Astron. Astrophys. 320, 172–176 (1997)

ASTRONOMY AND ASTROPHYSICS

The magnetic field and helium variation of the helium-strong star HD 184927

G.A. Wade[1], D.A. Bohlender[2], D.N. Brown[3], V.G. Elkin[4], J.D. Landstreet[1], and I.I. Romanyuk[4]

[1] Physics & Astronomy Department, The University of Western Ontario, London, Ontario, N6A 3K7, Canada,
[2] Canada-France-Hawaii Telescope Corporation, PO 1597, 96743 2 Kamuela, HI, USA
[3] Science Division, Bellevue Community College, 3000 Landerholm Cir. S.E., 98007-6484 Bellevue, Wa, USA
[4] Special Astrophysical Observatory, Russian Academy of Sciences, 357 147 Nizhnij Arkhyz, Russia

Received 25 July 1996 / Accepted 15 September 1996

Abstract. We have obtained 29 longitudinal magnetic field measurements of the helium-strong star HD 184927 using the University of Western Ontario photoelectric polarimeter and the Special Astrophysical Observatory Zeeman Analyzer. These measurements, obtained over $\sim$ 5500 days, confirm the presence of a variable line-of-sight magnetic field. A period search of these data reveals several acceptable rotational periods, the most significant of which is $9\overset{\mathrm{d}}{.}52961 \pm 0\overset{\mathrm{d}}{.}00731$. This period is the only one consistent with those determined previously from analysis of photometric, equivalent width and magnetic variations (Bond & Levato 1976; Levato & Malaroda 1979). When phased with this period, the longitudinal field data describe a smooth sinusoidal curve with extrema of -0.7 kG and +1.8 kG.

When we phase the helium equivalent width measurements and u-band photometry of Bond & Levato (1976) with our adopted period, the maximum of each of these quantities occurs at the same phase as the longitudinal field maximum. This indicates that an enhanced patch of helium may exist in the photosphere of HD 184927 near the positive magnetic pole. There is no evidence for such an enhancement near the negative pole. This suggests that significant differences may exist in the magnetic field of HD 184927 at the positive and negative magnetic poles, consistent with the presence of an important magnetic quadrupole component.

By synthesizing C II λ6582.9 at a single phase, we have attempted, with moderate success, to define the magnetic field geometry. Using the line profile morphology, the observed longitudinal field variation, an the position of HD 184927 on the $\log T_{\rm eff} - \log g$ diagram (which implies a radius $R = 6.6 \pm 0.8\ R_\odot$), we find the projected rotational velocity $v_{\rm e} \sin i = 14.5 \pm 2.5$ km s^{-1}, the inclination of the rotational axis to the line-of-sight $i = 25 \pm 5°$, and the obliquity of the magnetic symmetry axis $\beta = 78 \pm 3°$. Possible magnetic configurations range from nearly dipolar, to those which contain quadrupole and octupole components comparable in polar strength to the dipole component.

Key words: polarization – stars: chemically peculiar – stars: individual: HD 184927 – stars: magnetic fields

1. Introduction

The helium-strong (He-strong) stars represent the hottest of the main sequence peculiar stars, with effective temperatures in the approximate range 18000-23000 K (Bohlender et al. 1987). They are identified by exceptionally strong and generally variable He lines, the variability attributable to an inhomogeneous distribution of He (and of other elements) over the surfaces of these stars. In addition, the He-strong stars are photometric and magnetic variables, with photometric amplitudes at the 0.1 mag level and strong longitudinal magnetic fields as compared to the cooler magnetic peculiar stars. Their surface gravities are those of main sequence stars, indicating that these objects are hotter counterparts of the SrCrEu and Si Ap stars, and the helium-weak stars. Unlike most cooler magnetic stars, however, some He-strong stars exhibit variable, broad and asymmetric Balmer lines, variable ultraviolet resonance lines, and nonthermal radio emission, indicative of weak stellar winds and of circumstellar plasma trapped within their magnetospheres (Shore & Brown 1990).

HD 184927 (BD +30°3645, $m_{\rm V}$ = 7.5) was first classified by Guetter (1968) as B2 V. Shortly thereafter Bond (1970) mentioned the “very strong” He I lines in its spectrum, noting a similarity to σ Ori E, the prototypical He-strong star. Walborn (1975) detected significant ($\sim$ 50%) variability in the strength of the He I lines from spectra acquired at two different epochs. Bond & Levato (1976; hereafter B&L) acquired photoelectric photometry, as well as 13 spectra of HD 184927 from which the variation in helium equivalent width was measured. These data were found to vary with a period of $9\overset{\mathrm{d}}{.}48$, presumably the rotational period of the star. Levato & Malaroda (1979; hereafter L&M) improved this period to $9\overset{\mathrm{d}}{.}536 \pm 0\overset{\mathrm{d}}{.}05$ using additional

Send offprint requests to: G.A. Wade

He I equivalent width measurements. Glagolevski et al. (1992) found a phase-averaged He/H ratio of 0.27 for HD 184927 .

Leone et al. (1994) reported null results from an attempt to measure 6 cm radio emission from this object. However, Barker (1986) found remarkably strong variability in the profiles of the C IV resonance doublet, which, like those of σ Ori E, show maximum absorption at He maximum. In addition, these profiles show an extended shortward absorption which reaches -600 km s^{-1} and indicates the presence of a stellar wind (Barker 1986).

The effective temperature and surface gravity of HD 184927 have been derived by several authors (e.g. Higginbotham & Lee 1974; L&M). While some inconsistency exists among these results, the majority of measurements, as well as the Johnson colours, are consistent with $T_{\rm eff}$ = 22500 $\pm$ 600 K and log g = 3.80 $\pm$ 0.05.

2. Observations

Longitudinal magnetic field measurements of HD 184927 were acquired using the Special Astrophysical Observatory (SAO) Zeeman analyzer and the University of Western Ontario (UWO) photoelectric polarimeter between JD 2444422 and JD 2449890. The magnetic measurements are presented in Table 1.

The UWO photoelectric polarimeter was used as a Balmer line Zeeman analyzer at the Palomar 200-inch telescope (JD 2444422), the University of Hawaii 88-inch telescope (JD 2444802 through 2444833) and at the UWO 1.2-metre telescope. This instrument measures the fractional circular polarization in the wings of Hβ at $\pm$ 3.6 or 5.0 Å from line centre. The quantity thus measured is linearly related to the longitudinal magnetic field. For the most recent observations, a conversion factor γ = 25500 G per percent circular polarization was used, calculated from Hβ line scans. A more detailed description of the instrument and observing technique is given by Landstreet (1980).

SAO magnetic measurements were obtained from photographic spectra acquired using the 6-metre SAO telescope. Spectra were recorded on Kodak IIaO plates using an achromatic circular polarization analyzer with a reciprocal linear dispersion of 9 Å/mm . Further information on the equipment and observing technique is available in Glagolevski et al. (1986). The SAO magnetic measurements are in excellent agreement with the UWO measurements. No *ad hoc* scaling has been applied to the data.

In addition, a single intensity spectrum was obtained on JD 2448582 using the Canada-France-Hawaii 3.6-m telescope, coudé $f/8.2$ spectrograph and reticon detector. This spectrum, which is centred at 6600 Å and has a resolution of 0.25 Å, contains the C II doublet and was used to determine $v_{\rm e} \sin i$ for HD 184927 .

3. Period analysis

We performed a period search of the magnetic measurements for all independent periods between 1 and 100 days by least-squares fitting of the data using first-order sinusoids. Although several peaks were evident in the periodogram (the strongest at $9^{\rm d}.53$), they were all of insufficient strength to conclusively determine the period.

Table 1. Journal of longitudinal magnetic field observations of HD 184927 . Phases are calculated from the ephemeris cited in the text and σ_B is the 1 standard deviation uncertainty.

JD-244 0000	Phase	$B_{\rm l} \pm \sigma_B$ (G)	Instrument
4422.485	0.092	2700 ± 350	UWO
4511.615	0.445	-450 ± 500	UWO
4802.797	0.001	1780 ± 310	UWO
4803.814	0.108	990 ± 370	UWO
4804.884	0.220	1480 ± 330	UWO
4805.910	0.328	70 ± 350	UWO
4827.891	0.634	-90 ± 320	UWO
4828.771	0.726	410 ± 420	UWO
4829.781	0.832	670 ± 410	UWO
4830.794	0.939	1740 ± 340	UWO
4833.795	0.253	1280 ± 330	UWO
4918.130	0.103	980 ± 280	SAO
5069.509	0.989	2090 ± 510	SAO
5390.575	0.680	-390 ± 250	SAO
5391.603	0.788	-40 ± 540	SAO
5420.494	0.820	-50 ± 290	SAO
5512.390	0.463	-520 ± 200	SAO
5628.358	0.632	-1210 ± 380	SAO
5867.451	0.721	280 ± 300	SAO
5900.276	0.166	1460 ± 390	SAO
6286.728	0.719	990 ± 690	UWO
6287.714	0.822	1880 ± 680	UWO
6289.715	0.032	2280 ± 530	UWO
6377.542	0.248	490 ± 750	UWO
6626.706	0.395	-360 ± 600	UWO
6642.677	0.071	3020 ± 740	UWO
8700.571	0.018	1720 ± 740	SAO
8700.599	0.021	2370 ± 550	SAO
9890.758	0.912	1060 ± 450	UWO

These periods are to be compared with the results reported by B&L and L&M. We performed period searches of the helium intensity measurements and u-band photometry described in these papers (details of individual measurements were kindly provided for us by Dr. H. Bond). While the period search of the photometry also yielded inconclusive results, the periodogram of the 32 helium intensity measurements displayed only one significant peak at $9^{\rm d}.538 \pm 0^{\rm d}.07$, essentially the value found by L&M.

With this result to define a single narrow period window, we inspected the periodogram of the magnetic data around $9^{\rm d}.5$ to see whether we could improve upon the precision of the L&M period. Only one significant peak at $9^{\rm d}.52961 \pm 0^{\rm d}.00731$ was found in the magnetic data in this window. A sine curve fit to the He measurements with this period has essentially the same reduced χ^2 as a fit with the $9^{\rm d}.538 \pm 0^{\rm d}.07$ period.

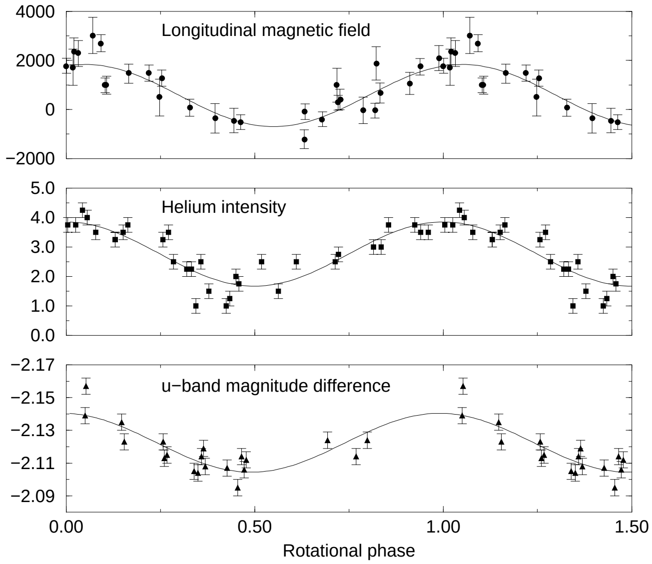

Fig. 1. Longitudinal magnetic field (in gauss), helium intensity (arbitrary units; 1=normal helium line strength, 5=very high helium line strength), and differential u-band magnitude (fainter toward bottom) of HD 184927 plotted vs. phase. The solid curves are least-squares fits

We therefore adopt $9^{\rm d}\!.52961 \pm 0^{\rm d}\!.00731$ as the rotational period of HD 184927 . All of the data (magnetic field, helium intensity and u-band magnitude) have been phased according to the ephemeris JD = 2442563.331 + $9^{\rm d}\!.52961$ E, where the helium line strength maximum has been taken as phase 0.0.[1] The data are plotted in Fig. 1.

Due to the $0^{\rm d}\!.00731$ uncertainty in the rotational period, an uncertainty of 0.12 cycles exists in the relative phase of the magnetic measurements and the helium line strength and photometric measurements.

4. Magnetic field

As can be seen in Fig. 1, the longitudinal field variation is approximately described by a least-squares fit using a function of the form

$$B_{\rm l} = B_0 + B_1 \sin 2\pi(\phi - \phi_0), \tag{1}$$

with coefficients B_0 = 567 ± 69 G, B_1 = 1265 ± 137 G, and ϕ_0 = 0.80. The reduced χ^2 of this fit is 1.79.

Longitudinal field measurements are limited in the amount of detailed information they can provide about the stellar magnetic field. Nevertheless, a description of the large-scale structure of the field may be extracted from their analysis. In the case of HD 184927 , the sinusoidal variation of the field with phase is indicative of a global dipole field geometry. It should be noted that this does not exclude significant contributions from higher-order multipole moments, since it has been shown (Schwarzschild 1950) that cancellation within a given hemisphere is sufficient that these moments contribute only slightly to the longitudinal field. However, it appears that the field geometry is not *dominated* by higher-order moments, as it is for the He-strong star HD 37776, for example (Thompson & Landstreet 1985).

The reversing nature of the longitudinal field curve shows that both the positive and negative magnetic poles transit the stellar disk during one rotation. This indicates that either the inclination of the stellar rotation axis or the obliquity of the dipole symmetry axis (the i and β parameters in the oblique rotator model) must be large (i.e. $\sim 90°$). For a magnetic field dominated by a dipole component (which we have shown is consistent with our measurements of HD 184927), i and β are related by the expression

$$\tan\beta = \left(\frac{1-r}{1+r}\right)\cot i, \tag{2}$$

where the parameter r is the ratio of the longitudinal magnetic extrema (Preston 1967).

From our fit to the magnetic data we obtain $-0.49 \le r \le -0.29$, with a best-fit value of $r = -0.38$.

B&L use a period $P = 9^{\rm d}\!.48$, their measured $v_{\rm e}\sin i$ = 17 km s^{-1}, an assumed radius of 5 $R_\odot$ and the elementary relationship

$$\frac{R}{R_\odot} = \frac{P\ v_{\rm e}\sin i}{50.6\sin i} \tag{3}$$

(where P is in days and $v_{\rm e}$ is in km s^{-1}) to find a rotational axis inclination of i = 39°. However, in their later analysis L&M state that the value of $v_{\rm e}\sin i$ employed by B&L may be only an upper limit, since this is about the velocity resolution of the plates from which the measurement was obtained. This analysis, which includes an estimate of the mass and radius based on the $\log T_{\rm eff} - \log g$ diagram position of HD 184927 , yielded a significantly larger value of R = 8 $R_\odot$ and the constraint $i \le 24°$.

Now, using the values of $T_{\rm eff}$ = 22500 ± 600 K and $\log g$ = 3.80 ± 0.05 found by Higginbotham & Lee (1974) with the theoretical evolutionary tracks of Schaller et al. (1992), we can determine the position of HD 184927 on the $\log T_{\rm eff} - \log g$ diagram. As can be seen in Fig. 2, this position is consistent with a mass of M = 10 ± 1 $M_\odot$, which implies a radius of 6.6 ± 0.8 $R_\odot$. It is clear from Fig. 2 that HD 184927 is a main sequence object.

Since our single spectrum of HD 184927 has a resolution in velocity units of about 11 km s^{-1}, we are in a position to improve upon the rotational velocity constraint given by L&M. We have used ZEEFIT (Landstreet 1988), an LTE line synthesis programme designed to model the effects of a magnetic field on the line profiles, to generate synthetic profiles of the C II λ6582.9 line. An ATLAS9 atmosphere with $T_{\rm eff}$ = 23000 K and $\log g$ = 4.0 was assumed for the calculations.

Because the line profile is sensitive to both $v_{\rm e}\sin i$ *and* the magnetic model (the surface magnetic field distribution as well as the angular parameters i and β), and because the rotational axis inclination i which we calculate depends upon $v_{\rm e}\sin i$ as

[1] Alternatively, a recent epoch of magnetic maximum is JD 2449987.388.

expressed in Eq. (3), the best-fit solution to the line profile must be obtained by searching the parameter space described by the constraints at hand.

For fixed stellar radius R as found above, we select a value of $v_e \sin i$ (we have attempted values ranging from 0 to 25 km s^{-1}). Using Eq. (3) the rotational axis inclination i consistent with these parameters is calculated. Next, the magnetic obliquity β is found via Eq. (2) and the polar strength of the magnetic dipole component calculated via the expression

$$B_d = 20\ B_l^{max} \left(\frac{3-u}{15+u}\right) \left(\cos\beta\cos i + \sin\beta\sin i\right)^{-1}, \quad (4)$$

as adapted from Preston (1967), where B_l^{max} is the value of the longitudinal field at maximum. We have assumed a value of the limb-darkening coefficient of $u = 0.2$, which has been estimated from a fit to the limb darkening profile synthesized using the (T_{eff} = 23000 K, $\log g$ = 4.0) ATLAS9 model atmosphere. This expression is appropriate for field configurations in which the magnetic dipole component dominates. We have shown this to be the case for HD 184927 .

Next, we add quadrupolar and octupolar magnetic moments to the field distribution in order to maximize the agreement between the observed and computed C II line profiles. It should be noted that the longitudinal field is only very weakly sensitive to these higher-order magnetic moments, and so modifying the field configuration in this way does not change the computed longitudinal field significantly.

We obtain convergence (i.e. reasonable agreement between the observed and computed line profiles, under the constraints outlined above) for a range of values of $v_e \sin i$: 14.5 $\pm$ 2.5 km s^{-1}. The magnetic field configurations consistent with these values of $v_e \sin i$ vary from nearly dipolar at $v_e \sin i$ = 17 km s^{-1} (B_d = 9.7 kG, B_{oct} = 2.0 kG with i = 29° and β = 76°) to geometries for which the higher-order moments are comparable in polar strength to the dipole component at $v_e \sin i$ = 12 km s^{-1} (B_d = 13.7 kG, B_q = −9.0 kG, B_{oct} = 12.0 kG with i = 20° and β = 81°). It is not possible to distiguish between the possible models based on the data at hand; improved spectroscopic phase coverage would be a significant contribution toward this goal.

While no further conclusion as to the magnetic geometry of HD 184927 can be made at this point, it should be noted that very few stars seem to populate either those regions of parameter space defined by purely dipolar magnetic models, or those regions defined by magnetic models which contain higher-order moments comparable in polar strength to the dipole component. It therefore seems reasonable that the magnetic field configuration of HD 184927 lies somewhere between these two extremes.

The observed and computed C II λ6582.9 line profiles are shown in Fig. 3.

5. Discussion

It is apparent from Fig. 1 that the maxima of the helium intensity, the longitudinal field and the u-band magnitude all occur near phase $\sim$ 0.0. In addition, the C IV resonance lines are strongest at phase 0.0 (Barker 1986). Even when we consider the uncertainty of 0.11 cycles in the relative phase of our new data and the data of B&L and L&M, this coincidence remains significant. The relative phasing of the magnetic field and helium intensity variations indicates the presence of an enhanced patch of helium at or near the positive magnetic pole. As is discussed by Vauclair (1975), this is consistent with the diffusion of helium in the presence of a quasi-dipolar magnetic field (which we have shown to exist) *and* in the presence of a weak ($\dot{M} \sim 10^{-12}\ M_{\odot}$/yr) stellar wind. However, we see no hint of a secondary maximum (i.e. a bump, or a flattening) of the He intensity curve near the phase of longitudinal field minimum. While this may be because of the proximity of the negative pole to the limb, the extent of the polar helium caps inferred for other He-strong stars (as large

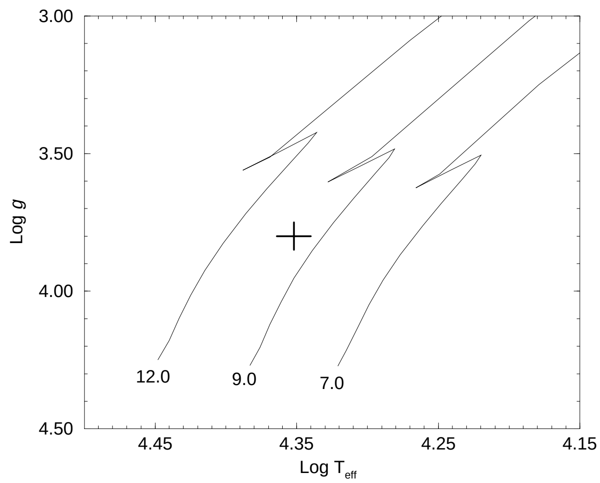

Fig. 2. Position of HD 184927 on the $\log T_{eff} - \log g$ diagram. Evolutionary tracks for 7, 9 and 12 M$_{\odot}$ are adapted from Schaller et al. (1992). Adopted effective temperature and surface gravity are from Higginbotham & Lee (1974)

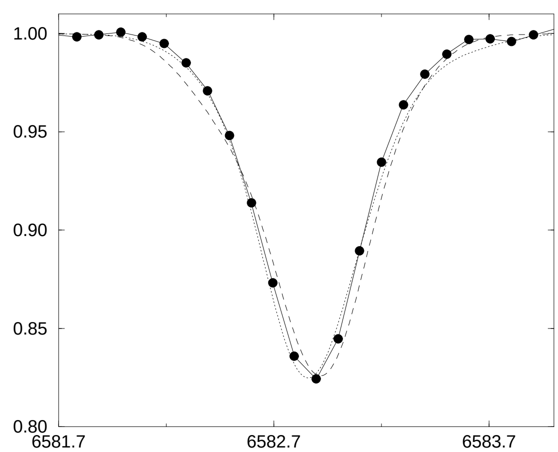

Fig. 3. Observed and computed profiles of C II λ6582.9 in the spectrum of HD 184927. Synthetic profiles are shown for $v_e \sin i$ = 12 km s^{-1} and the associated magnetic model (dotted profile) and $v_e \sin i$ = 17 km s^{-1} and the associated magnetic model (dashed profile)

as 70°; Bohlender 1988) would suggest otherwise. Therefore no evidence exists for a similar He abundance enhancement at the negative pole. This suggests that significant differences may exist in the magnetic field of HD 184927 at the positive and negative magnetic poles, causing differences in the mass-loss rates and thereby generating different polar helium accumulations.

By comparing the large amplitude of the u-band light variations (at least in part due to blanketing by helium in the stellar photosphere) and the exceptional variability of the He lines to those of other members of this class modeled by Bohlender (1988), we estimate a total He abundance contrast of 0.5-0.8 dex over the surface of this star.

When considered as a member of the class of He-strong stars, HD 184927 displays several unusual characteristics. Foremost among these is the sharpness of its spectral lines. This may prove useful for future attempts to model the spectral lines of this star, since their sharpness will allow any magnetic broadening to be more easily detected. Indeed, using our value for the radius of the star, we obtain from Eq. (3) an equatorial rotational velocity of v_e = 35 km s^{-1}, a value considerably lower than the mean for the He-strong stars. In addition, HD 184927 displays very strong C IV resonance line variability, the amplitude of which is second only to that found for the He-strong star HD 64740 (Barker 1986). **The combination of a low rotational velocity and strong variability makes this object unique among the He-strong stars.**

HD 184927 also displays many characteristics which are quite typical of the He-strong stars. For instance, the star is brightest in the u band at helium line strength maximum. Helium line strength maximum occurs at the same phase as a magnetic extremum, as it does for the majority of He-strong stars (Bohlender et al. 1987). Additionally, the magnetic field, regardless of which model we choose, must be very strong. This is consistent with the observation that the fields of these stars are systematically stronger than those of the Ap stars (Bohlender et al. 1987, Thompson et al. 1987).

6. Summary

We have shown that our new longitudinal magnetic field measurements of the He-strong star HD 184927 are consistent with the presence of a variable line-of-sight magnetic field. A period search of these measurements reveals a number of acceptable periods, but only one of these (at $9^{\mathrm{d}}.52961 \pm 0^{\mathrm{d}}.00731$) is consistent with previous determinations. When phased with this period, the magnetic measurements describe an approximately sinusoidal curve with extrema of −0.7 and +1.8 kG.

When we phase the u-band photometry and helium intensity measurements of Bond & Levato (1976) with the $9^{\mathrm{d}}.52961 \pm 0^{\mathrm{d}}.00731$ period, we find that the maxima of each of these quantities occurs at the same phase as longitudinal field maximum. This indicates that an enhanced patch of helium may exist in the photosphere of HD 184927 at or near the positive magnetic pole. We find no evidence for a similar enhanced patch at the negative pole. This suggests that significant differences may exist in the magnetic field of HD 184927 at the positive and negative poles, consistent with an important quadrupolar contribution to the field configuration.

Using the measurements of T_{eff} and $\log g$ obtained by Higginbotham & Lee (1974) we determined the position of HD 184927 on the $\log T_{\mathrm{eff}} - \log g$ diagram. According to the theoretical evolutionary tracks of Schaller et al. (1992), this position implies a mass of $10 \pm 1\ M_{\odot}$ and a radius of $6.6 \pm 0.8\ R_{\odot}$.

By synthesizing C II λ6582.9 at a single phase, we attempted to constrain the magnetic geometry. As a result of this synthesis we determined the projected rotational velocity $v_e \sin i$ = 14.5 ± 2.5 km s^{-1}, the inclination of the rotational axis to the line-of-sight i = 25 ± 5°, and the obliquity of the magnetic symmetry axis β = 78 ± 3°. Magnetic configurations consistent with line profile morphology the longitudinal field variation and with the constraint on i imposed by rigid rotation range from nearly dipolar, to those which contain quadrupole and octupole components comparable in polar strength to the dipole component.

Acknowledgements. Our thanks to Drs. H. Bond and H. Levato for making their original data available for our analysis. Some of the data presented in this paper were obtained by DNB and JDL while guest observers at the Palomar 200-inch telescope, and by DNB while a guest observer at the University of Hawaii 88-inch telescope. This work has made use of the Simbad database, operated at CDS, Strasbourg, France. This work was partially supported by the Government of Ontorio in the form of an Ontorio Graduate Scholarship held by GW.

References

Barker P.K., 1986, in *Hydrogen Deficient Stars and Related Objects*, K. Hunger et al. eds., p 277
Bohlender D.A., 1988, Ph.D. Thesis, The University of Western Ontario
Bohlender D.A., Brown D.N., Landstreet J.D. and Thompson I.B., 1987, ApJ 323, 325
Bond H.E., 1970, PASP 82, 321
Bond H.E. & Levato H., 1976, PASP 88, 905
Glagolevski Yu.V., Bychkov V.D., Romanyuk I.I., Chunakova N.M., 1986, Bull. Spec. Astrophys. Obs. North Caucasus 19, 26
Glagolevski Yu.V., Topilskaya G.P., Kartashova T.A., 1992, in *Stellar Magnetism*, Yu.V. Glagolevski and I.I. Romanyuk eds., p 36
Guetter H.H., 1968, PASP 80, 197
Higginbotham N.A & Lee P., 1974, A&A 33, 277
Landstreet J.D., 1980, AJ 85, 611
Landstreet J.D., 1988, ApJ 326, 967
Leone F., Trigilio C., Umana G., 1994, A&A 283, 908
Levato H. & Malaroda S., 1979, PASP 91, 789
Preston G.W., 1967, ApJ 150, 547
Schaller G., Schaerer D., Meynet G. and Maeder A., 1992, A&AS 96, 269
Schwarzschild M., 1950, ApJ 112, 222
Shore S.N. & Brown D.N., 1990, ApJ 365, 665
Thompson I.B. & Landstreet J.D., 1985, ApJ 289, L9
Thompson I.B, Brown D.N and Landstreet J.D., 1987, ApJS, 64, 219
Vauclair S., 1975, A&A 45, 233
Walborn N.R., 1975, PASP 87, 613