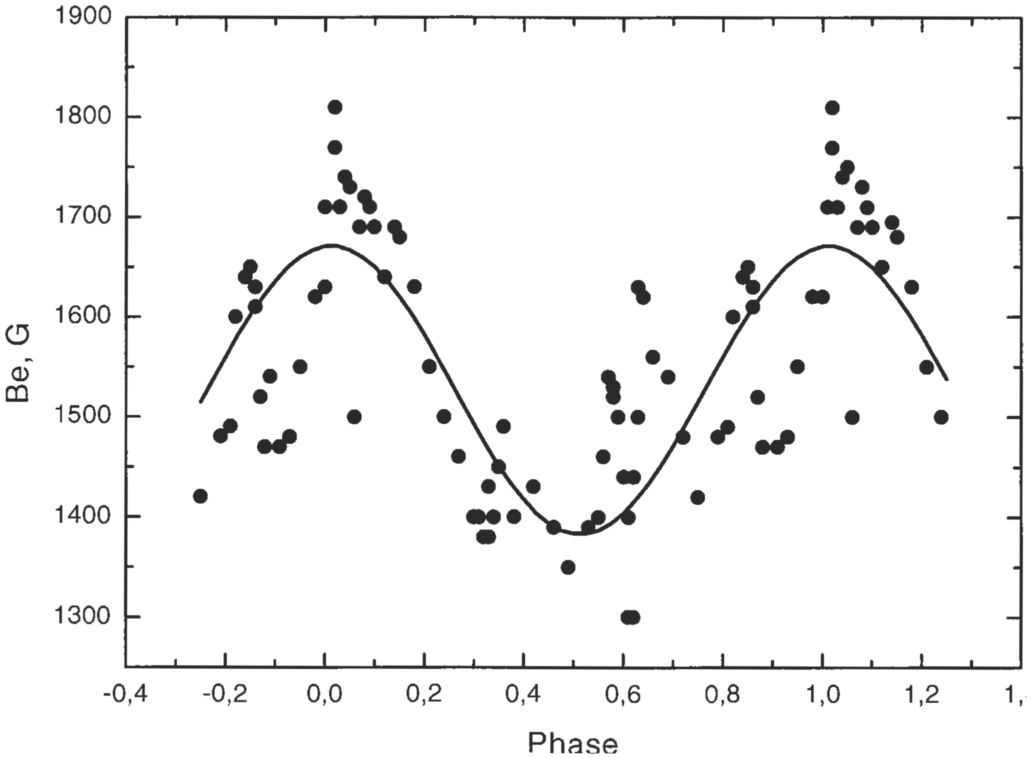


Figure 2: *The observed* B_e *strengths (dots) (Wolff, Preston 1980) and the first model relationship (central dipole).*

1978

Table 2: *Corrections*

Year	1971	1975	1979	1980	1982	1983
ΔB_e	0	−500	+630	−250	−310	+430
n	18	27	16	18	9	9

are the same. The parameters of the model are given in line 4 of Table 1. The inclination angle of the star is the same, $i = 50°$. The field at the poles proved to be $B_p = 1.78$ kG, approximately the same as in the case of the model from the data of Borra, Landstreet (1980). Neither did the angle $\beta = 40°$ change. A small shift of charges, by +20°, as compared to the 1st model may be due to the great scatter of points. This model is similar to the one obtained from the hydrogen line measurements of Borra and Landstreet.

5. The dipolar magnetic field model from the measurements of Gerth

The measurements of Gerth (1990) are the most numerous. The characteristic result of these measurements is the presence of a field with negative strength in 1977, 1978 and 1979. It is also stated in this paper that the magnetic field of 52 Her may have a secular trend (note that a similar effect is supposed in the paper by Wolff, Preston (1978)). In order that possible secular variations do not distort the phase relationship of the measurements made by Gerth in different years, we reduced them to the mean data by introduction of the quantity ΔB_e equal to the difference between average field obtained in all the years and the average field obtained in the given observational run. These values are presented in Table 2, a total number of measurements which were used is n = 97. We did not take the measurements obtained during the observational runs in which $n < 9$ because the quantity ΔB_e becomes uncertain.

It can be seen from Table 2 that the correction values do not change smoothly at all, rather they are random. The relationship B_e — the phase of the period P, plotted from the presented measurements, shows considerable scatter of points as in the case of the data of Wolff and Preston (1978). For this reason, it is difficult to understand the true phase relationship. In order to make it more clearly defined, all the field values were averaged over ten measurements by the moving-average method. The phase relationship plotted from these data is shown in Fig. 4 by dots. The magnetic field varies intricately. During the period of rotation the field undergoes 2 maxima and 2 minima, the maxima are near the phases $P = 0$ and 0.6 (as in the case of the 1-st model of Wolff and Preston), the minima are at the phases $P = 0.4$ and 0.8. On this basis we draw the conclusion that the structure of the magnetic field of 52 Her does not correspond to the dipolar model. One may attempt to describe the phase curve by the dipole model only as a first, rough approximation. In this case the calculated and the observed curves turn out to fit best if the former is derived from data of Gerth (1990) (see Table 1). The model curve in Fig. 4 differs greatly from the observed phase relationship. The dipole axis lies in a plane between the equatorial plane and the rotation axis. The marked difference of B_p from the previous results is due to the fact that the observations of Gerth show a considerably larger amplitude of B_e variations.

Table 3: *Parameters of quadrupole model 1*

No of charge	Sign	λ	δ
1	+	0	10
2	−	162	−17
3	+	190	0
4	−	308	−17

6. Quadrupole model 1

The number of measurements (54) obtained by Wolff and Preston (1978), Borra and Landstreet (1980), Bychkov et al. (1992) is smaller than the number of measurements made by Gerth (1990); the scatter of points is also less. Having reduced all the measurements to the data of Borra and Landstreet and having averaged them by the moving-average method over 10 measurements, we derived a phase relationship displayed in Fig. 5 by dots. It has a smaller amplitude than the one constructed from the data of Gerth, although the characteristic features are the same. Sharp maximum and wide minimum are well seen, but the peak at phase 0.6 visible from the measurements of Gerth is absent. To confirm this peculiarity, additional high accuracy measurements are needed.

It is seen from the distribution of points in Fig. 5 that the phase relationship is not consistent with the central dipole model. Using the method of "magnetic charges", by means of successive approximations we obtained a model which corresponds best to observations (solid line in Fig. 5). A model of two dipoles describes satisfactorily the characteristic shape of the phase relationship, the "magnetic charges" being shifted from the center of the star by a distance $r = 0.3R_\odot$. The coordinates of the charges are given in Table 3. The calculations were performed assuming the inclination angle of the star to be $i = 50°$. The model phase relationship is shown in Fig. 5 by the solid line. The field strength at the poles $B_p = 2.6$ kG.

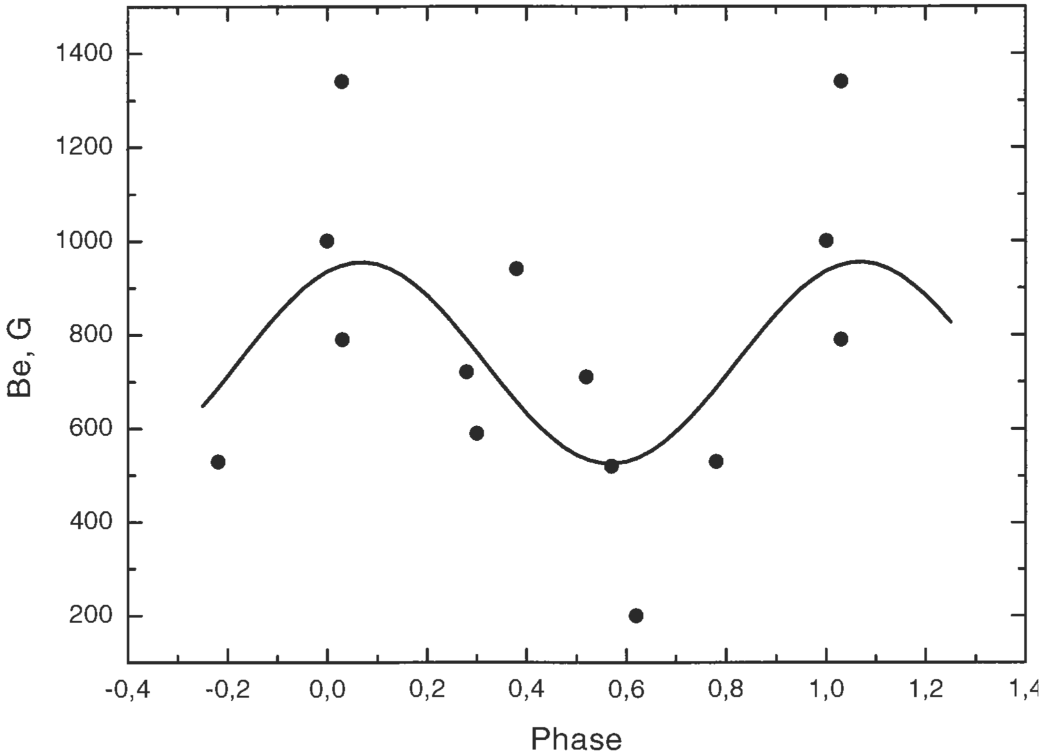


Figure 3: *The observed Be strength (Wolff, Preston 1978) and the second simulated relationship (central dipole).*

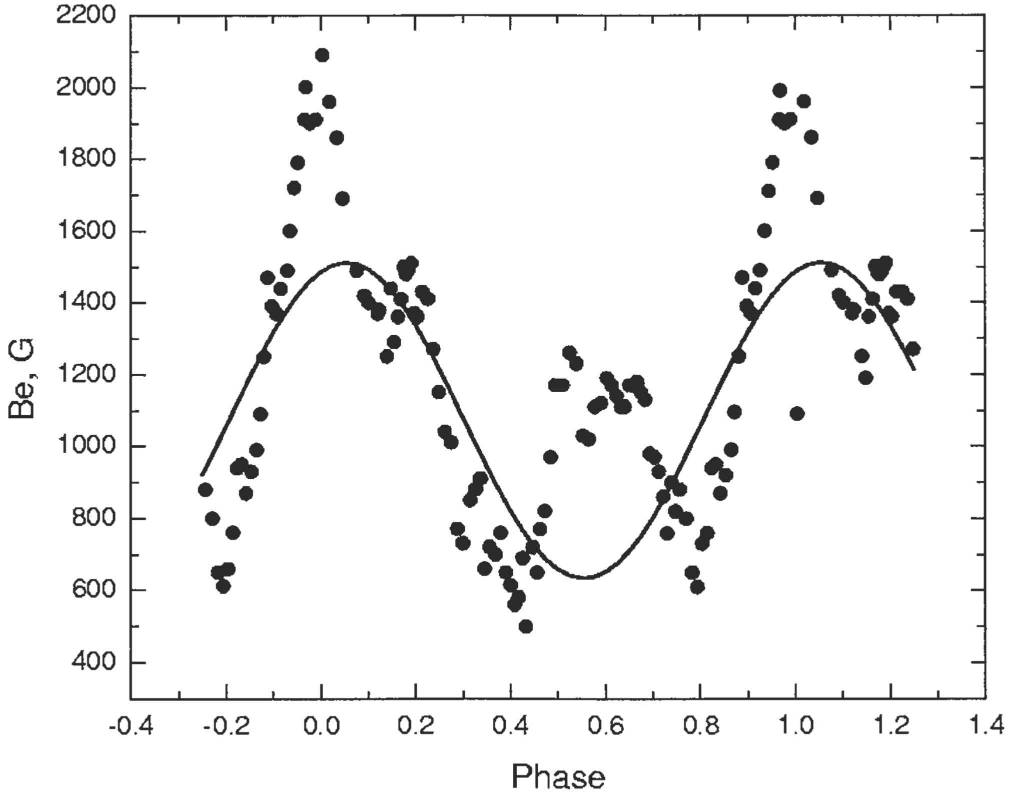


Figure 4: *The observed Be strength (Gerth 1990) and the simulated relationship (central dipole).*

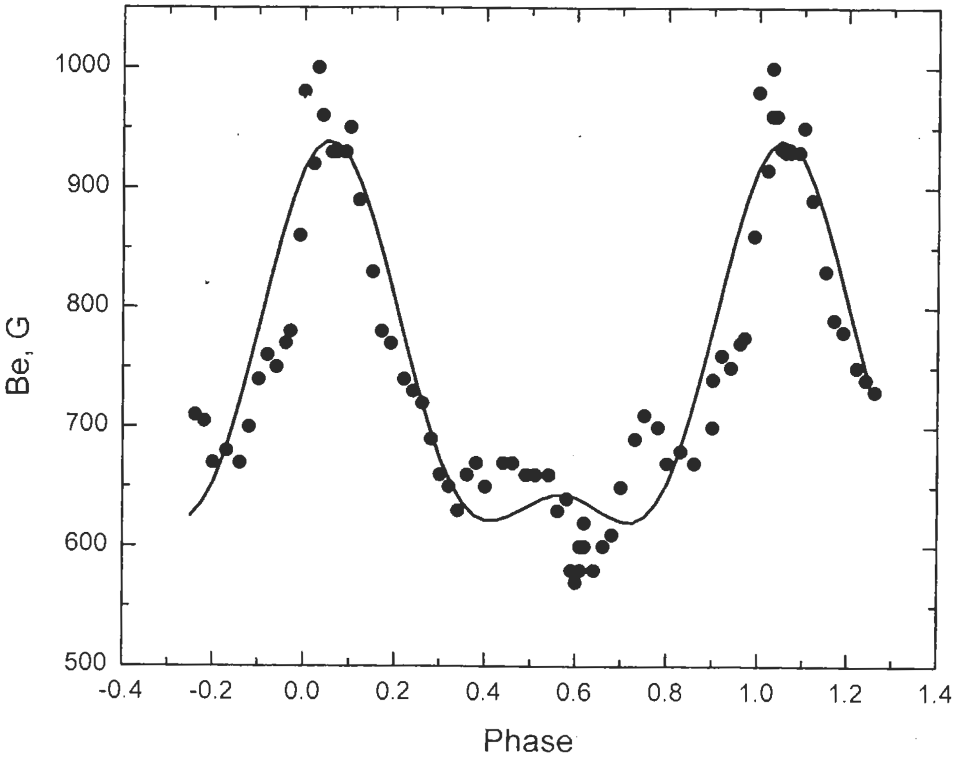


Figure 5: *The observed B_e strength (Wolff, Preston 1978; Borra, Landstreet 1980) averaged by the moving-average method and the model relationship (double dipole).*

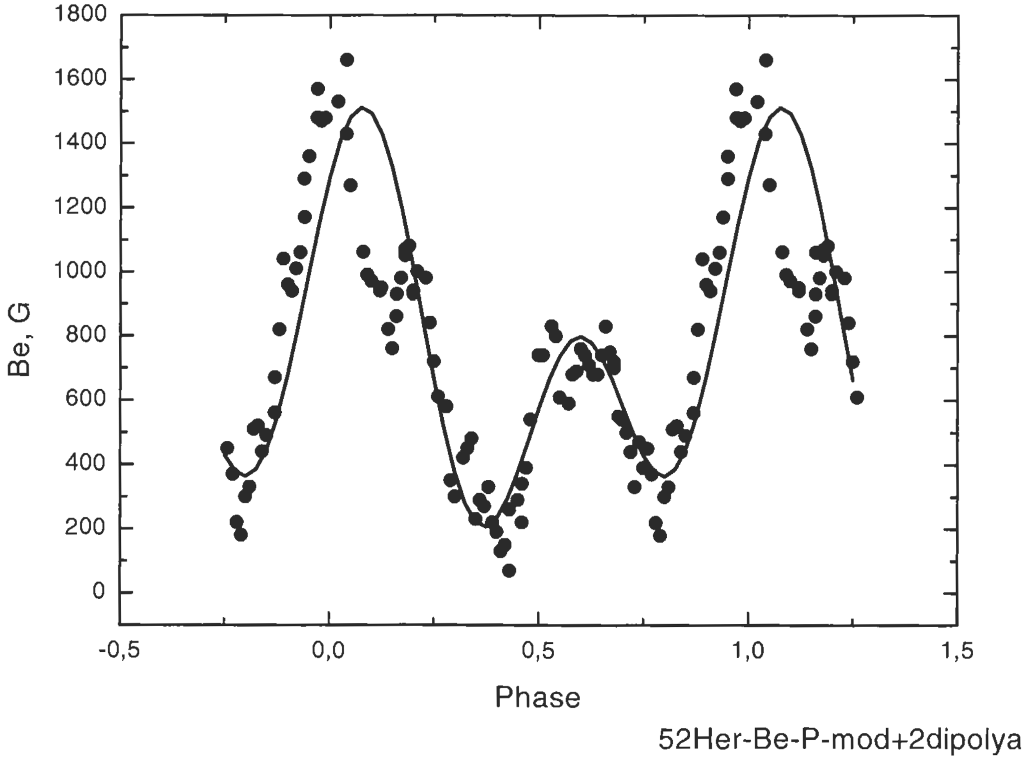


Figure 6: *The model from the data of Gerth (1990) (double dipole).*

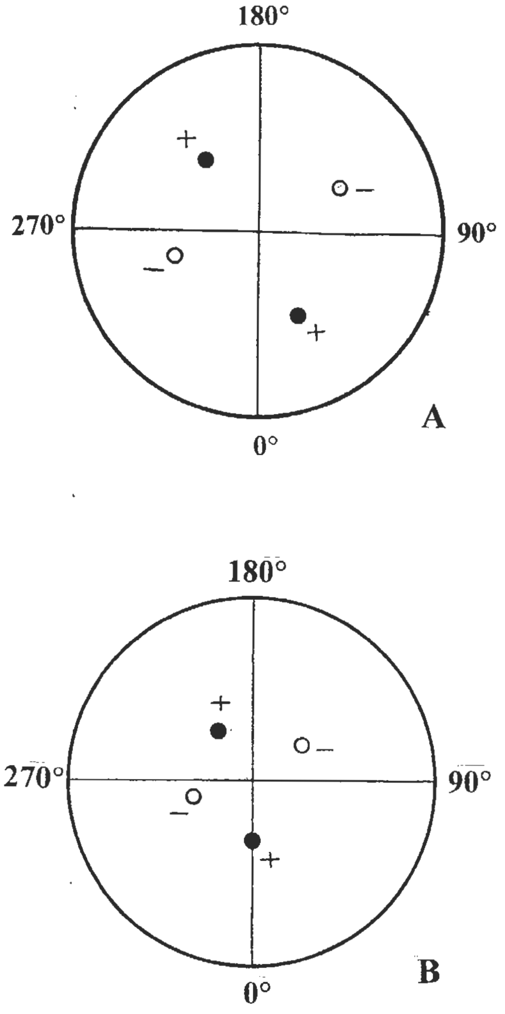


Figure 7: *The distribution of magnetic charges inside the star (view from the pole of rotation), A is the model computed from the data of Gerth (1990); B is the model obtained from the data of Borra, Landstreet (1980); Wolff, Preston (1978).*

7. Quadropole model 2

This model was constructed from "positive" data of Gerth (1990). To obtain a model which would describe all the maxima and minima in Fig. 6, we had to assume two dipoles shifted across the rotation axis to be present as in the previous case (that resemble very much the model of β CrB (Glagolevskij, Gerth 2003a)). The quest of an optimum model was carried out by the method of successive approximations. The simulated phase relationship is displayed in Fig. 6 by the solid line. It can be seen that the part of the relationship near $P = 0.5$ is in good agreement with the measurements, while the part of it near $P = 0$ agrees with the measurements only approximately. This may result from the high dispersion of measurements and may be a consequence of the peculiarity of the distribution of chemical elements from which the magnetic field was measured. The model parameters are given in Table 4.

Table 4: *Parameters of quadrupole model 2*

No of charge	Sign	λ	δ
1	+	25	7
2	−	120	−6
3	+	215	0
4	−	285	−4

The angles β turned out to be close to 90° for each dipole. It is characteristic that the monopoles are located at a distance of half the star radius ($r = 0.5R_{\odot}$). This model only slightly differs from the previous one, but for the fact that all magnetic charges are shifted on the average by $\Delta r = +0.2R_{\odot}$ towards the surface of the star.

The field strengths at all magnetic poles are approximately alike, on the average, 4.8 kG. The pattern of the distribution of magnetic charges for models 1 and 2, when viewed from the pole of rotation ($i = 0°$) is shown in Fig. 7A and B, respectively. It can be seen from the figure that in a first approximation this is a distorted quadrupole.

Based on the data available, one can not say whether the field inside the star is in fact nonsymmetric, or the irregular distribution of charges is due to measurement errors. All charges lie near the equatorial plane. Mercator's chart of the field strength distribution over the surface for the second model is exhibited in Fig. 8.

Comparison of both quadrupole models shows that in a first approximation they are the similar. The non-dipolar magnetic field structure is likely to cause ambiguity of measurements obtained by different authors with different spectrographs and under different conditions. For instance, the phase curves for β CrB, which also has the quadrupole field structure, derived by different authors are also considerably different. The differences amount to 1 kG in the same phases of the period.

8. Negative magnetic field values

The dots in Fig. 9 show the smoothed (by the moving-average method over 5 points) phase relationship obtained from negative values (Gerth 1990) of the magnetic field in 1977, 1978 and 1979 measured at the 2 m Tautenburg telescope. All these data are reduced to 1977. The shape of the relationship is considerably different from the shape the "positive" phase curve has: the amplitude does not exceed a few hundred gauss. This situation occurs only when the star turns to face the observer by the pole of rotation ($i = 0°$).

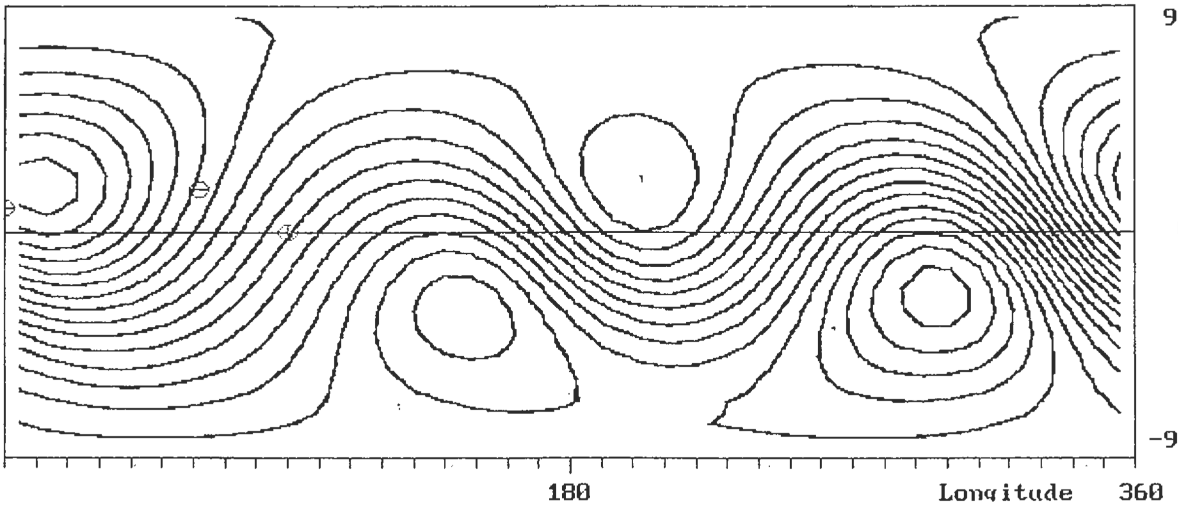


Figure 8: *The chart of the distribution of the surface magnetic field intensity according to the model constructed from the data of Gerth (1990).*

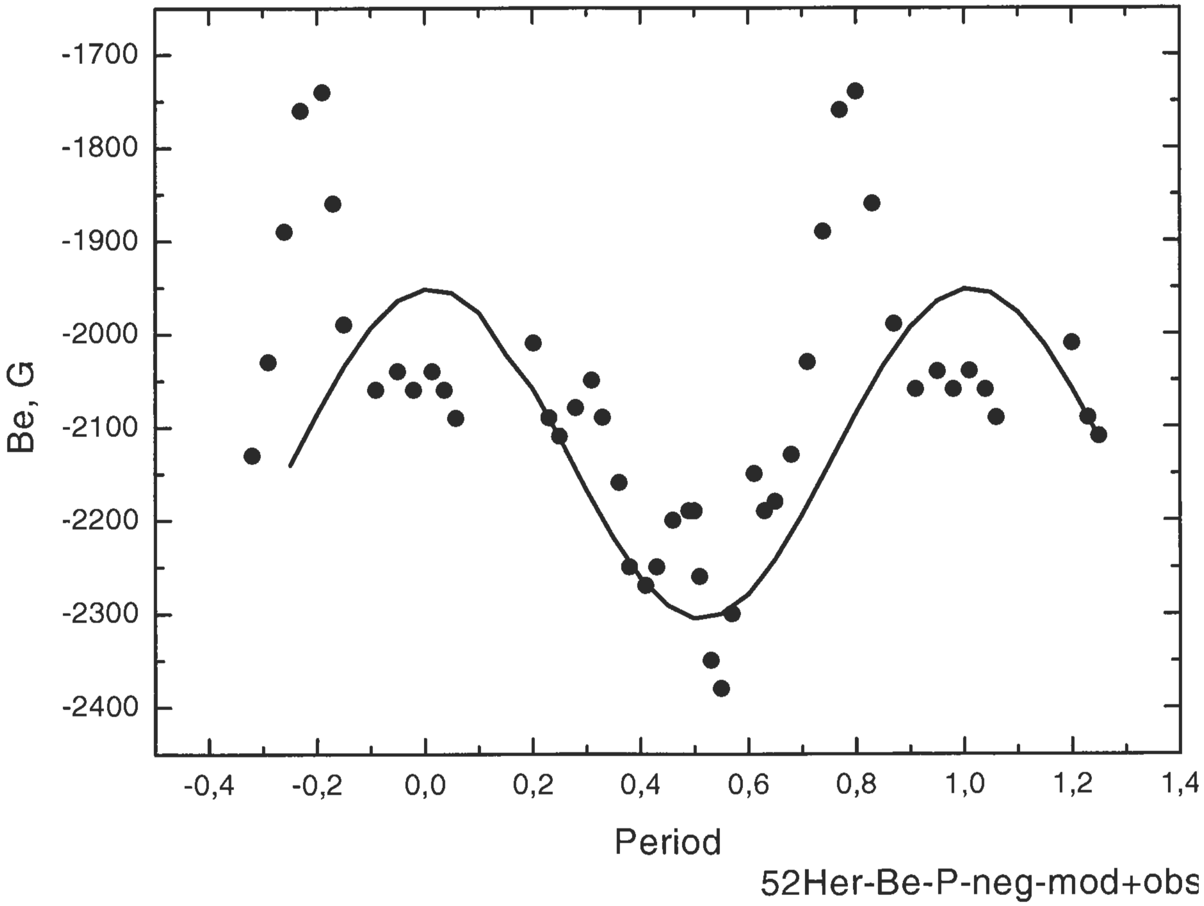
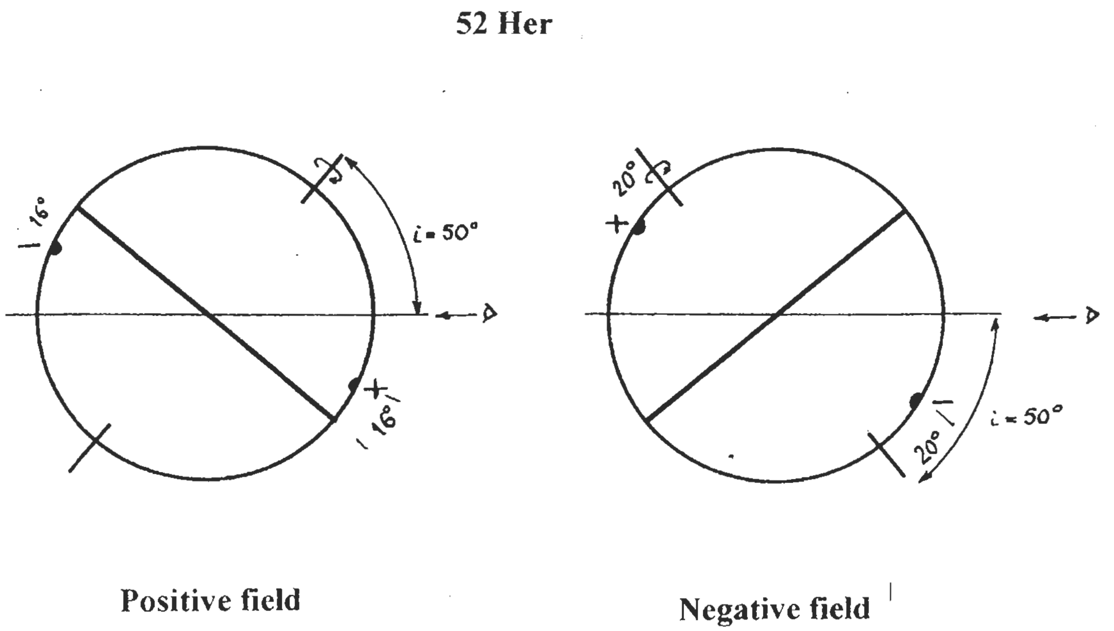


Figure 9: *The phase curve of the magnetic field in the period of negative field values (Gerth 1990).*



Positive field **Negative field**

Figure 10: *The orientation of the star 52 Her derived by simulation of the magnetic field from "positive" and "negative" values.*

Gerth (1990) suggested that such a change could take place as a result of precession in a close binary system. It follows from the models derived that the variation of the star inclination with respect to the observer alone cannot explaine shape of the "negative" phase relationship. Model phase curves obtained for different inclination angles i of the star show that the shape of relationship and its position are totally inconsistent with the phase relationship in Fig. 9. The orientation of the star with respect to the observer in correspondence with the dipole models obtained from "positive" and "negative" data is shown in Fig. 10. To explain the behavior of the field in this period, one has to assume not only a change in the star orientation but also a fundamental change in the structure of the field, which seems to be quite improbable. The quadrupole model is unable to explain this effect either. For this reason, it can be concluded that in consequence of the complex non-dipolar structure of the field erroneous estimates of the field strength and sign could probably arise.

9. Conclusions

By means of simulating the magnetic field of the star 52 Her using measurements of different authors it was managed to get a fuller view of the properties of this star.

1. The causes of the great scatter of points and the instability of results of measurements were considered in the paper by Wolff and Preston (1978). The causes may be different. As has already been mentioned, the star is a fast rotator. The value $v\sin i$ = 24 km/s is generally believed to be limiting, at which it is still possible to measure the magnetic field with sufficient accuracy by the photographic procedure. Secondly, the field is likely to be more complex than dipolar. Consequently the shape of the profiles differs significantly from the shape that must be with a dipolar field. This suggests that measurement results are strongly dependent on the spectral resolution, the method of measurement, the way of pointing at the line, the manner of choosing the profile center of gravity etc. All this leads to unstable results. The short period of time when negative fields were observed proved to be an involved problem (Gerth, 1990). It can hardly be expected that in the stable atmospheres of the CP stars, so stable that even processes of diffusion of chemical elements were possible, noticeable changes in the magnetic field structure and strength could occur. A great deal of research done over the passed years prove conclusively the remarkable stability of the magnetic flux during the whole lifetime of the star on the main sequence, but, possibly, near the ZAMS (Glagolevskij, Gerth 2003b).

2. We have tried to analyze the observational data for 52 Her, which have been accumulated by the present time to refine the magnetic field model. It is impossible yet to decide unambiguously whether the type of the field in 52 Her is dipolar or more complex. The model is most likely to be closer to quadrupolar. Nearly all the measurements lead to a similar characteristic shape of the phase relationship $B_e(P)$: a sharp

maximum near the phase $P = 0$ and a wide minimum at the phase $P = 0.5$, while the central dipole must lead to a sinusoidal shape of the phase relationship.

3. The extraordinary dispersion of the measured field strengths may be an indication of a complex structure of polarization in lines. The four magnetic spots with alternating polarity must cause inevitably large errors of measurements by the Zeeman procedure because on the visible part of the surface there exist simultaneously regions with positive and negative strength, which causes superposition of polarization of opposite signs. No wonder that erroneous results, even the change of the sign, may be obtained at individual phases of the period.

4. With the field configuration that we have considered, even small precession variations may, in principle, cause great differences in the results of measurements. Without rejecting completely the idea of influence of precession one can assert that it is not as strong as it was supposed. The modeling that we have carried out shows that a mere turn of the star by any angle cannot result in great negative values of field strengths. For this reason, instrumental and method effects are more likely.

5. As yet, there have been no convincing data on the existence of secular variations of the "positive" field. The variations that are being observed may be erroneous for the reasons mentioned above. Additional high accuracy measurements of the field of this interesting star with the use of new techniques are necessary, the more so as 52 Her is the only star showing so discrepant results.

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