Magnetic Field Models of CP Stars HD18296, HD19832, HD22470, HD24712

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Abstract—We model the magnetic fields of four magnetic stars using published longitudinal (Be) field measurements. The structure of the magnetic field of each of the four stars is close to that of the central dipole. Unfortunately, the number of measurements for each star is insufficient for accurate finding of the field parameters, and therefore we find no dipole shift exceeding its error \( \Delta a \approx 0.1 \), expressed as a fraction of the stellar radius. Our data support the opinion that the results of modeling depend most strongly on the adopted inclination of the star’s rotation axis \( i \).

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1. INTRODUCTION

This paper continues our investigation of large-scale structures of the magnetic fields of chemically peculiar (CP) stars. We use our technique of “magnetic monopoles” described in our earlier paper [1]. Modeling is based on the published phase dependences of the longitudinal magnetic field \( B_e \), and sometimes of the average surface magnetic field \( B_s \) in the cases where the latter is known. The simplest model has the form of a dipole field with its center coincident with that of the star. The results of modeling strongly depend on the accuracy of measurements. If it is sufficiently high, the position of the dipole inside the star can be determined with higher precision. In many cases the observational data cannot be described in terms of a single dipole model, and we must assume that there are two or more dipoles inside the star. It should obviously be borne in mind that our technique gives only an approximate idea of the field structure. We always use a simple central dipole model in cases where the observations are scarce or the phase dependences demonstrate a large scatter. The results of our previous studies indicate that magnetic fields of many objects can indeed be well described in terms of the central dipole model. A substantial number of stars have fields with structures that can be described by an eccentric dipole model with the dipole offset from the star’s center amounting to \( \Delta a = 0.5 – 0.6 \) of the stellar radius. There appears to be a smooth transition between objects with central and eccentric dipoles. The distribution of \( \Delta a \) is difficult to obtain, because in many cases we analyze the stellar magnetic fields in terms of the central dipole model only due to the low accuracy of phase dependences. The inclination \( \beta \) of the dipole axis with respect to the rotation axis is an important parameter. The data gathered so far indicate that to a first approximation the dipoles are oriented randomly. However, this conclusion still needs to be corroborated by analyzing sufficiently extensive data. Our aim is to get the most comprehensive idea of the collected magnetic-measurement data from the viewpoint of the magnetic fields structure.

2. HD18296 (21Per)

This is an SrCrEu-type star, which exhibits detectable magnetic, photometric, and spectroscopic variability. Its temperature is \( T_e = 10950 \text{ K} \) [2]. Different authors report rather discrepant rotation velocities for the star: \( v \sin i = 5 \text{ km/s} \) [3] (based on two estimates), \( v \sin i = 25 \text{ km/s} \) [4], \( v \sin i = 10 \text{ km/s} \) [5]. The weighted average is \( v \sin i = 11\pm 5 \text{ km/s} \).

Preston’s [6] ephemeris corresponds to the maxima of photometric light variations (\( JD = 2439491.77 + 2.88422E \)).

The star’s radius in solar units is \( R = 2.5R_\odot \) [7]. We reported a similar estimate \( R = 2.6R_\odot \) in one of our earlier papers [8]. Hence the average velocity is \( v = 50.6 \times R/P = 45 \text{ km/s} \) and \( i = 14^\circ \pm 6^\circ \).

Our magnetic field model is based on the longitudinal Be field measurements from hydrogen lines, which are almost unaffected by the nonuniform distribution of chemical elements on the stellar surface. To compute this model, we use the data of Borra and Landstreet [9] and Glagolevskij et al. [10]. We show these data in Fig. 1a as dots. The scatter of data points is large, and hence there is no use in trying to build a precise model for the star’s magnetic field.
Therefore, we used the central dipole model from the very beginning.

We use the least-squares method to match the computed variation of the Be field with the observational data Be(Φ). We show this variation in Fig. 1a by the solid line. Figure 1b represents the computed dependence of the average magnetic field Bs(Φ). Table I lists the magnetic field parameters inferred from the model.

The angle between the star’s rotation axis and the dipole axis is β = 88° ± 1°, and the average surface magnetic field is Bs = (Bs(max) + Bs(min))/2 = 890 ± 200 G. The errors are listed in Table 1 and indicate how the corresponding parameters change in response to a ±5° change in angle i. In the case of the given field configuration and the star’s inclination, the inferred errors are rather large for the polar field, Bp. The dipole axis lies near, but not exactly in the equator of the plane of the rotation, and therefore the ratio of the amplitudes of magnetic field variations is r = 0.65 and not unity. It is evident from Table 1 that the extrema of the field do not coincide exactly with the phases of 0 and 180, but are shifted by +36°, probably because the period of rotation is not quite correct. The measurements of Borra and Landstreet [9] appear to differ by −220 G from ours. According to Glagolevskij et al. [10], the average surface magnetic field is Bs = 600–800 G, which is close to our current result of 890 G (Fig. 1b).

In our earlier paper [11] we studied the distribution of a number of chemical elements on the surface of HD18296. The two strongest “spots” overabundant in rare-earth elements and Fe have longitudes of 0° and 180° and latitudes of −20° and +20°, respectively. The coordinates of these spots are close to those of the magnetic poles. The characteristic radii of the spots are 55°. Two other small spots found by Glagolevskij et al. [11] are located between the large ones. It appears more likely that the overabundant elements in these regions concentrate in a belt along the magnetic equator rather than in circular spots. Figure 2 shows the Mercator map of the distribution of the magnetic field over the star’s surface. The dashed line shows the positions of the two chemical "spots" found in the paper mentioned above. The small difference between the latitudes of the magnetic and chemical centers may be due to measurement errors and to a different inclination i = 40° adopted by Glagolevskij et al. [11]. This result demonstrates once again that the strongest chemical anomalies are found near the magnetic poles. The elements Ti, Mn, Eu, and Gd are concentrated in the regions shown in Fig. 2. In the same regions the strongest magnetic field is observed. Although HD18296 is a weakly magnetic star, the distribution of chemical elements on its surface resembles distributions typical for stars with strong magnetic fields. The elements Ca, Si, Sr, Cr, and Mg are not concentrated within limited areas on the star’s surface, but are distributed more or less uniformly [11]. Glagolevskij et al. [11] discuss why the secondary maximum of photometric variations at the phase of 0.5 is too weak, although both maxima are usually of the same height in stars with a central dipole. Most probably, the visibility of the negative magnetic pole of HD18926 must be less than that of the positive magnetic pole, resulting in unequal visibility of the two spots. It is evident from Fig. 1b that the maximum of Bs at the phase of 0.5 is also lower than the primary maximum.

### Table 1. Magnetic field parameters for HD18296

<table>
<thead>
<tr>
<th>Sign of the monopole</th>
<th>Longitude (λ), °</th>
<th>Latitude (δ), °</th>
<th>Polar field (Bp), G</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>36 ± 5</td>
<td>2 ± 1</td>
<td>1580 ± 400</td>
</tr>
<tr>
<td>−</td>
<td>216 ± 5</td>
<td>−2 ± 1</td>
<td>1580 ± 400</td>
</tr>
</tbody>
</table>

3. HD19832 (56Ari)

This is an Si-type star. The times of the V-band light minima are given by the ephemeris JD = 2437667.728 + 0.72789 E [12]. The star’s rotation velocity has been measured repeatedly and was found to be v sin i = 110 [4], 85 [5], and 128 [7] km/s, with the mean of the measurements equal to v sin i = 108 km/s. We adopt the star’s temperature, absolute bolometric magnitude, and radius, which are Te = 12390 K, Mb = −0.8, and R = 2.8R⊙, respectively, from [2]. Therefore, v = 50.6 × R/P = 194 km/s and i ≈ 34°.

We adopt the Be longitudinal field measurements from [9]. Due to the rather large scatter of data points, we compute the simple field configuration, where the dipole is located at the star’s center. The results are summarized in Table 2. The phase dependence is shifted with respect to Φ = 0 by 90°. Figure 3a demonstrates the observed (dots) and computed (solid line) dependences. The latter proves absolutely symmetric with respect to Be = 0 G. Figure 3b represents the model phase dependence Bs(Φ).