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COMPLEX STRUCTURE OF THE MAGNETIC FIELD OF THE CP STAR HD32633

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Abstract—The method of "virtual magnetic charges" is used to analyze the structure of the magnetic field of the CP star HD32633. The phase relation of its magnetic field differs strongly from a sine wave. The structure of the star's field can be described fairly well by two dipoles located in the opposite regions of the star near its rotation equator. Each of these dipoles produces two pairs of magnetic spots of opposite polarity similar to sunspots. The dipoles are located at a distance of Δa=0.6 R from the center, where R is the radius of the star. The field strength at the poles is equal to ±42 and ±19 kG.

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1. INTRODUCTION

In this paper we continue our study of the structure of magnetic fields of chemically peculiar (CP) stars using the method of "virtual magnetic charges" [1]. We used this technique to analyze a total of 23 stars and found nine of them to have the magnetic-field structure corresponding to a central dipole; one star (HD137909) to have a two-dipole structure, and one star (HD37776) to have a more complex field structure. In this paper we analyze yet another star whose magnetic-field phase relation Be(Φ) differs strongly from a sine wave in the case of a central dipole.

2. PHYSICAL PARAMETERS

The star HD32633 of a peculiarity type Si+SrCrEu has a temperature of T_e=12750 K and an absolute bolometric luminosity of Mb(β)= -1.4, and Mb(G)= -1.1 according β index and HIPPARCOS data, respectively [2]. In the same paper ([2]) we also determine the parameter, $R/Rz \approx 1.3$, of the star, i.e., we find it to be of luminosity class V. Here R and R_z are its current and zero-age main sequence radii, respectively.

We adopt the rotation velocity $v\sin i$, which is needed for estimating the tilt angle i of the rotation axis to the line of sight, from Borra and Landstreet [3]: $v\sin i = 23$ km/s. Leone et al. [4] showed that $v\sin i = 23$ km/s implies a radius of $R \geq 2.9R_\odot$ for the star.

Our data show that Mb(G) and Mb(β) absolute-magnitude values imply the radii of $R = 1.6R_\odot$ and $R = 3.1R_\odot$, respectively. Thus the latter value agrees with the estimates of Leone et al. [4]. We adopt the average of the two values, $R = 3.0R_\odot$.

The star's rotation period is P = 6.43 days [5], and hence we find, in accordance with the well-known formula, $v = 50.6.\ R/P = 23.7$ km/s ($\sin i = 0.97$), so that $i = 84° \pm 5°$ (or 96° if we count the angle from the rotation pole in the hemisphere of the positive field polarity). Hence we see the star virtually equator on.

Note that the Mb(G) luminosity value implies $v =$ 2.6 km/s and $\sin i > 1$. Hence the Mb(β) = -1.4 estimate is more realistic.

3. PHASE RELATION BE(Φ) FOR HD 32633

Currently, several series of magnetic-field measurements are available for HD 32633, which were made at different phases of the period [5–9]. All these series except those of Preston and Stepien [6] agree well with each other. To use these series, we, like Renson [5], multiplied the corresponding values by 0.75. We thus have at our disposal a total of 94 measurements, which securely determine the phase variations. For better visualization we constructed the phase relation using three-point sliding-average values. This curve is shown in Fig. 1 by dots. It is immediately evident from the figure that the shape of the phase relation differs strongly from a sine curve typical for stars with a central-dipole magnetic configuration. We compute the phases by the ephemeris adopted from Renson [5].

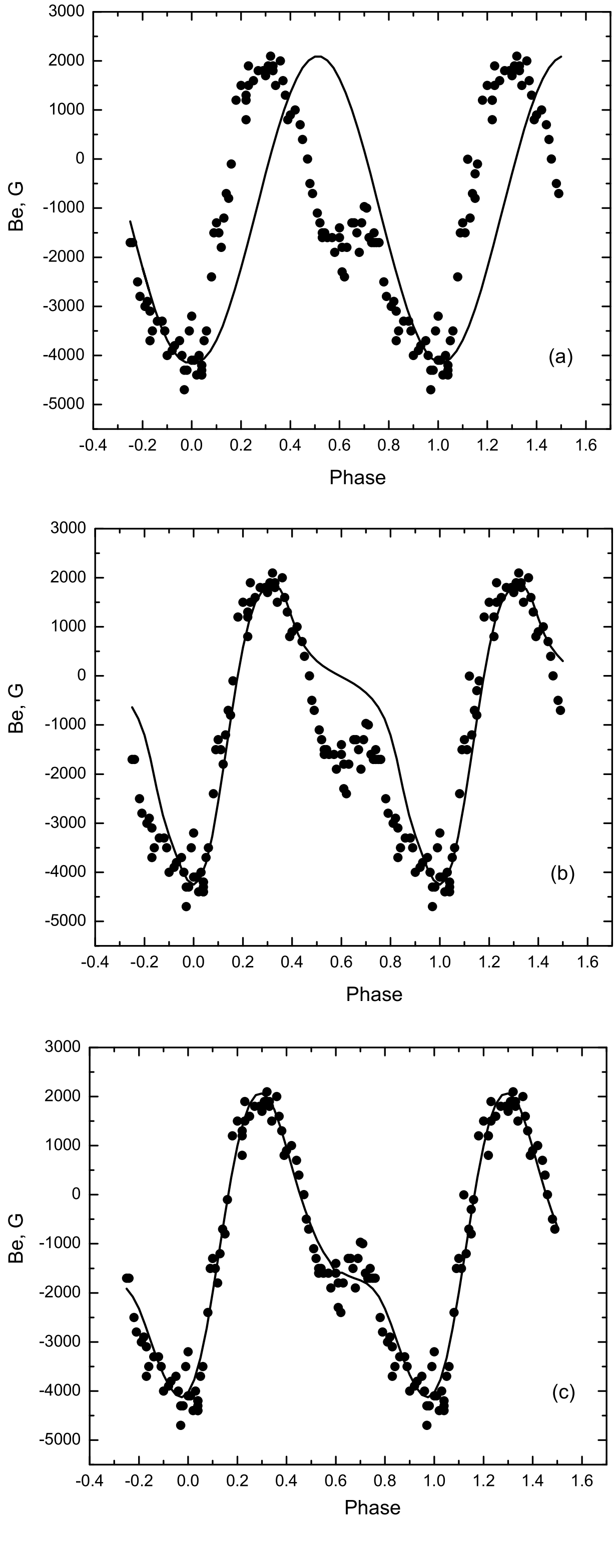

Fig. 1. Observed and model phase relations of the star's magnetic field. (a) Central-dipole model, (b) a model with a single shifted dipole, and (c) a model with two shifted dipoles.

We construct our models using our usual method of "virtual magnetic charges" whose detailed description can be found in [1, 10].

4. CENTRAL-DIPOLE MODEL

As usual, our first step in modeling is in constructing the central-dipole model.

We construct the central dipole for HD 32633 so as to make the amplitude of Be equal to the observed amplitude. The results of computations are shown in Table 1 and Fig. 1a. As is evident from the figure, the form of the computed phase relation Be(Φ) differs strongly from that of the observed dependence, i.e., the configuration of the magnetic field of HD 32633 is inconsistent with the central-dipole model.

5. THE MODEL OF SHIFTED DIPOLE

Quite a few CP stars have fields whose structure can be described in terms of a magnetic dipole shifted with respect to the star's center. Therefore our next step was to compute such a model. The results are summarized in Table 2 and in Fig. 1b. It is evident from the figure that the ascending branch of the model phase curve in the phase interval Φ=0–0.3 agrees well with the observed phase relation, whereas the descending branch of the model curve ($\Phi > 0.5$) differs markedly from the observed curve. The distance between the dipole and the star's center is equal to 0.6 stellar radius. It is evident that the observed configuration cannot be described in terms of a single shifted dipole.

6. THE COMPLEX TWO-DIPOLE MODEL

For the two-dipole magnetic-field structure we used the method of iterations to obtain a model phase relation that describes satisfactorily the observational data (Fig. 1c, Table 3).

We find the shift of both dipoles to be the same and equal to $\Delta a = (0.6 \pm 0.1)$ of the star's radius. The phase relation changes only slightly with shift Δa, which is therefore difficult to determine accurately enough. Given that the error of Δa is within ± 0.1, it is safe to assume that the levels at which the dipoles are located hardly differ by more than this value. We believe $\Delta a = 0.6$ to be a sufficiently safe estimate, because if decreased even by 0.1, it would imply an appreciably wider model maximum and a smoother step. With greater Δa the maximum becomes more narrow than the observed maximum and the step appears lower than is actually observed.

According to our experience the errors of the inferred parameters depend primarily on the accuracy of angle i. The errors that are due to the scatter of data

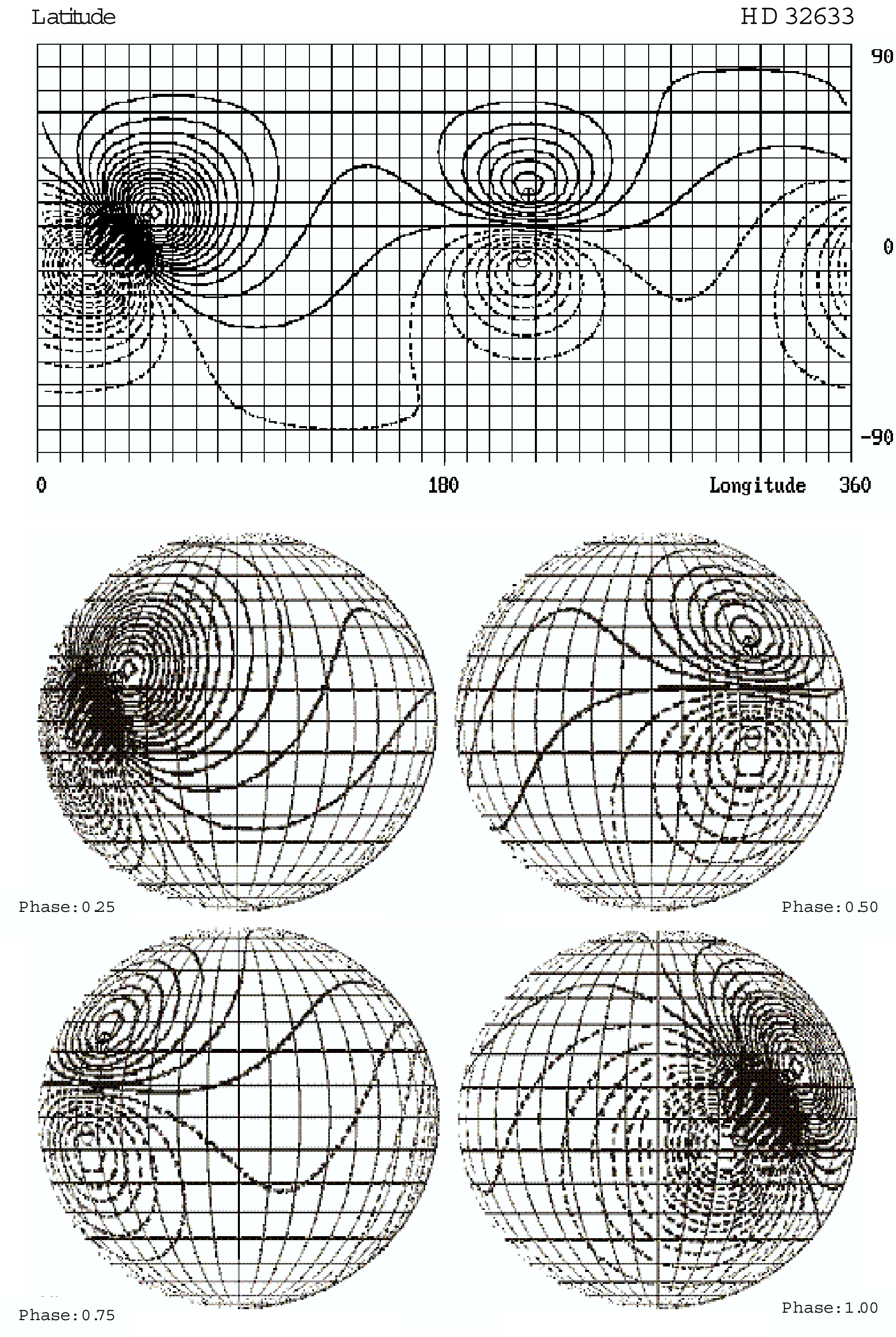

Fig. 2. Mercator map and globes showing the distribution of magnetic field over the surface of HD32633.

points on the phase relations are much smaller and are equal to ±1° and 300–400 G for the coordinates and Bp, respectively. To estimate the magnitude of the errors in the inferred parameters of the two-dipole model that are due to the uncertainty of angle i, we repeated our computations with angles i changed by the error value, ±5°. In Table 3 we give in parentheses the deviations of the parameters so computed. These deviations show the extent of the effect of the assumed error in angle i.

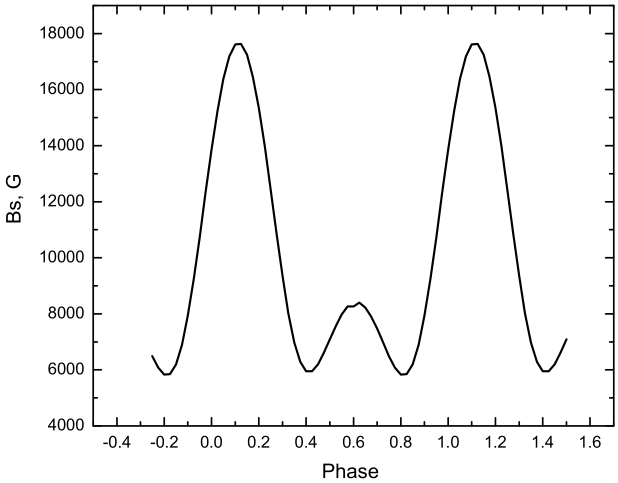

Fig. 3. Phase relation of the average surface magnetic field Bs computed in terms of the two-dipole model.

It is evident from Fig. 1c that in the vicinity of the step at phase $\Phi \approx 0.7$ the magnitude of the observed field varies more abruptly than it follows from the model, which yields a smoother step. However, abrupt variations are most likely not real, because we observe the field integrated over the hemisphere and all local features must be smoothed out. The abrupt variations are probably due to complex variations of polarization in line profiles, which distort the measurements at some phases of the period.

We adopt the resulting model as a first approximation and consider our main result to be the reproduction of the form of the variation of magnetic field, and the quantitative parameter estimates to be more uncertain.

We found the following coordinates for the points with the highest magnetic-field strength: the positive and negative poles of the "strong dipole" at λ=51°, δ=15°and λ=24°, δ=−9°, respectively; the positive and negative poles of the "weak dipole" at λ=217°, δ=28°and λ=215°, δ=−10°, respectively. According to our estimates the errors of the inferred coordinates are on the same order of magnitude as those of the coordinates of the monopoles.

The angle β between the dipole axis and the axis of rotation is one of the main characteristics of the magnetic field of CP stars. In the model considered parameter β is inferred separately for each dipole. In our case β is the angle between the axis of the dipole and the plane passing the axis of rotation and the center of the dipole. Figure 2 shows the Mercator map of the distribution of the magnetic field of HD 32633 and the globes of the star at different rotational phases. It is evident from the figure that the monopoles are sufficiently far apart, i.e., dipoles have

Table 1. Parameters of the central-dipole model for HD32633

Polarity of the monopole	λ, °	δ, °	Bp, G	β, °
−	0	−60	12970	40
+	180	60	12970	

Table 2. Parameters of the shifted-dipole model for HD 32633

Polarity of the monopole	λ, °	δ, °	Bp, G	β, °
−	27	-5	143000	−
+	47	15	157000	

the form of bar magnets. The axes of the dipoles are tilted at large angles to the equator of rotation, namely at $\beta \approx$48° and 5° (for the strong and weak dipoles, respectively) with respect to the plane passing through the axis of rotation. The model obtained can be used to compute the phase relation of the average surface magnetic field, Bs (Fig. 3). The average Bs is equal to 10±2 kG. The structure of the magnetic-field strength contours in Fig. 2 resembles the structure of sunspots as we in our earlier papers [11, 12] when analyzing the potentialities of our modeling technique. Such spots are modeled assuming the existence of sources of magnetic field of opposite polarity located at a small depth under the surface. This is the effect of maximum "noncentrality" of the magnetic dipole. Gerth and Glagolevskij [13] discuss the possibility of using the method to describe the structure of the field for any offset of the dipole with respect to the center of the star, even if the dipole is located above the surface, e.g., on a companion star. The code that we use to compute the distribution of magnetic field over the surface of the star based on the concept of "virtual magnetic charges" operates in all cases employing the same algorithm. The computation of the magnetic map allows us solely to describe the structure of magnetic field on the surface of the star without invoking any assumptions about the mechanism of its generation and the history of its evolution.

7. DISCUSSION

Of the 23 stars studied in this paper only two—HD 32633 and HD 137909—have a two-dipole magnetic-field structure [10]. However, the forms of the phase relations Be(Φ) differ substantially for these two stars. As we mentioned above, the axes of the dipoles in HD 32633 are approximately perpendicular to the plane of the equator of rotation, whereas the dipole axes in HD 137909 are parallel to the plane

Table 3. Parameters of two-dipole model of the magnetic field of HD32633

Polarity of the monopole	λ, °	δ, °	Bp,kG	β, °
−	27±1	−5±1	−40.6±4.9	48±2
+	47±1	12±6	+41.6±4.9	
−	215±1	−5±1	−19.3±2.4	5±2
+	217±1	23±3	+19.3±2.4	

of the equator. This important distinction should be borne in mind when analyzing the initial phases of the formation of magnetic stars and their subsequent evolution. The researchers have paid much attention to the problem of initial phases in recent years. For example, Braithwaite and Nordlund [14] analyze the conditions of the formation of initially unstable and entangled magnetic field and its gradual transition into the stable state observed in magnetic stars. The above authors found that the stable configuration has the form of a ring (toroid) located inside the star and made up of interwined magnetic field lines. This structure is axisymmetric. Inside this ring magnetic field lines form, which make up the poloidal component of the magnetic field—i.e., the component that we observe. Computations show that such a configuration is stable over a time interval of 10^{10} years, and observations by Gerth and V.Glagolevskij [13] confirm this fact. With time, only Ohmic dissipation continues to destroy this field [15, 16]. In our opinion, this work marks an important step forward in the study of the initial stages of stellar evolution, however, this direction of research needs to be improved in all possible ways. In particular, it is still unclear how to explain the magnetic-field configurations of he two stars studied in terms of our approach. It is evident from Fig. 1c that the computed dependence agrees fairly well with the observed dependence. It follows from this that the magnetic field has, in the first approximation, a two-dipole structure or does not differ from it substantially. Both stars are old, they belong to the luminosity class V, and the structure of their magnetic fields must have simplified after the stars in question settle on the Main sequence. On the other hand, by the end of the star's life on the Main sequence, the toroidal field must emerge [14], as on the Sun. However, HD32633 and HD137909 are not old enough for such instability to develop. The scenario considered by Braithwaite and Nordlund [14] also ignores the fact that magnetic stars may have arbitrary angles β between the axis of the dipole and the rotation axis.

REFERENCES

1. E. Gerth and Yu. V. Glagolevskij, Bull. Spec. Astrophys. Obs. **56**, 25 (2003).
2. Yu. V. Glagolevskij, Bull. Spec. Astrophys. Obs. **33**, 33 (2002).
3. E. F. Borra and J. D. Landstreet, Astrophys. J. Suppl. Ser. **42**, 421 (1980).
4. F. Leone, G. Catanzaro, and S. Catalano, Astron. and Astrophys. **355**, 315 (2000).
5. P. Renson, Astron. and Astrophys. **139**, 131 (1984).
6. G. Preston and K. Stepien, Astrophys. J. **151**, 577 (1968).
7. E. F. Borra and J. D. Landstreet, Astrophys. J. Suppl. Ser. **42**, 421 (1980).
8. G. Mathys, Astron. and Astrophys. Suppl. **89**, 121 (1991).
9. G. A. Wade, J-F. Donati, J. D. Landstreet, and S. L. S. Shorlin, MNRAS **313**, 851 (2000).
10. Yu. V. Glagolevskij and E. Gerth, in *"Magnetic stars"*, Eds. by Yu. V. Glagolevskij, I. I. Romanyuk, D. O. Kudtryavtsev (Nizhnij Arkhyz, 2004), p. 142.
11. E. Gerth and Yu. V. Glagolevskij, in *"1-st Potsdam Thinkshop on Sunspots and Starspots"*, Eds. by K. G. Strassmeier, A. Washuettl (Potsdam, Germany, 2002), p. 111.
12. E. Gerth and Yu. V. Glagolevskij, in *"Modelling of Stellar Atmospheres"*, Eds. by N. Piskunov, W. W. Weiss, D. F. Gray (Uppsala, Sweden, 2002), p.111.
13. E. Gerth and Yu. V.Glagolevskij, in *"The A-stars puzzle"*, Eds. by J. Zverko, J. Ziznovsky, S. J. Adelman, W. W. Weiss (Poprad, Slovakia, 2005), p. 629.
14. J. Braithwaite and A. Nordlund, Astron. and Astrophys. **450**, 1077 (2006).
15. Yu. V. Glagolevskij, in *"Magnetic stars"*, Eds. by Yu. V. Glagolevskij, I. M. Kopylov (Leningrad, Nauka, 1988), p. 206.
16. Yu. V. Glagolevskii and E. Gerth, Bull. Special Astrophys. Obs. **58**, 17 (2005).