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REMARKS ON THE PROPERTIES OF THE MAGNETIC FIELD OF THE STAR HD37776

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Studies of the magnetic field and its structure in the star HD37776 by various authors are discussed. Significant conflicts among these results are noted which suggest that the star has not been definitively studied. The main reason for the erroneous results is the complexity of the magnetic field structure. This leads to difficulties in measuring and interpreting the magnetic field.

Keywords: *magnetic fields of stars: models: the star HD37776*

1. Introduction

Here we again examine the magnetic field of the unique magnetic star HD37776 because studies of this star are highly contradictory. The history of research on it is quite rich. We are interested primarily in the internal structure of the magnetic field of this star, because a surface structure does not exist as such. Chemically peculiar (CP) stars usually have strong surface magnetic fields with large-scale magnetic structures that are adequately described by virtual magnetic dipoles inclined to the axis of rotation. A plot of the variation in the longitudinal component Be of the magnetic field is similar in this case to a sinusoid because of the star's rotation. The star HD 37776 (like the stars HD18078 and 149438 [1]) is an exception to this general tendency. It has a rotational modulation of the

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longitudinal magnetic field that indicates a complicated surface and internal structure of the field.

2. Results of previous studies

Thompson and Landstreet [2] first obtained a phase plot of the longitudinal magnetic field *Be*(Φ) of the star HD37776 using an Hβ polarimeter. The advantage of these measurements is that they were obtained on hydrogen lines and were not subject to the influence of the nonuniform distribution of different chemical elements over the surface. The phase curve has an unusual shape; over a single rotation period, two positive and two negative maxima of the magnetic field are observed, in fact six, as subsequent data will show. These authors decided that a quadrupole field structure is most probable. It is assumed that there are two current loops inside the star which create two magnetized volumes and lead to a two-dipole structure of the magnetic field. Thus, for the first time a star with a complicated magnetic field structure was found that was different from the usually observed simple single-dipole magnetic field and the actual internal structure of the field was predicted.

Bohlender [3] described the variation in the magnetic field of HD37776 by proposing a dipole + quadrupole + octupole magnetic field structure. Thus, for the first time a **mathematical description of the shape** (not a physical explanation!) of the phase dependence of the variation in the longitudinal magnetic field *Be*(Φ) of HD37776 was realized.

Bohlender and Landstreet [4] again discussed a complicated model for the magnetic field of HD37776 that gives a good description of the phase dependence *Be*(Φ) of the magnetic field. As opposed to Ref. 2, where the magnetic field distribution over the surface is determined by two virtual magnetic dipoles inside the star, here the distribution of the field on the surface is **described** by a mathematical combination of dipole, quadrupole, and octupole. It is important to note that the model predicts a maximum magnetic field on the order of **60** kG on the surface. Here three values of the magnetic field are obtained which correspond, respectively, to a dipole, quadrupole, and octupole. Evidently, **they have no physical significance and do not imply that points with such an intensity exist on the star's surface.** Experience with using this method shows that values of the magnetic field corresponding to a dipole, quadrupole, and octupole are always high (see the *Conclusion*), but sometimes researchers treat them as real surface quantities.

An angle of inclination $i = 90°$ of the star HD37776 has been estimated and a model of a magnetic field consisting of collinear dipole + quadrupole + octupole with corresponding magnetic fields of 3.4, -59, and 44 kG constructed in Ref. 5. We note, by the way, that knowledge of the angles i is crucial for modeling and for studies of the origin and evolution of magnetic stars, but the value of $i = 90°$ for this star was not confirmed subsequently. We make the same comment regarding the unreality of the multipole method for describing the surface structure of a magnetic field as in the previous example.

A new method for modeling magnetic structures was developed in Refs. 6-8. A program was developed for modeling the magnetic fields of chemically peculiar (CP) stars assuming they have a dipole structure (an early name was the "magnetic monopole" method). Thus, the problem was to find an internal magnetic field structure that would create an observable surface distribution of the magnetic field, as is done correctly in Ref. 2, rather than provide a formal mathematical description of the surface structure of the magnetic field. The reasons for this sort of assumption are given in the *Conclusion*. This method was used later (2001) to study a model for the magnetic field of HD37776.

Romanyuk, et al. [9], have discussed the history of research on HD37776, introduced its main parameters, and presented data from spectral observations. It turns out that the longitudinal magnetic field *Be* measured using helium lines varies over ±20 kG, rather than over ±2 kG as in Ref. 2. The authors note the record strong local field, which reaches **60** kG, during measurements of the lines of several chemical elements (the results are examined in more detail below), and that this result confirms the predictions of the multipole models [3,4]. Romanyuk, et al. [9], cite the relationship of the variation in the intensity W_λ of the $\lambda 5875.7$ helium line and the phase of the rotation period. A broad maximum is observed at phases $\Phi \approx 0.5-1$, and at $\Phi = 0.3$ a narrow minimum. This relationship will be analyzed in section 3.

Another attempt has been made [10] to find a construction consisting of a dipole, quadrupole, and octupole for describing the observed phase dependence of *Be*(Φ) for HD37776. A mathematical construction of this sort was found but, as noted above, it is physically meaningless (see the *Conclusion*).

Khokhlova, et al. [10], have studied the magnetic field configuration of HD 37776 using a Doppler-Zeeman mapping technique based on spectra obtained with a 6-m telescope [9]. Here it was found that the angle $i = 90^\circ$ estimated in Ref. 5 is wrong; in fact it lies within 30-50°. In a solution of the inverse problem, a magnetic field configuration was sought in the form of a combination of a dipole, quadrupole, and octupole with arbitrary orientation located in the center of the star. The distribution of the magnetic field over the surface was studied using lines of different chemical elements. It was noted that in this way Doppler-Zeeman mapping of the rapidly rotating magnetic star HD37776 was carried out for the first time. Figure 1 shows a chart of the distribution of the magnetic field over the surface of HD37776 using Zeeman spectra of helium. This distribution by no means corresponds to the dependence of *Be*(Φ) from Ref 2. The result was the same when lines of other chemical elements were used. It can be seen from later papers on modeling the magnetic field distribution over the surface of HD37776 that the distribution obtained in Ref. 10 has nothing in common with them, including when the same observational material is used. A complicated magnetic field topology is definitely established in Ref. 4, owing to the fact that the phase

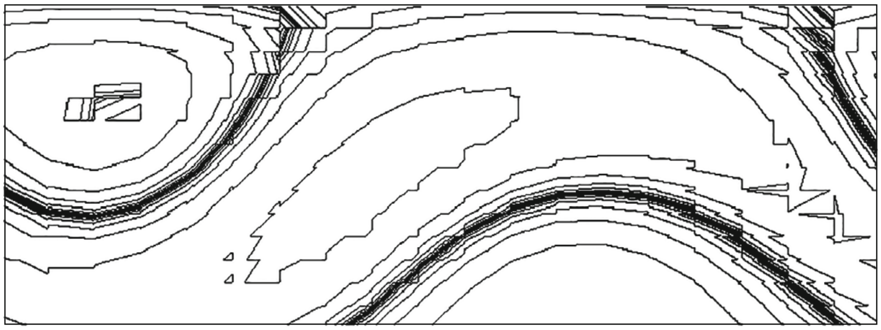

Fig. 1. The distribution of the magnetic field over the surface of HD37776 obtained by Doppler-Zeeman mapping.

dependence has two positive and two negative extrema. Nevertheless,in this model this fact absolutely does not show up. The authors emphasize the fact that regions with an extreme magnetic field *Be* = **60** kG exist, which confirms the result in Ref. 4.

A model of the magnetic field of HD37776 by the "magnetic dipole (monopole)" method has been constructed in Ref. 11 using the phase dependences of the longitudinal field *Be*(Φ) from Ref. 2 and the average surface magnetic field *Bs*(Φ) (mean magnetic field modulus) from Ref. 9. Modeling using these two phase dependences makes it possible to proceed without knowledge of the angle of inclination *i* of the star, which is obtained automatically during construction of the models. In that paper it was definitely shown that **the magnetic field is formed by three magnetic dipoles**, rather than one as usually happens. The angle was taken to be $i = 90°$ based on *v*sin*i* from Ref. 9, confirming the estimate made in Ref. 5. As a result it turned out that the magnetic field has a structure similar to a single-dipole structure with its axis parallel to the axis of rotation. The extrema of *Bs* occur at phases $\Phi = 0.1$ (minimum) and 0.62 (maximum). The dipoles lie at small angles to the equatorial plane. Thus, the structure of HD37776 is quite unusual (see section 3). Another model assuming $i = 45^{o}$ was calculated later; it differs substantially from the one examined in the paper discussed here.

Kochukhov, et al. [12], have made a new study of the magnetic field structure of HD37776 using a magnetic Doppler technique with analysis of the spectrum line profiles by the DI Invers10 method described by Piskunov and Kochukhov [13] and Kochukhov and Piskunov [14]. The angle of inclination of the axis of rotation to the line of sight was taken to be $i = 45°$. which was found in Ref. 10.

At the beginning of their paper the authors reexamined the multipole model of Bohlender [5]. In this model, the magnetic field strength and its structure are determined by the values of the field at the poles from the dipole B_d, quadrupole B_q, and octupole B_o, which equal -1, -4.3, and 97 kG, respectively. As a result of this combination, the field at the surface varies from 35 to 100 kG. The average surface field varies from 43 to 49 kG. The authors of Ref. 12 regarded this **result as incorrect**.

The next step was to reconstruct the magnetic field topology of HD37776 using the DI Invers10 method, which makes it possible to find the surface distribution of the magnetic field vector and the chemical composition with **simultaneous use of spectropolarimetric data** from Ref. 9 and **a plot of the longitudinal field** from Ref. 2. This approach is valuable because it is physical by comparison with the previously used multipole method. The new method models individual line profiles. During modeling, the chart of the surface was broken up into 1176 cells (see Fig. 5c in Ref. 12) and a polarized synthetic spectrum was calculated for the HeI 5876 Å line. This yielded the magnetic field distribution over the surface shown in Fig. 2a (taken from Ref. 12). The existence of several magnetic regions can be seen clearly. The dashed ellipses indicate the "magnetic" regions and the black circles show the position of the magnetic poles obtained by modeling with the "dipole method" [6-8]. More will be said about this in section 3. In a first approximation the character of the magnetic field distribution is the same in both cases. This is natural because the initial data are the same. Thus, a distribution of the magnetic field over the surface is obtained that differs fundamentally from the result of Ref. 10.

Unlike the unsatisfactory results obtained with the aid of the *multipolar field model*, in the opinion of the authors, a reconstruction of the magnetic geometry of the field with DI Invers10 yields outstanding agreement for

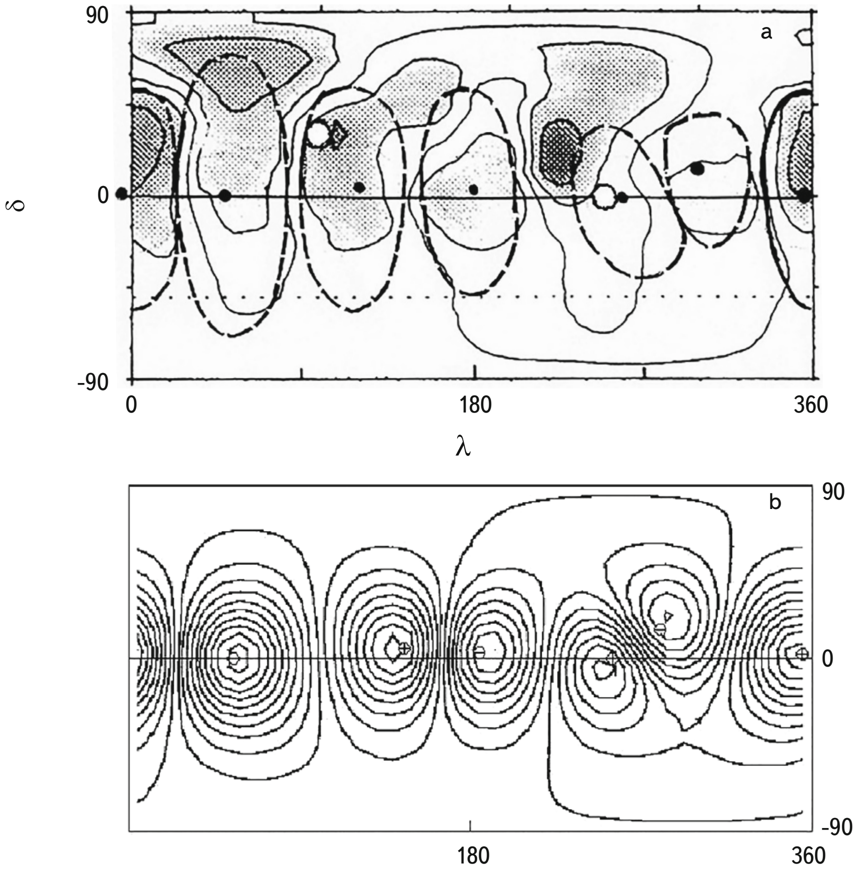

Fig. 2. The distribution of the magnetic field over the surface of HD37776. (a) The distribution obtained with the code Invers10 based on spectropolarimetric data and a plot of *Be*(Φ). The dashed curves denote the regions of the magnetic field obtained by "magnetic dipole" modeling. The circles indicate the position of helium "spots." (b) The magnetic field distribution obtained by the "magnetic dipole" method [6-8].

the circular polarization of the spectra and an adequate description of the phase dependence *Be*(Φ) found in Ref. 2 (Fig. 1 in Ref. 12, upper frame). Besides the distribution of the magnetic field over the surface obtained by analyzing the HeI 5876 Å line, the distribution of the concentration of helium in different parts of the surface was also obtained. The helium is concentrated in two "spots" indicated by the white circles in Fig. 2a. The position of the centers of the **two helium "spots"** at phases Φ = 0.3 and 0.7 is taken from Ref. 12. It turned out that the amount of helium varies from a moderate shortage relative to the sun's chemical composition to an excess by 100 times. The problem is that *the helium concentration is not connected in any way with the distribution of the longitudinal field Be or the average surface magnetic field Bs* (Fig. 1 of Ref. 12). The helium "spot" at phase 0.3 coincides with a minimum of *Bs*, while the other helium spot at phase 0.7 coincides with a maximum of *Bs* [12]. This indicates that there is no connection between the amount of helium and the magnetic field strength, in conflict with a well known property of helium and other chemical elements. Turning to the results of Ref. 9, a similar conclusion can be reached. It is known from the series of our studies that the amount of helium in magnetic He-r stars is proportional to the magnitude of the magnetic field. This is a big problem.

The authors have noted elsewhere that the DI Invers10 method yields a strikingly different picture of the distribution of the magnetic field over the surface of HD37776 compared to the assumptions of the previous multipolar models. The topology of the field is complicated and especially non-axisymmetric. There are six different regions with positive and negative magnetic polarity, which confirms the result obtained in Ref. 11. It should be noted especially that the model DI Invers10 yields a **significantly weaker field** than proposed by earlier authors ([4,9,10] *Bs* = 60 kG) on the basis of multipolarity models. (We have pointed out above that the magnetic fields obtained by the multipolar models lack physical meaning; this will be discussed in the *Conclusion*.) The field varies from ≈ 5 to ≈ 30 kG over the star's surface, which is still a lot relative to typical B-type magnetic stars but is certainly less than the field in some of the more extreme representatives of CP stars. The average modulus of the magnetic field in HD37776 ranges from 13 to 16 kG, which is considerably lower than the predicted modulus of ≈ 46 kG according to the multipolar model and direct measurements in Ref. 6. (See the lower frame of Fig. 1 in this article.) This study of the variation in the longitudinal magnetic field of HD 37776 clearly demonstrated the fundamental limitation of the multipolar field models based on using just the *Be*(Φ) curve. While the multipolar model requires a record field, for reproducing the measured Be the magnetic DI Invers10 gives a field that is lower by an order of magnitude with an average field strength of *Bs* = **14.5** kG. But this is greater than that obtained with modeling by the "dipole method" (see section 3), where *Bs* = **3.76** kG. This is less than the average surface field directly measured by Zeeman splitting in many CP stars.

The model of Kochukhov, et al. [12], describes only the visible hemisphere of a star, so the magnetic regions in Fig. 2a mostly occupy the upper part of the chart, while there are none below the equator. This method cannot describe the field distribution over the entire surface exactly. In summarizing this, we note that this work has to be repeated using the *Be*(Φ) curve from Ref. 9, where the amplitude *Be* derived from the helium lines is ten times greater. It is also important to evaluate the influence of overlap of regions with different values and signs of the magnetic field. The DI Invers10 method was created for a single-dipole field structure but does not account for the fact that in the visible hemisphere of HD37776 there are always regions with different signs and magnitudes of the field. It is difficult to predict how this affects the profile and distribution of the polarization in it, but it is evident that the *Be*(Φ) profile from Ref. 2 that was used is subject to the influence of this effect. It is definitely reduced in amplitude. Thus, the results of Ref. 12 have to be regarded as somewhat distorted.

In this paper the authors take note of the results of a numerical simulation [15] that showed that both toroidal and poloidal magnetic fields of comparable strength must exist in the star in order to maintain global stability of the structure of the relict field. But it is impossible to explain the complicated multi-dipole magnetic fields and structures with a significant displacement of the dipole from the center, as in HD37776 and other stars [16,17], from this standpoint.

3. Our study

Version 1. A model of a large-scale component of the magnetic field of HD37776 by the "magnetic dipole (monopoles)" method has been constructed in Refs. 18 and 19. For this, as in the previous case, the phase dependences *Be*(Φ) from Ref. 2 are used, and the model was calculated assuming the angle of inclination $i = 45°$ of the star to the line of sight found in Ref. 10. Our current estimate of $v\sin i$ yields $i = 65^{\circ}$, but the model results do not differ greatly. The model parameters are listed in Table 1 in the first columns denoted by "H." The virtual magnetic charge is usually measured in units of the maximum value, but here the values were all roughly the same and are taken equal to 1. The notation in the table is: λ longitude and δ latitude of the monopole, Δa the distance of the monopole from the star's center in units of the radius, and Δl the distance between the monopoles in units of the star's radius.

TABLE 1. Parameters of the Models Constructed from "Hydrogen" (H) and "Helium" (He) Measurements.

N	Charge		λ, °		δ, °		Δa, R_*		Δl, R_*	
	H	He	H	He	H	He	H	He	H	He
1	+1	+1	355	20	0	0	0.5	0.5	0.42	0.38
2	-1	-1	55	75	0	-3	0.5	0.5		
3	+1	+1	145	137	+5	-3	0.5	0.5	0.35	0.50
4	-1	-1	185	198	+3	0	0.5	0.5		
5	+1	+1	255	259	0	-6	0.5	0.5	0.22	0.54
6	-1	-1	280	324	+15	-6	0.5	0.5		

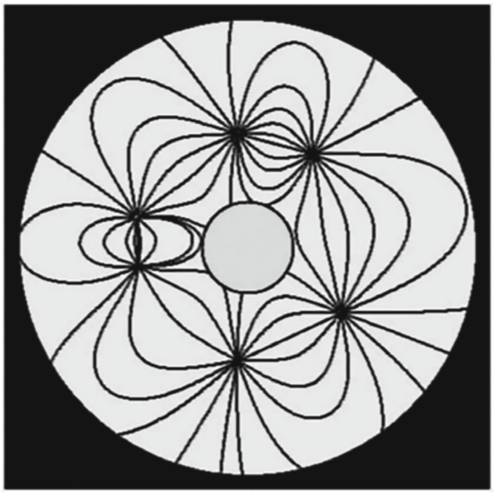

Fig. 3. The distribution of the lines of force in the equatorial plane inside the star HD37776 obtained by the "magnetic dipole" method.

Our earlier result [11] that **the magnetic field is formed by three magnetic dipoles** located essentially in the plane of the equator of rotation was confirmed, but with different distances between the monopoles. The distance Δa of the monopoles from the star's center turned out to be the same, on the order of ~0.5 stellar radii. The magnetic field distribution over the surface is shown in Fig. 2b and schematically in Fig. 2a. The magnetic dipoles lie near the equator (Table 1). Figure 3 shows the distribution of the lines of force inside the star; the white circle at the center denotes the position of the convective core within which there is probably no strong magnetic field. The observed (points) and model (smooth curve) phase dependences $Be(\Phi)$ are shown in Fig. 4a, and the model phase dependence of the mean surface field $Bs(\Phi)$ is shown in Fig. 4b. The deviation of the individual measurements from the model dependence is within 3σ. The shape of the $Bs(\Phi)$ curve differs from that obtained in Ref. 12. The average surface magnetic field was equal to $Bs = 3760$ G [6] and the maximum model polar values Bp are +10358 and -10733 G.

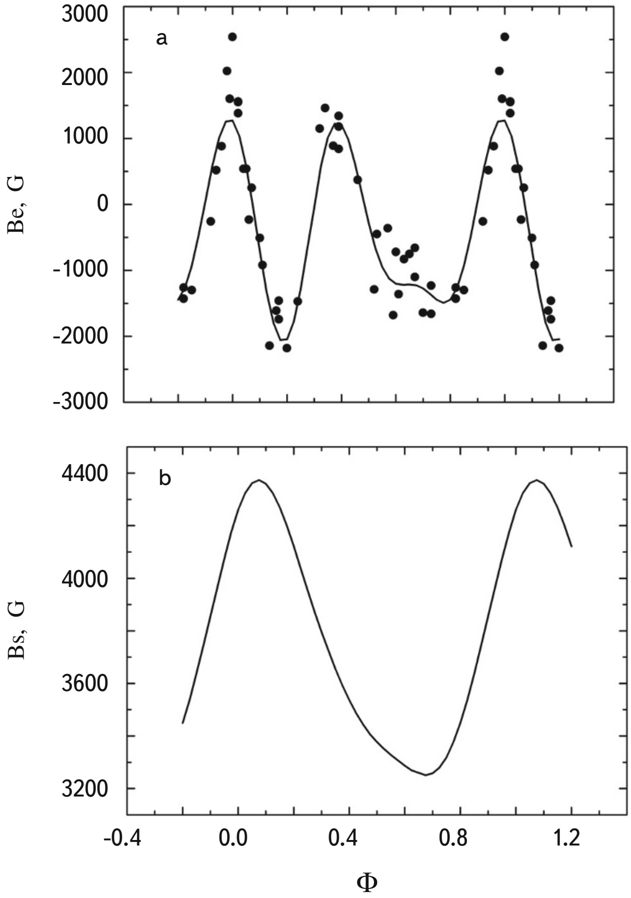

Fig. 4. Results of modeling by the "magnetic dipole" method. (a) The variation in the magnetic field based on "hydrogen" measurements; the points are the measurements and the smooth curve is the model. (b) The model variation in the average surface magnetic field $Bs(\Phi)$ with phase Φ of the rotation period.

We note that HD37776 is one of the magnetic stars with helium anomalies, which have an average field of *Bs* = 2.5 kG, which is half that in Si and SrCrEu-type stars [20]. We estimate that this is because of the low age of the stars with helium anomalies, where a large-scale dipole magnetic field has not been able to form to a sufficient extent. In addition, it is impossible to imagine a magnetic field structure for which the longitudinal component would equal *Be* = 2 kG, while the average surface field would be *Bs* = 60 kG. We noted above that the amplitude *Be*(Φ) appears to be somewhat reduced owing to overlap of regions with different signs and magnitudes of the field. There is reason to assume that *Be* should be increased by a factor of 1.5-2, but no more. Thus, the probable value is $Bs \approx 6-7$ kG.

Our model, based on the hypothesis of dipole magnetic structures, makes it possible to predict the magnetic field distribution over the entire surface (Fig. 2, a and b). The black dots in Fig. 2a indicate the position of the magnetic poles in accordance with our model, the dashed loops schematically represent the positions of the magnetic regions, and the white circles show the position of the centers of the helium "spots" taken from Ref. 12. A positive pole lies near $\lambda = 0^{o}$, after which their signs alternate. Comparing Figs. 2a and 2b, we can see that at longitudes $\lambda = 0^{o}$, 25^{o}, 60^{o} and 180° the magnetic regions generally coincide, although there are some differences. Thus, the field region with a negative polarity ($\lambda = 25^{o} - 30^{o}$) lies substantially above the equator, while in our chart the magnetic pole is at the equator. This is the first distinction. In the same figure there is a region with high magnetic field at the point ($\lambda = 205^{o}$, $\delta = 30^{o}$), which does not appear in our figure; there we have a region between positive and negative magnetic poles. This is the second distinction. If this region actually existed, then at this phase there should have been a substantial peak in the *Be*(Φ) curve which was not observed.

Version 2. We tried to illustrate the structure of the magnetic field of HD37776 using measurements of the magnetic field based on the helium $\lambda 5876\text{Å}$ line from Ref. 9. The angle i=45^{o}, as in the previous case. In Fig. 5a the points show the observed dependence and the smooth curve, the model. It has the same shape as the "hydrogen" curve, i.e., three positive and three negative maxima are observed, but the amplitude of the variations in the "helium" magnetic field is greater by **a factor of ten**!!! Figure 5b shows the model dependence *Bs*(Φ), which is the opposite of the "hydrogen" dependence in Fig. 4b. It has a shift according to the phase of the "helium" curve relative to the "hydrogen" curve by an amount ΔΦ = 0.5 shown in Table 2 in the second columns denoted "He." The major parameters of the model obtained after shifting the *Be*(Φ) curve by ΔΦ = 0.5 are shown in Table 1 in the second columns marked "He". The agreement among the parameters for this model, except for *Be* obtained from "hydrogen' and "helium" for HD37776 is satisfactory; this shows that the structure of the magnetic field is determined by the same **three magnetic dipoles.** The distributions of the field over the surface for them are essentially the same. Given these remarks, we suggest that the internal structure shown in Fig. 3 is correct for both models.

We have discussed, earlier in this paper, an incomprehensible phenomenon in which the distribution of helium is absolutely unrelated to the magnetic field. Figure 2a shows a map of the magnetic field distribution from Ref. 12 with a scheme for the magnetic field distribution which is the same for "hydrogen" and "helium" measurements. The average surface "helium" field is improbably higher at *Bs* = 66 kG. This is greater than the *Bs* = 14.5 kG predicted by a detailed calculation [12] or the *Bs* = 3.76 kG derived by us from "hydrogen" measurements. We have, therefore, come upon a problem that the magnetic field derived from the helium is exactly ten times greater than that derived from the hydrogen lines. This amazing result is clearly unreal and it must be explained in some

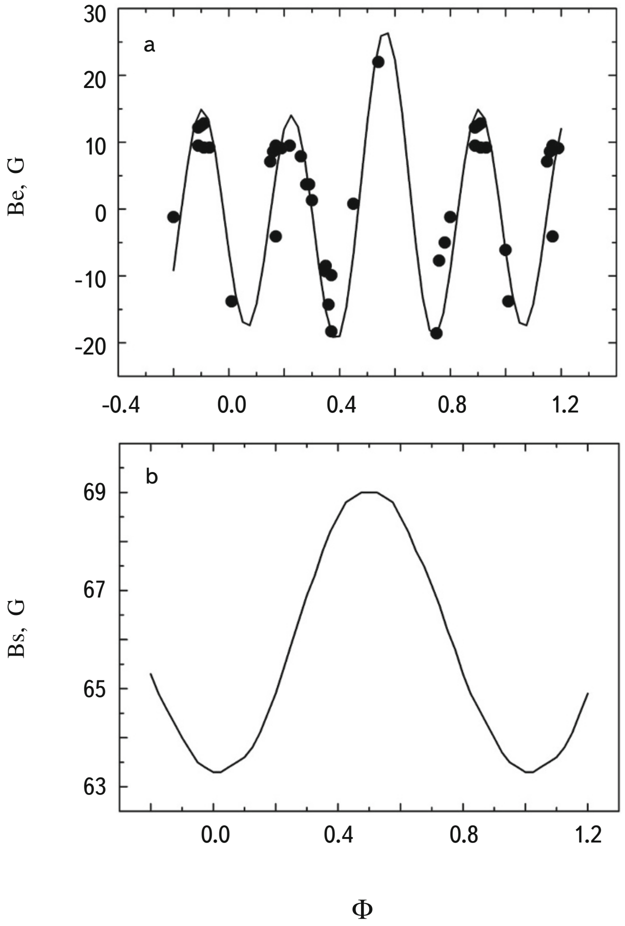

Fig. 5. Modeling of the magnetic field by the "dipole" method based on measurements of the helium λ5876Å line. (a) The points are observations and the smooth curve is the model. (b) The model dependence of *Bs*(Φ).

way. This event may arise in part as a result of some feature of the measurement technique. In order to try to understand what may be going on, we examine the results of measuring the magnetic field from the shift in the centers of gravity of the same spectrum line. The dependence in Fig. 5a is constructed from measurements of the central regions of the lines, and that in Fig. 6, from measurements of the center of gravity of the helium lines taken from Ref. 9. It can be seen clearly that a large spread averaging about 2 kG is observed and this dependence has nothing in common with Fig. 5a. This suggests that a high magnetic field is **noticeable only when measuring the central region of spectrum lines** and the remainder of a spectrum line essentially does not manifest the Zeeman effect. Probably for the same reason the "hydrogen" measurements are an order of magnitude smaller than the "helium" measurements. If this is so, then it may be that measurements based on the centers of the hydrogen lines would also have led to a high value of the field. The magnitude of the magnetic field measured with 4 Si lines was of the same

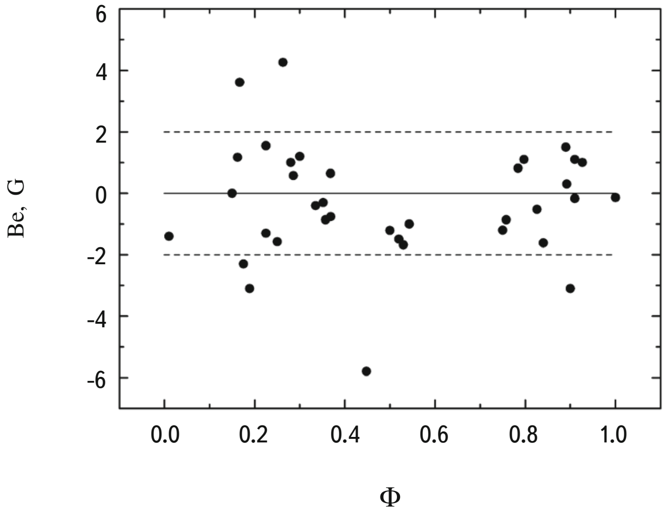

Fig. 6. The variation in the magnetic field *Be*(Φ) derived from measuring the center of gravity of the He λ5876 Å line.

order as those based on the He lines if the one measurement at 61 kG [9] is excluded. It is clear that this effect may be one of the reasons for the strongest disagreement among the results, i.e., **one of the causes of the discrepancy is a difference in the measurement methods.** This example shows that the result of a magnetic field measurement can differ by a factor of 10 depending on the method for plotting the line. It is entirely understandable why an excessive value of the field is given by the multipolar mathematical method. But the difference in the results derived from hydrogen and helium lines is obscure.

It is evident that, besides this effect, there is an effect owing to overlap of regions with different polarities on the visible hemisphere that should lead to a reduction in the amplitude and the “hydrogen” and “helium” phase dependences *Be*(Φ). We pointed out above that including overlap might lead to an increase in Bs by factor of 1.5-2. In this case, the “hydrogen” dipole model yields *Bs*~6-7 kG, and the “helium” model, 100-120 kG It is clear that the DI Invers10 method, which uses the *Be*(Φ) phase curve derived from hydrogen lines, does not account for the influence of the overlap of positive and negative regions on the magnitude of *Be* and it also leads to a reduction in the magnetic field values.

4. Conclusion

At the beginning of this research, some authors attempted to describe the phase dependence *Be*(Φ) and the magnetic field distribution over the surface using spherical harmonics. Series of Legendre polynomials of different orders (dipole, quadrupole, octupole, etc.) were examined. In this way it was possible to describe the observed phase dependence *Be*(Φ) satisfactorily with different coefficients that were chosen experimentally. But these coefficients lack physical meaning. In physics, a magnetic field is described by a virtual magnetic dipole similar to an electric dipole. The description of phase relationships in terms of a sinusoid also lacks physical significance. The observed magnetic field is not a purely surface phenomenon; it is associated with deep structures. The dipole representation of magnetic field structures does have a physical basis.

Having examined the above results from studies of the magnetic field of HD37776, we see that they are full of contradictions. First of all, we have to justify the reality of our model calculations. The relict hypothesis of the origin of magnetic stars is currently generally accepted [21,22]. Compressed together with the protostellar cloud, the poloidal magnetic field obviously sometimes has a complicated structure, especially owing to passing through the nonstationary Hayashi phase. It is believed by some [23,24] that the field in these protostars is concentrated in separate layers, cells, magnetic bundles, fibers, etc. As a result, in the HAeBe phase, future magnetic stars have a very weak, intricate field. Nevertheless, in the volume of a future magnetic star, a common large-scale vector, or two-three vectors of a poloidal magnetic field, are conserved. Thus, the total magnetic field of a star before it enters the main sequence consists of two fractions: large scale relict (poloidal) and small-scale (entangled). After formation of a magnetic radiative star, the fine magnetic structures vanish relatively rapidly owing to Ohmic dissipation over a time $t = 4\pi\omega r^2$, where ω is the conductivity of the plasma and r is the characteristic size of the magnetized plasma. In addition, the magnetic lines of force change under the influence of tensile forces $T = AB/4\pi$, where A is the transverse cross section of a magnetic tube and B is the magnetic field strength. Moss evidently had this possibility in mind when he said [23] that the small-scale field must diffuse into a more homogeneous shape. Thus, complex magnetic systems are unstable and are destroyed over time. Because of the long ages of magnetic stars, only the large-scale poloidal component, which to a first approximation is well described by a virtual magnetic dipole, remains. This was shown by our model results for about 120 magnetic stars [20]. Already in the very beginning of his studies, Babcock discovered that the profiles of spectrum lines do not contain signs of the existence of “spots” in the stars being studied. A star is magnetized entirely and the field has a dipole structure. Mathys, et al. [25], emphasize that, among the lines split by a magnetic field, no unshifted component is noticeable that might have arisen if there were regions on a star’s surface without a field or with a different value of the field. Preston [26] also notes that if higher order multipoles are present, then they have a very small integral effect; the predominant component in magnetic stars is always a dipole field. These and other considerations led to the creation of the method for modeling the magnetic fields of chemically peculiar stars known as the “dipole method” [6-8].

The star HD37776 is young, with an age of log$t$ = 7.00 years [27], so that conserved inhomogeneities of the magnetic field may exist on its surface. This can be explained in part by the “flocculence” of the magnetic regions that can be seen in Fig. 3. Figure 7 shows the relationship between the age of He-r stars and their position on the main sequence. The star indicates the position of HD37776 [27]. The value of R/Rz is probably excessive; most likely the star is closer to the ZAMS. Figure 8 shows the distribution of helium stars with respect to Bs taken from Ref. 27. It is clear that the average surface values of the magnetic field are within a narrow range of 0-10 kG. In terms of the value of Bs determined from “hydrogen” measurements, HD37776 lies within the limits occupied by other stars with helium anomalies; it is indicated in the figure by a star. But according to models based on “helium” measurements it has jumped strongly to the right. The result of Kochukhov, et al., is within the limits occupied by

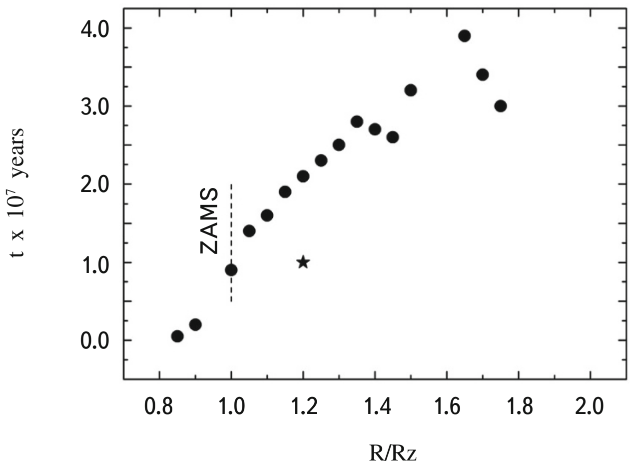

Fig. 7. The position of the star HD37776 among other stars with the same type of peculiarity on a Hertzsprung-Russell diagram.

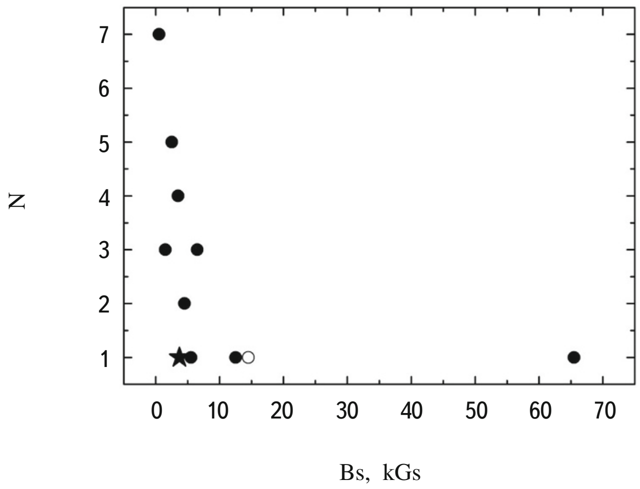

Fig. 8. The distribution of stars with anomalous helium lines with respect to Bs. The star indicates the star HD37776 according to the model of Refs. 18 and 19, the circle is the same according to the model of Ref. 12, and the point on the right is based on measurements of a helium line.

stars with helium anomalies. An examination of this distribution suggests that the magnetic field measurements in Ref. 9 either contain some sort of error or we are dealing with a outstanding phenomenon. Based on experience with numerous studies of the magnetic field structures of chemically peculiar magnetic stars, we believe that the field measurements on HD37776 have to be increased by a factor of 1.5-2 in order to account for the influence of overlap of regions with different signs of the magnetic field, but even then the star lies within observable limits. If this kind of correction is made for the field measurements based on He lines, then it appears that $Bs > 100$ kG. We note especially that Khokhlova, et al. [10], have pointed out that "the width of the spectrum lines reaches 5 Å and this is caused by Zeeman splitting, but because of the rapid rotation, **the observed components are washed out and not resolved**." At the same time, a field of 60 kG is confidently mentioned. But then the value of $v\sin i = 132$ km/s in the catalog of Ref. 28 estimated by several authors, does not correspond to a linewidth of 5 Å.

The complicated structure of the profiles of the star HD37776 is discussed in Ref. 29, where signs of emission in Hα are mentioned. If this is so, then the validity of measuring the field using the centers of spectrum lines is questionable. Overlapping effects from magnetic regions with different signs are hard to take into account in measurements of polarization and the profile shapes of spectrum lines. Our dipole model takes this into account, but the measurements themselves do not.

As opposed to Fig. 3, according to our model calculations the magnetic poles lie along the star's equator (Fig. 2b). The predominantly small angle α in magnetic stars is a known property of magnetic stars. It is explained by the fact that in magnetic protostars the predominant direction of the magnetic fields along the equatorial plane arises from selection processes during magnetic braking. The maximum loss of angular momentum and, thereby, separation from nonmagnetic normal protostars, takes place in those magnetic protostellar clouds that have a small inclination of the magnetic axis to their rotation plane [30]. Thus, the idea of a dipole character for the magnetic field structure of magnetic protostars developed during the early phase of research. The results of our modeling confirmed this. The small probability that the loss of angular momentum occurred during the HAeBe phase is discussed in Ref. 31.

In this analysis we propose that the large differences in the magnetic field on the surface of HD37776 detected by different methods is explained by the complicated structure of the large-scale magnetic field, as well as by the presence of a small-scale fraction of which isolated fragments can have a strong field. As stated above, the observed "hydrogen" phase dependence $Be(\Phi)$ (Fig. 4a) influences the **overlapping** of different magnetic regions with different signs that appear simultaneously on the visible hemisphere. This circumstance should lead to **some reduction in the amplitude of the variation in the magnetic field *Be***. Thus, it is evident that after this effect is taken into account, the **magnitude of *Be*** and the model average surface field **Bs should increase**. The upward rebound in the measurements at $\Phi = 0$ in the phase curve of Fig. 4a probably takes place for this same reason. But it is clear that including this effect does not raise the field to 30, much less 60 kG. This conclusion, as we have seen, was reached in Ref. 12. We assume that including the "overlap effect" increases the average surface magnetic field determined by the "dipole method," by no more than a factor of 1.5-2. Thus, we obtain $Bs \approx 6\text{-}7$ kG. The DI Invers10 method also neglects the overlap effect. A third effect involves a small-scale fraction of the magnetic field consisting of cells with positive, negative, and zero magnetic field. The combined effect should lead to broadening of a spectrum line, with a fictional increase in vsini. In the phases with positive field, there are more cells with a strong positive field in the visible hemisphere (or their area is greater), and *vice versa*. Evidently, the Zeeman components split in the strong field are superimposed on a profile that has been broadened by several effects and become noticeable. With age the small-scale magnetic structures relax into a large-scale poloidal form, so that the average magnetic field *Bs* of the helium stars tends to increase with age, as in Si and SrCrEu-stars. He-strong stars are two orders of magnitude younger than SrCrEu stars. Therefore, their magnetic field contains a substantial portion of a small-scale fraction that has still not been able to reach, after the HAeBe stage, the same degree of relaxation into the large-scale structure observed in SrCrEu-stars. For this reason, stars with anomalous helium lines have an average magnetic field that is smaller by half [20]. For this same reason the yet younger HAeBe stars have fields only on the order of tens, sometimes hundreds, of gauss. It is possible that **the example of HD37776 shows why HAeBe stars have only a very weak field**. The intricate field may have small cells with very high fields [23,24]. They should stand out well against the background of the complicated profile if they occupy a sufficiently large area. But among the **narrow** spectral lines of the metals, Zeeman splitting from the most magnetized cells is easier to distinguish from cells with another field magnitude than when the **broader** hydrogen lines are used. Up to now, this is only an assumption. More detailed study of this star is needed. Thus, the strong differences in the magnetic field on the surface of HD37776 found by various methods can be explained by the intricate structure of the large-scale magnetic field, as well as by the presence of a small-scale fraction, individual cells of which can have a strong field. The same method for measuring the magnetic field in terms of the Hb lines used to study the stars α^2CVn and 53Cam, where the magnetic field has a simpler configuration, has yielded nice results [32].

Distorted data are also given in Ref. 12 because it neglects the effect of overlapping on the phase relation *Be*(Φ) from Ref. 2.

The following comment should be made in concluding. At present there is a discussion in the literature regarding the opinion that only poloidal-toroidal magnetic structures are stable [15]. In our studies of magnetic structures, we have repeatedly tried to discuss the problem of the discrepancy between the observed properties and these theoretical predictions. One gets the impression that this poloidal-toroidal theory of the stability of the structure of magnetic fields is not taking something into account.

In connection with these problems, we note the major tasks for further study of the star HD37776:

1) What is the reason for such a colossal difference between the results of “hydrogen” and “helium” magnetic field measurements?

2) Why is the distribution of helium over the surface of a star not related to the distribution of the magnetic field?

3) How do regions with different signs of the magnetic field on the visible hemisphere of a star influence the phase relation *Be*(Φ) for the magnetic field?

REFERENCES

1. Yu. V. Glagolevskij and A. F. Nazarenko, Astrophys. Bull. **72** (2017).
2. I. B. Thompson and J. D. Landstreet, Astrophys. J. **289**, L9 (1985).
3. D. A. Bohlender, PhD Thesis, Univ. Western Ontario, Canada (1988).
4. D. A. Bohlender and J. D. Landstreet, Science News, Jan. 27, 1990.
5. D. Bohlender, in: L. A. Bolona, H. F. Henrichs, and J. M. Le Contel, ed., Pulsation, rotation and mass loss in Early-type stars, IAU Symp., No 162 (1994), p. 155.
6. E. Gerth, Yu. V. Glagolevskij, and G. Scholz, in: Yu. V. Glagolevskij and I. I. Romanyuk, eds., Stellar magnetic

fields, Moscow (1997), p. 67.

7. E. Gerth and Yu. V. Glagolevskij, in Magnetic fields of chemically peculiar and related stars, Moscow (2000), p. 151.
8. E. Gerth and Yu. V. Glagolevskij, Bull. SAO, **56**, 25 (2003).
9. I. I. Romanyuk, et al., Bull. SAO, **45**, 93 (1998).
10. V. L. Khokhlova, et al., Astron. Lett. **26**, 177 (2000).
11. Yu. V. Glagolevskij and E. Gerth, Bull. SAO, **51**, 84 (2001).
12. O. Kochukhov, et al., Astrophys. J. **726**, 24 (2011).
13. N. Piskunov and O. Kochukhov, Astron. Astrophys. **381**, 736 (2002).
14. O. Kochukhov and N. Piskunov, Astron. Astrophys. **388**, 868 (2002).
15. J. Braithwait and A. Nordlund, Astron. Astrophys. **450**, 1077 (2006).
16. Yu. V. Glagolevskij and A. F. Nazarenko, Astrophys. Bull. **72**, 411 (2017).
17. Yu. V. Glagolevskij, Astrophys. Bull. **73**, 201 (2018).
18. Yu. V. Glagolevskij, Astrophys. Bull. **71**, 43 (2016).
19. Yu. V. Glagolevskij, Astrophys. Bull. **68**, 356 (2013).
20. Yu. V. Glagolevskij, Astrophysics, **59**, 321 (2016).
21. Yu. V. Glagolevskij, Astrophysics, **57**, 204 (2014).
22. Yu. V. Glagolevskij, Astrophys. Bull. **72**, 334 (2017).
23. D. Moss, IAU Symp. **224**, 245 (2004).
24. A. E. Dudorov, in: G. M. Rudnitskii, ed., Itogi nauki i techniki, Ser. Astronomiya, VINITI, Moscow, Vol. 39, p. 77 (1990).
25. G. Mathys, S. Hubrig, J. D. Landstreet, et al., Astron. Astrophys. Suppl. Ser. **123**, 353 (1997).
26. G. Preston, Publ. Astron. Soc. Pacif. **83**, 571 (1971).
27. Yu. V. Glagolevskij, Astrophys. Bull. **74**, 66 (2019).
28. Yu. V. Glagolevskij, Astrophys. Bull. **72**, 457 (2017).
29. I. I. Romanyuk, et al., IAU Symp., No. 176, Vienna (1995), p. 153.
30. T. Ch. Mouschovias and E. V. Paleologou, Astrophys. J. **230**, 204 (1979).
31. Yu. V. Glagolevskij, Astrophysics, **61**, 413 (2018).
32. E. F. Borra and J. D. Landstreet, Astrophys. J. **212**, 141 (1977).