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Magnetic field model of HD 37776

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Abstract. A model of the magnetic field of HD 37776 has been constructed on the basis of phase relationships $B_e(P)$ and $B_s(P)$. A map of distribution of magnetic field intensity over the surface has been obtained. This distribution is rather complex, however, the structure characteristic of a displaced dipole is clearly seen. The dipole axis is approximately parallel to the axis of rotation. The magnetic field is well simulated by a system of 6 magnetic monopoles.

Key words: stars: chemically peculiar — stars: magnetic fields — stars: individual: HD 37776

1. Introduction

The study of the magnetic field structure of the chemically peculiar (CP) stars is of interest in solving the problems of the origin of fields, of relationship between magnetic field and chemical anomalies, of the effect the magnetic field has on the origin and evolution of stars, etc. These questions are presently being extensively discussed in the literature. The structure of the magnetic field of HD 37776 is likely to be the most complex of all the known CP stars, therefore a detailed study of this star with all available techniques is quite urgent. The history of investigation of this star has been described in some detail by Romanyuk et al. (1998). The variation curve of the effective magnetic field B_e with phase of the period P is presented in the paper by Thompson, Landstreet (1985). The measurements have been made from hydrogen lines, and as experience shows, they must not be distorted by inhomogeneous distribution of other chemical elements over the surface. Based on these data, the authors have attempted to construct a magnetic field model and drawn a conclusion that its configuration is quadrupole rather than dipole. Bohlender (1988) and Bohlender, Landstreet (1990) have obtained a more accurate result by using a model of an axially symmetric multipole magnetic field. One has to assume in this model that the average surface magnetic field B_s reaches 60 kG in some phases, which means that the field strength in some individual regions of the surface is substantially larger than this value. Depending on the field configuration, the maximum strengths may exceed this value by a factor of ≈ 2. Indeed, Kopylova and Romanyuk (1992) have detected a noticeable splitting of spectral lines on photographic Zeeman spectra, which indicates the presence of a strong magnetic field of complex configuration. The modeling presented in the paper by Khokhlova et al. (2000) has shown that the dipole-quadrupole model is best suited, but, however, this model does not describe the variation curve of the effective magnetic field during the period of rotation $B_e(P)$. In our work (Gerth et al., 1997) we also made an attempt to model magnetic field of this star, and it was found that the curve $B_e(P)$ is well represented by the configuration dipole+quadrupole+sextupole located in the same plane, the sextupole being predominating in strength in this configuration. The inclination angle of the star turned out to be 82°, which is close to the angle found by Bohlender (90°).

The structure of the magnetic field is not conclusively defined. For this reason, an additional attempt of modeling the magnetic field by the method described by Gerth et al. (1997; 1998), Gerth, Glagolevskij (2000) is undoubtedly a pressing task.

2. Modeling

The idea of the method consists in that inside the star magnetic "monopoles" are specified and the result of addition of their magnetic fields at the surface is computed. In so doing, it is required that the observed and theoretical relations of $B_e(P)$ and $B_s(P)$ had the best fit. Selection of parameters and of the number of monopoles is performed by the method of iterations and the final version is chosen by the least squares method. The field structure is determined by the collection of magnetic monopoles with moments M, by the coordinates of each monopole in longitude λ, latitude δ, and by the distance of monopoles from the star centre a (in fractions of the star radius). The shape of the curves $B_e(P)$ and $B_s(P)$ depends on the star inclination angle i to the line of sight, its original value should therefore be determined from $v \sin i$. Since this value for the star under study is determined extremely unreliably (Khokhlova et al., 2000), we estimate its value as preliminary. Romanyuk et al. (1998) presented the value of $v \sin i = 80\,\mathrm{km/s}$, the star temperature from Glagolevskij (1994) is $T_e = 23350\,\mathrm{K}$. Gomez et al. (1998) presented $M_v = -2.2$. Using the bolometric corrections from Strayzis, Kuriliene (1981) obtain $M_b = 2\overset{\mathrm{m}}{.}4$ and hence the star radius is $R/R_\odot = 1.58$. The period of rotation of the star being $P = 1\overset{\mathrm{d}}{.}54$, its rotational velocity at the equator is $v = 50.6 \cdot R/P = 57\,\mathrm{km/s}$. This means that the value of $v \sin i$ is too large, this is why we have taken the angle $i \approx 90°$, which is close to the one we obtained previously and consistent with the data of Bohlender (1988).

The observational data are presented in Figs. 1 and 2. They were borrowed from the papers by Thompson, Landstreet (1985) and Romanyuk et al. (1998). The relationships $B_e(P)$ and $B_s(P)$ enables more accurate estimation of the star inclination angle i than $v \sin i$ does. Examination of the phase curve $B_e(P)$ shows that in the course of star rotation the regions of magnetic field with predomination of now positive now negative polarity pass alternatively across the central meridian. In our previous paper (Gerth et al., 1997) this led to an inference that the star is chiefly dominated by the effect of the sextupole. To illustrate this, Fig. 3 displays the phase curve of $B_e(P)$ for the most simple case where all the monopoles lie in the equator plane. It is well seen that the extrema of the computed curve coincide with those of the observed relationship, but only in the latter case the curve is deformed. In our paper (Gerth et al., 1997) the deformation was taken into account by introduction of the configuration dipole+quadrupole. However, this representation characterizes the shape of the curve rather than the true internal structure of the magnetic field. By manipulating such parameters as the coordinates of magnetic monopoles and their distance from the centre (assuming the charges to be equal), we sought first of all for coincidence of the computed and observed relations $B_e(P)$. In contrast to our previous modeling (Gerth et al., 1997), in this paper the data of measurement of the surface magnetic field are taken into account (Fig. 2) (Romanyuk et al., 1998). Unfortunately, the number of B_s measurements is inadequate to compute the exact shape of the relation, and in the modeling we took into consideration its mean value, which sufficed for making an accurate enough estimate of the angle i.

If we calculate the phase curve $B_s(P)$ for the case of disposition of monopoles in the equator plane which we use (Gerth et al., 1997), the model relation $B_s(P)$ will turn out to be a horizontal line, and in Fig. 2 a maximum is observed in the region of phases 0.5 – 0.7. Therefore the model must also give a rela-

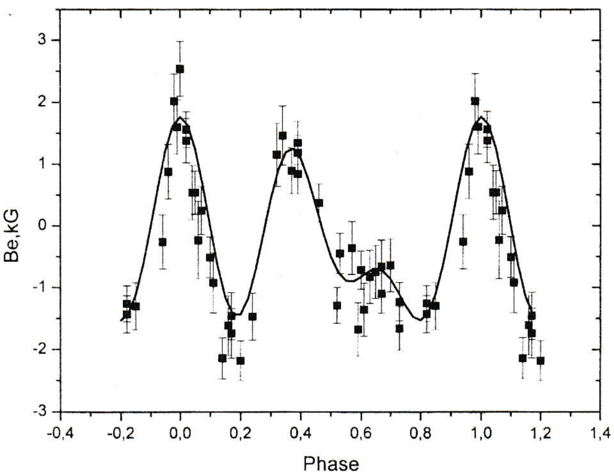

Figure 1: *The model (solid line) and observed (squares) relationships between the magnitude of the effective magnetic field* B_e *and the phase* P *of the period of rotation of HD 37776.*

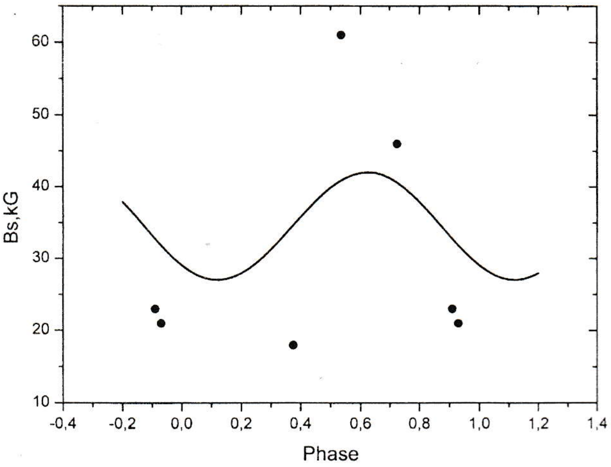

Figure 2: *The same for the average surface field* B_s.

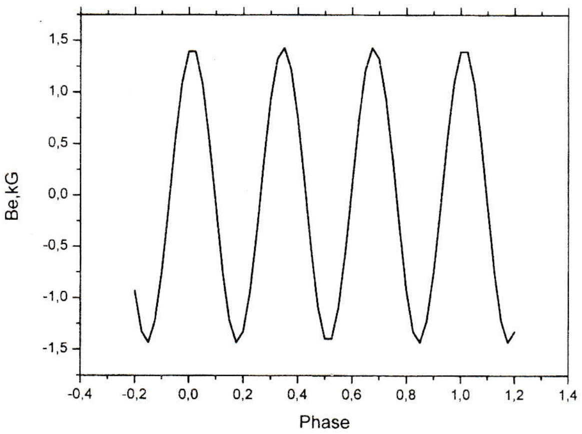

Figure 3: *The model relation* $B_e(P)$ *for the case of location of magnetic monopoles in the equatorial plane.*

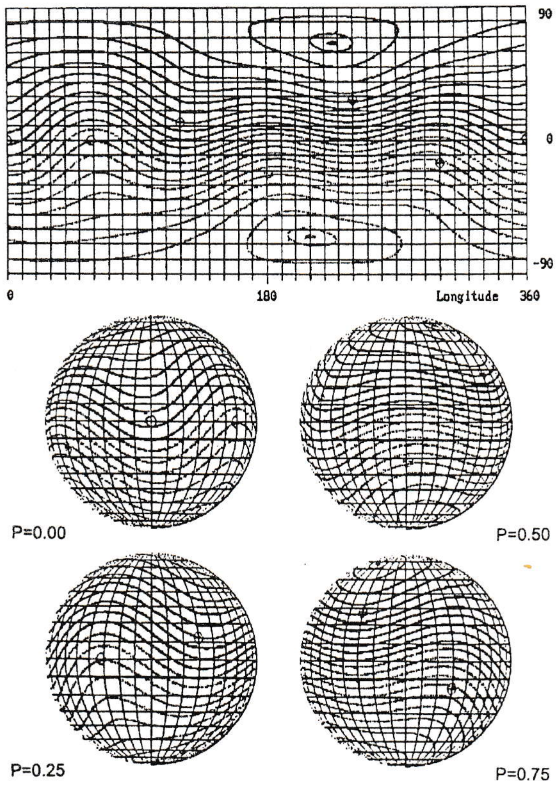

Figure 4: *The distribution of magnetic field intensity over the surface of the star HD 37776.*

tion with a maximum at those phases.

Using the method of step by step approximations, such a configuration of magnetic monopoles was found which led to an excellently consistent phase relation $B_e(P)$ and to an approximate relation $B_s(P)$. The computed curves are displayed in Figs. 1 and 2 with solid lines. The amplitude of the model curve $B_s(P)$ differs from the observed one, although they are similar in shape. It is evident that to obtain a conclusive result, additional measurements of B_s are urgently needed. It should be borne in mind that the available measurements of B_s have been made from the helium lines whose distribution is inhomogeneous and the relationship $B_s(P)$ is somewhat distorted.

Fig. 4 shows a map of the magnetic field intensity distribution over the star surface. The circles with plus or minus signs show the position of magnetic monopoles. The isolines are drawn so that the maximum field strength is divided into 20 levels. The field strength at the magnetic poles is $B_p(+) = 47\,\mathrm{kG}$ and $B_p(-) = 45\,\mathrm{kG}$, the coordinates of the poles are $\lambda = 235°$, $\delta = +65°$ (+) and $\lambda = 205°$, $\delta = -65°$ (−). The coordinates and the distances of the monopoles from the centre are given in Table 1. The positive monopoles are predominantly in one hemisphere, the negative ones — in the other. They are distributed inhomogeneously in latitude, although in longitude they are separated by 60°. The parameter a is the same on the average for all monopoles and is equal to about 0.18 R, however, the accuracy of B_e measurements was such that it had to be chosen with a step of 0.001 R. Reduction of the average value of the parameter a causes "blurring" (diminishing of details) of the phase curve and decrease of the amplitude and vice versa. Such a large value of the parameter a shows that the field structure is more distorted near the surface. First of all we sought to obtain coincidence of the curves $B_e(P)$ and only then of $B_s(P)$. We failed in deriving the amplitude of B_s from 20 to 60 kG, the model curve changed over smaller limits. This is likely due to the effect of inhomogeneous distribution of helium over the surface.

Table 1:

Monopole (sign)	a	Longitude	Altitude
1 (+)	0.180	0°	0°
2 (-)	0.182	58	0
3 (+)	0.167	120	12
4 (-)	0.176	181	−22
5 (+)	0.176	240	28
6 (-)	0.176	300	−15

Approximate estimates show that assuming helium, from the lines of which the field B_s is determined, to concentrate near the magnetic poles in a circle of about 100°, the model relationship $B_s(P)$ will then be consistent with the observed one. Observational data, however, point to another disposition of helium "spots".

The latter note is concerned with the star inclination angle i. The modeling has confirmed that $i = 90° \pm 1°$. (Its change even by 1° will change the shape of the phase curve by a value exceeding the errors).

3. Conclusions

It is seen in Fig. 4 that the structure of the magnetic field is rather complex, and no wonder that difficulties arise in interpreting the spectral line profiles and polarization in them. To refine the model, additional measurements of B_s are quite indispensable.

We regard the results of modeling the magnetic field of the star HD 37776 as an alternative which has to be improved in the future, but it is difficult to presuppose that the new alternative will be essentially different.

It is shown in the paper by Leushin et al. (2000) that the star HD 37776 is located on the Hertzsprung–Russel diagram near the initial main sequence. Thus it has either formed recently as a magnetic chemically peculiar star, or is being formed at present (Glagolevskij, Chountonov, 1998). The complex structure of the magnetic field is likely to be associated with the heterogeneity of the physical condition over the surface in the top layers of the star. With age its structure will get more simple because of the rapid ohmic dissipation of complex structures. As a result the star will prove to have a dipole field whose axis will be nearly parallel to the axis of rotation. The dipolar component is well visible even now on the map of the field distribution over the surface.

It is worth mentioning here one more fascinating star, HD 126515 (Glagolevskij, Gerth, 2000) in which the magnetic field appears in a certain limited region of the surface. The configuration of the magnetic field is extremely nonsymmetric. This is also a young magnetic star located on the Hertzsprung–Russel diagram near the initial main sequence. It is not clear at present what kind of processes cause so characteristic features of the structure of magnetic fields of newly formed stars. Possibly, the inhomogeneous fall of accreting masses at the "pre-main sequence" stage of evolution distorted the field near the star surface. Accumulation of data on modeling magnetic fields of the CP stars will certainly make the solution to this problem possible.

References

Bohlender D.A., 1988, Ph.D.Thesis

Bohlender D.A., Landstreet J.D., 1990, Science News, Jsan.27

Gerth E., Glagolevskij Yu.V., Scholz G., 1997, in: Stellar magnetic fields, eds. Yu.V.Glagolevskij, I.I.Romanyuk, Moscow, 67

Gerth E., Glagolevskij Yu.V., Scholz G., 1998, in: Contr. Astron. Obs. Skalnate Pleso, **27**, 45

Gerth E., Glagolevskij Yu.V., 2000, in: Magnetic fields of Chemically Peculiar and Related stars, eds.: Yu.V. Glagolevskij, I.I.Romanyuk, 151

Glagolevskij Yu.V., 1994, Bull. Spec. Astrophys. Obs., **38**, 152

Glagolevskij Yu.V., Gerth E., 2000, in: Magnetic fields of Chemically Peculiar and Related stars, eds.: Yu.V. Glagolevskij, I.I.Romanyuk, 161

Glagolevskij Yu.V., Chountonov G.A., 1998, Bull. Spec. Astrophys. Obs., **45**, 105

Gomez A.E., Luri X., Grenier S., Figueras F., North P., Royer F., Torra J., Mennessier M.O., 1998, Astron. Astrophys., **336**, 953

Khokhlova V.L., Vasil'chenko D.V., Stepanov V.V., Romanyuk I.I., 2000, Pis'ma Astron. Zh., **26**, 217

Kopylova F.G., Romanyuk I.I., 1992, in: Stellar magnetism, eds.: Glagolevskij Yu.V., Romanyuk I.I., St.Petersburg, Nauka, 54

Leushin V.V., Glagolevskij Yu.V., North P., 2000, in: Magnetic fields of Chemically Peculiar and Related stars, eds.: Yu.V. Glagolevskij, I.I. Romanyuk, 173

Romanyuk I.I., El'kin V.G., Kudryavtsev D.O., Wade G.A., Landstreet J.D., 1998, Bull. Spec. Astrophys. Obs., 45, 93

Strayzis V., Kuriliene G., 1981, Astrophys. Space Sci., **80**, 353

Thompson I.B., Landstreet J.D., 1985, Astrophys. J. Lett., **289**, L9