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COMPLICATED MAGNETIC FIELD STRUCTURE OF THE STAR HD 45583

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Preliminary data on the magnetic field structure of the unique magnetic star HD 45583 are obtained. The observational data are well described by a configuration of two magnetic dipoles located on opposite sides relative to the star's center, with their axes directed roughly in a radial direction. The positive monopoles are closer to the surface and the negative, closer to the star's center. For this reason, there appear to be two positive magnetic poles on the star's surface but no negative poles. The need for further observations of this unique object is pointed out.

Keywords: stars: magnetic fields-- individual: HD 45583

1. Introduction

In the course of a program to search for new magnetic stars on the 6-m telescope, the star HD 45583, with a complicated, unique magnetic configuration, was discovered [1]. The longitudinal field of this star varies nonsinusoidally over a range of -2000 to +4000 G. A preliminary study of the magnetic field [1] using the FLDCURV program developed by Landstreet showed that the phase curve of the magnetic field is well described by a structure consisting of a combination of a noncentral dipole and an octupole that is coaxial with the dipole. The average surface field is then predicted to vary over 20-30 kG. Because of this unique field structure, and despite a lack of observational data, it was decided to study this star in more detail using the method of "magnetic charges" [2].

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2. Physical parameters of the star

The star HD 45583 has an Si-type peculiarity, an effective temperature of $T_e = 12900$ K, and an absolute bolometric magnitude of $M_b = 1.3$ [3]. Thus, the star's radius in terms of solar radii is $R = 3.2 R_{\odot}$. The rotational velocity of the star has been found to be $\upsilon \sin i = 70$ km/s [4]. Its rotational period was found to be $P = 1^{d}.177177$ and its initial phase, JD 2453272.490 [5]. Subsequently, Semenko et al. [6] obtained a more precise value of the period, $P = 1^{d}.177000$. With the standard formula $\upsilon = 50.6\ P/R$ and using the value of $\upsilon \sin i$, we obtain an angle of

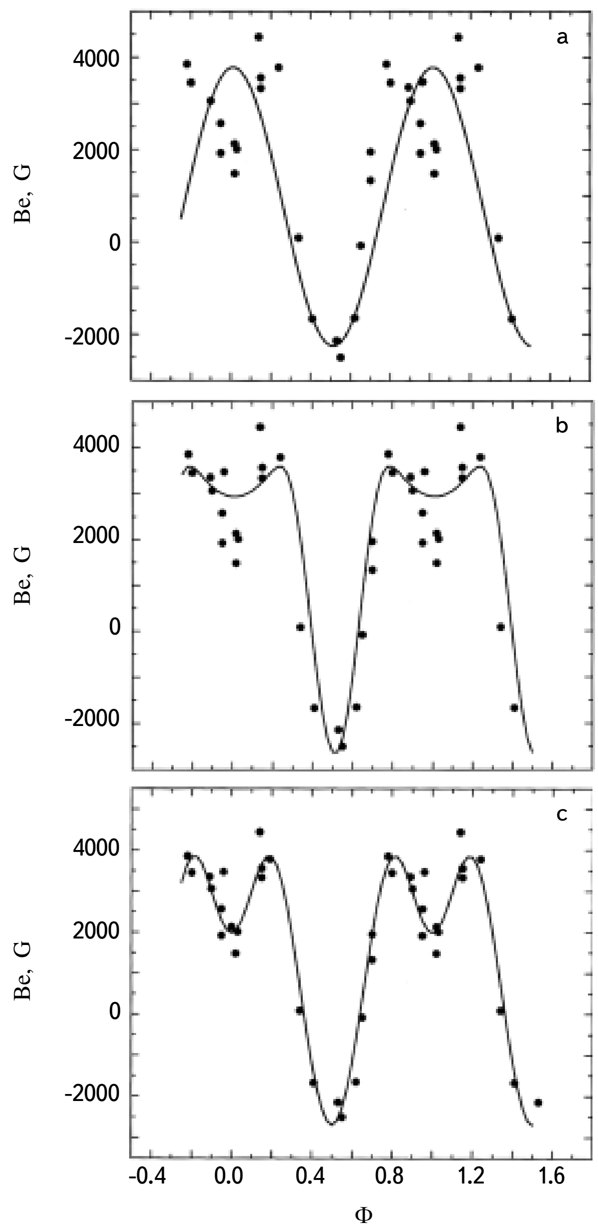

Fig. 1. Comparing the observed data (circles) with model calculations (smooth curves): (a) central dipole model, (b) shifted dipole model, and (c) two dipole model.

inclination of the star to the line of sight of $i=39^o \pm 5^o$, as needed for modelling the magnetic field. The most probable error for the angle i has been estimated on the basis of the errors in the parameters given above.

The measured values of the effective magnetic field *Be* are taken from Refs. 1 and 6. These are plotted as the points in Fig. 1. The conditions under which the Zeeman spectra were obtained and measured have been described in sufficient detail in those papers. It is evident that the shape of the phase dependence is nonsinusoidal. The following magnetic field configurations are most often encountered: central dipole, shifted dipole field, more complicated configurations (e.g., HD 32633 [7] and HD 137909 [8]). We now consider the applicability of these three models to HD 45583 in succession.

3. Central dipole model

The form of the calculated phase dependence assuming a central dipole differs substantially from the observed curve, so we have chosen the amplitude of the model phase dependence approximately, by eye. The coordinates of the magnetic charges in terms of longitude λ and latitude δ, as well as the magnitude of the magnetic field at the magnetic poles *Be* on the star's surface are listed in Table 1. In the calculations we have used an angle $i=39^o$, as found in the preceding section.

The calculated phase dependence is plotted as a smooth curve in Fig. 1a. Clearly, it does not fit the observed data. In the positive half wave region the observed values form a broad maximum, within the center of which the field is seen to drop from 4000 to 2000 G. The model phase dependence yields a narrow maximum in this region.

4. Shifted dipole model

The next step was an attempt to construct a shifted dipole model. It turns out that the best result is obtained when the dipole is shifted toward the negative charge by 0.6 stellar radii. Such a large shift was needed in the model in order to describe the deep minimum at phase 0. The other parameters are given in Table 2. The calculated phase dependence in this variant is shown in Fig. 1b, where it can be seen that in a first approximation this phase dependence is similar to the observations. However, it is not so good near the broad maximum. It was not possible to obtain a sufficiently deep minimum at phase 0 with this model. In addition, the part of the curve near phase 0.5 is narrower in the model than in the observations. The magnitude of the field at the negative pole seems too high. In order to obtain a better result, we have tried making the model more complicated by adding yet another dipole.

TABLE 1. Parameters for the Central Dipole Model

Sign of charge	Longitude, λ	Latitude, δ	Bp (G)
+	0^o	$+5^o$	16200
-	180	-5	16000

TABLE 2. Parameters for the Shifted Dipole Model

Sign of charge	Longitude, λ	Latitude, δ	Bp (G)
+	0^o	-7^o	9400
-	180	9	-314000

5. Two dipole model

A model of this type was constructed for HD 45583 by the method of successive approximations. The parameters of the best variant are listed in Table 3.

The angle of inclination of the star is $i = 39^o$ and the distance of the two dipoles from the center was found to be $\Delta a = 0.6 \pm 0.1$ times the star's radius. A comparison of the computed phase dependence and the observations is shown in Fig. 1c. The phase dependence of the average surface magnetic field *Bs*, as calculated with this model, is shown in Fig. 2. The average surface magnetic field *Bs* varies from 11400 to 19300 G, but, because of the closeness of the positive monopole to the surface, the field strength Bp is very high. The magnetic monopoles are located

TABLE 3. Parameters for the Two Dipole Model

Sign of charge	Longitude, λ	Latitude, δ	Bp (G)
+	$283^o \pm 1^o$	$21^o \pm 3^o$	158000 ± 20000
-	283 ± 1	-7 ± 1	-
+	68 ± 1	21 ± 3	158000 ± 20000
-	68 ± 1	-7 ± 1	-

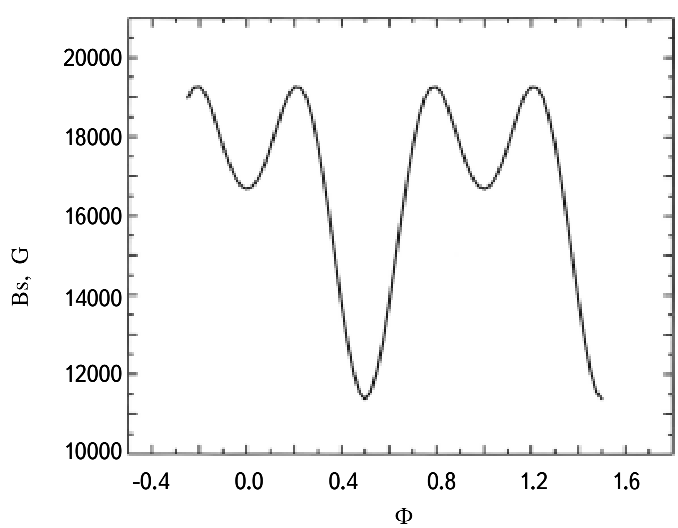

Fig. 2. The *Bs*- phase dependence calculated using the two dipole model.

at distances of 0.8 and 0.4 stellar radii, i.e., in the case of HD 45583 the magnetic field structure is close to that of a bar magnet. Such a large shift of the monopoles is required in order to fit the deep minimum at phase 0. Because of this, as can be seen in Table 3, *Bp* is very high, but since the area of the surface with such a high field strength is relatively small (about 20%), the intensity of the strongly split segment of the spectrum line superimposed on the main line should also be low. The step size in λ and δ was chosen to be 1° for the calculations, so a deviation of even one degree from the chosen value causes a significant deterioration in χ^2/n. For the same reason, the amplitude step size for the model was chosen to be 100 G.

The error in the angle *i* has the greatest effect on the magnitude of *Bp* and the other parameters. In order to clarify how large the effect of this error is, we constructed models with angles *i* that varied from the chosen value by the amount of the error, i.e., by ±5°. Table 3 lists the ranges of variation of the parameters in these calculations. It can be seen that they are relatively small.

It is quite clear that this model fits the observed data better than the other models. Figure 3 shows a Mercator

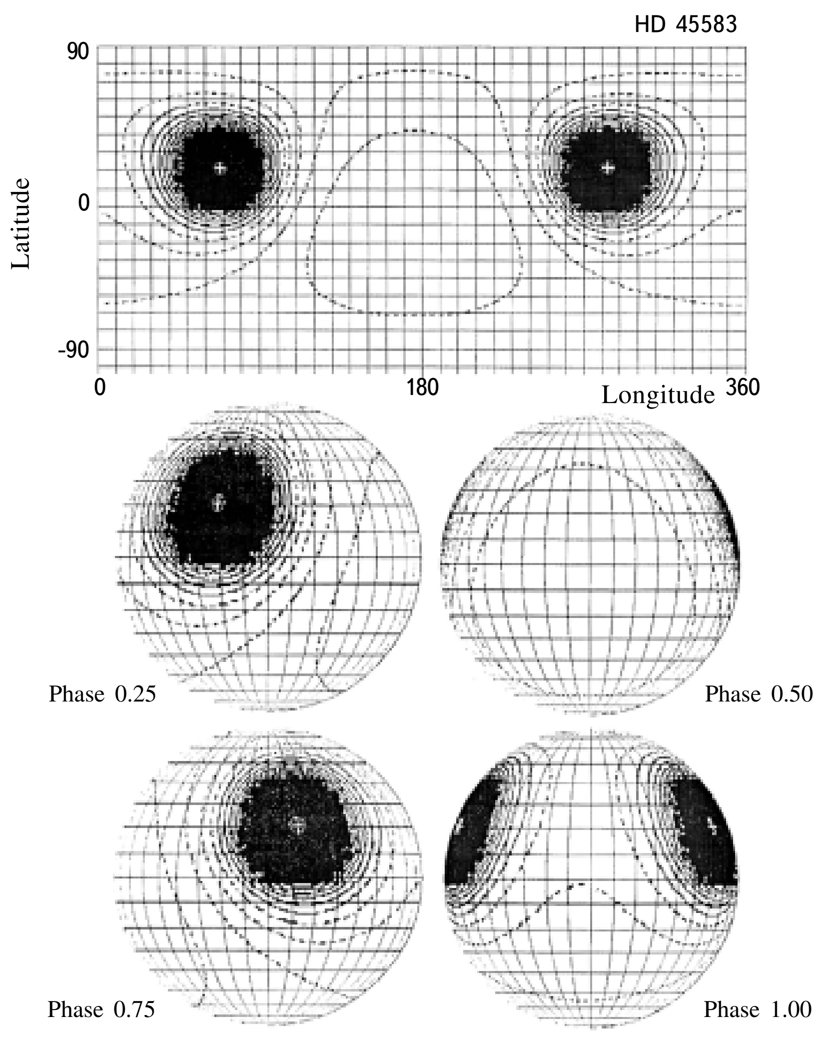

Fig. 3. Distribution of the magnetic field strength over the surface for the two dipole model.

map of the magnetic field distribution over the star's surface, as well as global views for different phases of the rotation period.

6. Discussion

Despite the approximations in the model chosen here (because of the paucity of observational data), we can make some interesting comments. Our problem was not to derive reliable parameters for the magnetic field, but to determine the most probable structure of the magnetic field based on the available data. A second task was to interest observers in continuing their observations of this interesting object.

The observational problem in the future is also to find the strongly split component of the Zeeman spectrum with a high signal/noise ratio at phase 0. Because the number of field measurements in the different phases is insufficient, it is impossible to guarantee that the magnitude of the field *Bp* is exactly what has been found here, although it is undoubtedly comparatively high.

The most remarkable thing is that this is the only star among all those known for which there is no negative magnetic pole. This unique result indicates a need for further observations in order to obtain a more precise phase dependence and better models of this most interesting star, especially in phases 0.2-0.5, where there has been a lack of observational data. Photometric measurements [5] indicate that the secondary brightness maximum near phase 0.5 lies closer to the maximum at phase 1.0, i.e., the photometric measurements are asymmetric. This may mean that the magnetic curve could also be asymmetric.

Additional measurements might also help establish once and for all which of the models is most probable: the shifted dipole or the two dipole model. We have used our method to study two other stars besides HD 45583 which appear to have a two dipole magnetic field structure: HD 32633 [7] and HD 137909 [8]. It is interesting that, despite the utterly different form of the phase dependences for the three stars, the models turn out to be two dipole models, with monopoles located near the equatorial plane. The orientations of the dipoles inside the stars are completely different. These properties are undoubtedly somehow connected with the origin and evolution of magnetic stars. These peculiarities cannot be explained in terms of the poloidal-toroidal model discussed by Braithwaite and Spruit [9].

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