SPECTROPOLARIMETRY OF MAGNETIC STARS: HD 125248 *

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ABSTRACT. We present preliminary results about the magnetic field of the Ap star HD 125248, from spectra recorded in RCP and LCP light with the Zeeman analyzer of the CASPEC at ESO.

In this paper we present a preliminary report about the diagnostic contents of spectra of the A0p star CS Vir (= HD 125248) simultaneously recorded in right (RCP) and left (LCP) circularly polarized light with the Zeeman analyzer of the CASPEC at the ESO 3.6m telescope. The instrumentation and its performance have been described by Mathys and Stenflo (1986). The journal of observations is given in Table 1, where the phases are computed according to the ephemeris (Babcock, 1960) HJD (positive extremum of the longitudinal field) = 2 430 143.07 + 9.2954E. We have analyzed the set of Fe II lines listed in Table 2. The identification of the transitions is from Johansson (1978). In columns 3 and 4, the values of the Landé factors of the lower (g_l) and upper (g_u) levels are the experimental ones (Reader and Sugar, 1975) whenever possible; computed values (see Mathys and Stenflo, 1986) are quoted between parentheses. We employ the new parameterization of the line profiles introduced by Mathys (1987); the reader is referred to this paper for a detailed description of the notations. In this preliminary work, we make use of averages, either over the various phases (which we will denote by $\{\ldots\}_{av}$) or over the various lines (for which we use the notation $[\ldots]_{av}$) in order to reduce the scatter due to measurement errors, etc. in the relations that we try to evidence.

The average over the phases of the abslolute value of the wavelength shift between the centres of gravity of the RCP and LCP lines, $\{|\langle\lambda_R\rangle - \langle\lambda_L\rangle|\}_{av}$ is expected for weak lines to be proportional to $\bar{g}\lambda_0^2\{|\langle H_z\rangle|\}_{av}$, where $\bar{g}$ is the effective Landé factor of the transition, λ_0 is its wavelength, and $\langle H_z\rangle$ is the longitudinal field, i.e. the line-intensity weighted average over the visible stellar hemisphere of the component of the magnetic field vector along the line of sight. Figure 1 shows a plot of $\{|\langle\lambda_R\rangle - \langle\lambda_L\rangle|\}_{av}$ vs. $\bar{g}\lambda_0^2$. The lines represented by squares nicely match the predicted linear dependence of $\{|\langle\lambda_R\rangle - \langle\lambda_L\rangle|\}_{av}$ on $\bar{g}\lambda_0^2$. The dashed line is a linear regression (forced through the origin) defined by these points. Its slope corresponds to $\{|\langle H_z\rangle|\}_{av} = (1449 \pm 39)$ G. The cross ($\times$) in Fig. 1 represents the line λ 6446, which could not be measured in one of the polarizations on the spectrum taken on HJD 2 446 896.594 because of the superimposition of a radiation event ("cosmic ray"). The three lines represented by plus signs (+), $\lambda\lambda$ 5955, 6149 and 6416, definitely lie below the straight line defined by the other lines. These three lines happen to be the three strongest lines of the sample, and it is thus tempting to conclude that their behaviour in Fig. 1 reflects the fact that the proportionality breaks down for strong lines. However it should also be pointed out that: (i) these lines are also peculiar in their Zeeman pattern and (ii) they may, as well as λ 6175, suffer

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Table 1. Spectra of HD 125248 recorded with the Zeeman analyzer of the CASPEC

Date of mid-exposure HJD 2 440 000.+	Duration of exposure (s)	Phase	$\langle H_z \rangle$ (G)
6219.581	300	0.513	-1816 ± 207
6547.621	360	0.803	980 ± 202
6548.601	420	0.909	1647 ± 128
6549.614	390	0.018	1952 ± 136
6894.559	330	0.127	1933 ± 179
6894.901	360	0.164	2080 ± 117
6895.557	420	0.234	1273 ± 112
6895.896	600	0.271	1004 ± 148
6896.594	900	0.346	$-\ 417 \pm 258$
6896.901	480	0.379	-1007 ± 193
6897.680	480	0.463	-1382 ± 166
6897.891	420	0.485	-1830 ± 177

Table 2. Sample of Fe II lines used for the study of the magnetic field

λ_0 (Å)	Transition	g_l	g_u
5952.525	$3d^7\, d\,^2D_{5/2}$ — $(a\,^3P)\ 4p\ z\,^2P^o_{3/2}$	(1.200)	1.329
5955.700	$(^5D)\ 4d\ e\,^4F_{5/2}$ — $(^5D_3)\ 4f\ ^2[3]^o_{7/2}$	(1.029)	(1.357)
5961.706	$(^5D)\ 4d\ e\,^4F_{9/2}$ — $(^5D_4)\ 4f\ ^2[6]^o_{11/2}$	1.29	(1.244)
5991.368	$(^3G)\ 4s\ a\,^4G_{11/2}$ — $(^5D)\ 4p\ z\,^6F^o_{9/2}$	1.237	1.43
6060.991	$(a\,^3F)\ 4p\ x\,^4D^o_{7/2}$ — $(^5D)\ 5s\ e\,^4D_{7/2}$	1.385	(1.429)
6084.099	$(^3G)\ 4s\ a\,^4G_{9/2}$ — $(^5D)\ 4p\ z\,^6F^o_{7/2}$	1.15	1.399
6149.246	$(^3D)\ 4s\ b\,^4D_{1/2}$ — $(^5D)\ 4p\ z\,^4P^o_{1/2}$	(0.000)	2.70
6175.138	$(b\,^3F)\ 4s\ c\,^4F_{7/2}$ — $(^3G)\ 3p\ x\,^4F^o_{7/2}$	(1.238)	1.21
6383.721	$(^5D)\ 4p\ z\,^4D^o_{5/2}$ — $4s^2\ c\,^4D_{5/2}$	1.35	(1.371)
6416.921	$(^3D)\ 4s\ b\,^4D_{5/2}$ — $(^5D)\ 4p\ z\,^4P^o_{5/2}$	1.327	1.592
6442.951	$(^5D)\ 4p\ z\,^4F^o_{7/2}$ — $4s^2\ c\,^4D_{7/2}$	1.29	(1.429)
6446.402	$(b\,^3F)\ 4s\ c\,^4F_{7/2}$ — $(^3G)\ 4p\ x\,^4G^o_{9/2}$	(1.238)	(1.172)

from unrecognized blends. Therefore it seems safer to determine the longitudinal field using only the "weak" lines. Thus the values of $\langle H_z \rangle$ given in table 1 were derived using the lines of table 2 except for $\lambda\lambda$ 5955, 6149, and 6416. (At phase 0.346, λ 6446 was not employed either.)

For weak lines and a strong randomly oriented field, the second order moment of the intensity profile about the line centre λ_0, $R_I^{(2)}(\lambda_0)$, is expected to be in a first approximation proportional to $\left(\frac{2}{3}\,C_2^{(-1)} + \frac{1}{3}\,C_2^{(0)}\right) \lambda_0^4 \langle H^2 \rangle$, where $C_2^{(-1)}$ and $C_2^{(0)}$ are atomic parameters describing the Zeeman pattern of the transition (Mathys and Stenflo, 1987a, b), and $\langle H^2 \rangle$ is the line-intensity weighted quadratic average over the stellar disk of the modulus of the magnetic field. The field is probably not randomly oriented at a given phase, but when averaging over the phases, this should be a good approximation. A plot of $\{R_I^{(2)}(\lambda_0)\}_{av}$ vs. $\left(\frac{2}{3}\,C_2^{(-1)} + \frac{1}{3}\,C_2^{(0)}\right) \lambda_0^4$ is shown in Fig. 2. Except for $\lambda\lambda$ 5955 and 6175, a quite nice correlation appears. Though this may be purely coincidental (in particular in view of the arbitrariness involved in the choice of a random field geometry), we performed a linear regression of $R_I^{(2)}(\lambda_0)$ as a function of $\left(\frac{2}{3}\,C_2^{(-1)} + \frac{1}{3}\,C_2^{(0)}\right) \lambda_0^4$, for all the lines but $\lambda\lambda$ 5955 and 6175. The result is the dashed line of Fig. 2. The slope corresponds to $\{\langle H^2 \rangle\}_{av} = 4.98\ 10^7\ \mathrm{G}^2$, or $\sqrt{\{\langle H^2 \rangle\}_{av}} \approx 7$ kG (which implies $\sqrt{\{\langle H_z^2 \rangle\}_{av}} \approx 4$ kG for an isotropic distribution of field vectors), which are quite plausible values.

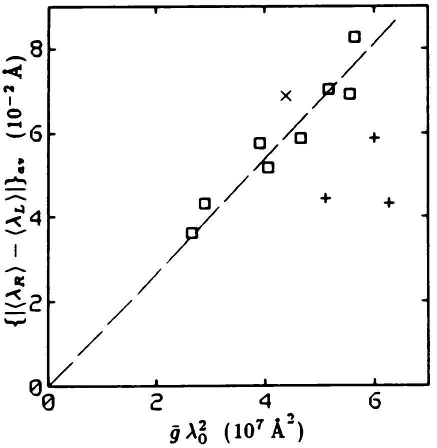

Fig. 1. $\{|\langle\lambda_R\rangle - \langle\lambda_L\rangle|\}_{av}$ vs. $\bar{g}\lambda_0^2$

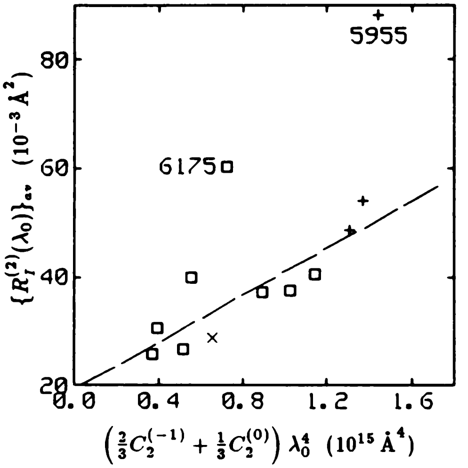

Fig. 2. $\{R_I^{(2)}(\lambda_0)\}_{av}$ vs. $\left(\frac{2}{3}\,C_2^{(-1)} + \frac{1}{3}\,C_2^{(0)}\right)\lambda_0^4$

The difference between the second order moments of a line in the RCP and LCP spectra about the corresponding centre of gravity ($\langle\lambda_R\rangle$ and $\langle\lambda_L\rangle$), $\Delta R^{(2)} \equiv R_R^{(2)}(\langle\lambda_R\rangle) - R_L^{(2)}(\langle\lambda_L\rangle)$, provides a quantitative measure of the crossover effect (the oppositely polarized line components have different widths, Babcock, 1956). For weak lines, $\Delta R^{(2)}$ is expected to be proportional to $\bar{g}\,v_e\,\sin i\,\lambda_0^3\,\langle xH_z\rangle$, where $v_e \sin i$ is as usual the projected equatorial velocity and $\langle xH_z\rangle$ is the line-intensity weighted first order moment of the line-of-sight component of the field about the plane defined by the line of sight and the rotation axis of the star (x is in units of the stellar radius). Excluding the lines $\lambda\lambda$ 5955, 6149 and 6416, and λ 6446, for the reasons given above, we have performed a linear regression, forced through the origin, of $\{|\Delta R^{(2)}|\}_{av}$ vs. $\bar{g}\lambda_0^3$. If we adopt a value of $10\,\mathrm{km\,s^{-1}}$ for $v_e \sin i$, the slope of the regression line corresponds to an average (over the phases) absolute value of the first order moment (about the plane defined by the line of sight and the stellar rotation axis) of the line-of-sight component of the field $\{|\langle xH_z\rangle|\}_{av} = (640 \pm 50)\,\mathrm{G}$, not unreasonable.

Finally we have computed the value of $\Delta R^{(2)}$ averaged over the line sample, $[\Delta R^{(2)}]_{av}$, at the various rotation phases. Only those lines that were included in the above regression are used, but the shape of the variation curve of $[\Delta R^{(2)}]_{av}$ is not significantly different when the whole sample is considered. A smooth variation appears, which is compatible with the previously reported observation that the crossover effect is maximum near phases 0.4 and 0.7.

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DISCUSSION

SAAR Blends will cause systematically different effects on line cores and wings, so that even for many lines and a random distribution of blends, there will be systematic effects. Do you have any preliminary idea of how blends may affect your measurements ?

MATHYS We have not looked at this point in detail yet. I believe that the effect is less critical than in a two-line method, such as Robinson's, but you may actually know more than I do about this problem, since you have studied it more completely.

BASRI Do you determine the fitting parameters separately for each spectral type, or just use the solar values ?
Remark following : As you have already mentioned, you can profitably use the profile information you have to do a more detailed physical analysis later, and perhaps assign physical meaning to your empirical parameters.

MATHYS We used the same form for the regression equation for all stars as well as for the Sun, but perform the calculation of the regression coefficients for each star individually. We have also tested different regression equations, but either they hardly affect our conclusions about the magnetic field, or they yield a much larger scatter about the fit and can thus be discarded.

RUTTEN In your regression analysis, you also obtain solutions for non-magnetic line formation parameters, e.g. excitation energy, wavelength, Doppler width. I think it is necessary to interprete these dependences in detail to be certain they don't backfire on the magnetic parameters. Do you understand the behaviour of these other parameters in detail ?

MATHYS Since we derive empirically the dependences that we introduce in our regression equation, we do not interpret them in detail. However, the dependences that we introduce seem physically reasonable and the conclusions that we draw about the magnetic field are not very sensitive to the exact form of the regression equation that we use.