The A-Star Puzzle
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A survey of the weakest-field magnetic Ap stars: discovery of a threshold magnetic field strength?

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Abstract. We are conducting a magnetic survey of a sample of about 30 spectroscopically identified Ap stars, with weak or previously undetected magnetic fields. For 28 studied stars, we have obtained 25 detections of Stokes V Zeeman signatures. Our results suggest that all Ap stars are magnetic. Further there may exist a minimum field strength for which Ap-type characteristics are produced.

Keywords. Methods: data analysis, techniques: polarimetric, stars: magnetic fields

1. Introduction

Although thousands of chemically peculiar (CP) and Ap stars are catalogued (Renson *et al.* 1991), only about 210 Ap stars have magnetic field measurements (Romanyuk 2000). The catalogue of magnetic CP stars by Romanyuk (2000) contains 117 of 211 stars (55%) with maximum unsigned longitudinal fields larger than 1 kG. On the other hand, according to Bohlender & Landstreet (1990), the median rms longitudinal magnetic field of Ap stars (based on a magnitude-limited sample observed by Borra & Landstreet 1980) is approximately 300 G (the largest one they report is only 710 G). In the catalogue of Bychkov *et al.* (2003) the distribution of the averaged magnetic field strength is described by a decreasing exponential function above 100 G, which again implies that weak-field Ap stars represent the majority of their class. Thus the weak part of the magnetic distribution in Ap stars is unknown and one may even ask if there is there is a minimum magnetic field needed for making an Ap star (Glagolevskij & Chountonov 2002). To improve our knowledge of these stars and to be able to make an unbiased investigation of Ap star magnetic fields, we have undertaken the study of a sample of about 30 spectroscopically identified Ap stars (selected from the HD catalogue), but with weak or previously undetected magnetic fields.

2. Method

Observations were obtained during 5 runs from June 2001 to February 2004 using the MuSiCoS spectropolarimeter attached to the Bernard Lyot telescope (TBL) at the Ob-

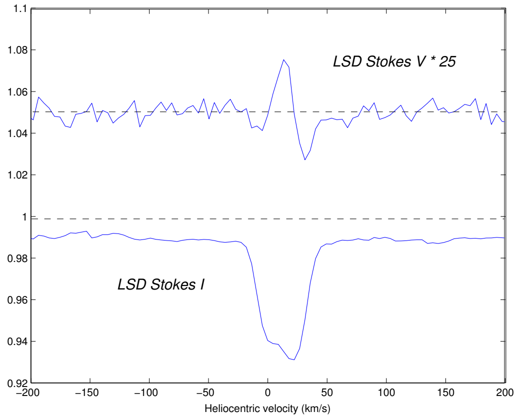

Figure 1. Stokes I and Stokes V LSD Zeeman signatures for the weak-field magnetic Ap star 43 Cas (HD 10221). Notice the easily-detected Stokes V Zeeman signature, although at a phase when the longitudinal magnetic field is only 93 ± 32 G.

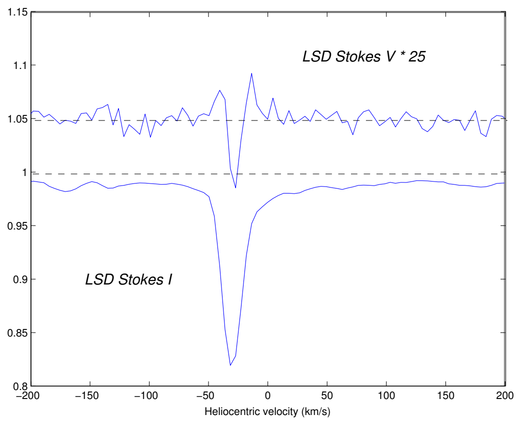

Figure 2. Stokes I and Stokes V LSD Zeeman signatures for the weak-field magnetic Ap star 65 UMa, at a phase when the longitudinal magnetic field is only -43 ± 26 G.

servatoire du Pic du Midi. The aim of our study is to detect circular polarisation which is characteristic of the longitudinal Zeeman effect. For this we used the Least Squares Deconvolution (LSD) procedure (Donati *et al.* 1997). This method enables the "averaging" of several hundreds of lines and thus to obtain Stokes I and Stokes V profiles with greatly improved S/N ratios. LSD gives us a single quantitative criterion for detection of Stokes V polarisation: we perform a statistical test in which the reduced χ^2 statistic is computed for the Stokes V profile, both inside and outside the spectral line (Donati et al 1997). The statistics are then converted to detection probabilities and the probabilities are assessed to determine if we have definite detection (DD, false alarm probability $< 10^{-5}$), marginal detection (MD, false alarm probability $> 10^{-5}$ and $< 10^{-3}$), or no detection. We also computed mean longitudinal magnetic fields B_z for the stars in our survey, Figures 1 through 3 illustrate that we can obtain strong Stokes V polarisation detections, and thus significant magnetic field detection, even if B_z is null at the observed phase.

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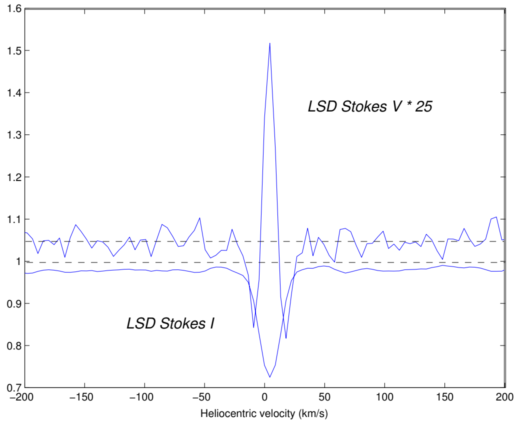

Figure 3. Stokes I and Stokes V LSD Zeeman signatures for the magnetic Ap star HD 43819. Notice the very strong Zeeman signature, although at a phase when the longitudinal magnetic field is only -72 ± 39 G.

Table 1. Maximum $|B_z|$ observed for definitively detected stars of our survey (results are currently improving with new observations and new reductions). Note that the majority of these stars are of early A/late B spectral type; hence this survey complements the survey of cool Ap stars reported by Johnson *et al.* (2005).

Name	HD	Spec.Type	# Obs	Max. Obs. $|B_z|$ (G)	Error (G)
HN And	8441	A2p	1 DD (1)	65	29
43 Cas	10221	A0sp	3 DD (6)	93	32
ι Cas	15089	A5p	2 DD (2)	285	140
	15144	A6Vsp	2 DD (2)	648	19
9 Tau	22374	A2p	1 DD (2)	459	32
56 Tau	27309	A0sp	5 DD (5)	649	79
	37687	B8	1 DD (1)	760	165
	40711	A0	1 DD (1)	492	75
	43819	B9IIIsp	6 DD (6)	770	79
15 Cnc	68351	B9sp	1 DD (7)	264	62
3 Hya	72968	A1spe	8 DD (8)	371	26
45 Leo	90569	A0sp	8 DD (8)	538	45
	94427	A5	1 DD (4)	194	47
	96707	F0p	1 DD (6)	119	58
65 Uma	103498	A1spe	7 DD (8)	160	21
21 Com	108945	A2pvar	7 DD (7)	256	52
	138633	F0	1 DD (2)	246	48
ω Her	148112	B9p	4 DD (5)	234	43
10 Aql	176232	F0spe	3 DD (3)	337	15
19 Lyr	179527	B9sp	2 DD (5)	329	92
4 Cyg	183056	B9sp	2 DD (2)	186	134
	204411	A6pe	1 DD (1)	30	11
κ Psc	220825	A0p	2 DD (2)	212	86

3. Results

For the 28 stars observed to date, 25 are exhibit a significant circular polarisation in their spectral lines (although of only marginally significance in two cases). For a majority

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of the sample, a detection was obtained during the first observation. For some objects, obtaining one positive detection required several observations. This can be due to phase effects and of course to meteorological conditions and/or not having large enough signal to noise ratio. For three of our stars with a sufficiently large number of measurements and suitable phase sampling, and having well-determined periods (3 Hya, 21 Com, 45 Leo), dipolar oblique rotator models have been determined. We find that geometry alone can explain the weakness of the measured fields, at least in some cases. Table 1 shows the maximum unsigned longitudinal magnetic field measured presently for each star of our survey which is definitively detected (DD). These values are rather high, and when one takes into account that the polar field strength in an Oblique Rotator Model (Preston 1967) is greater than 3 times this value, the suggested polar field strengths must be at least several hundred G. This result may indicate that there is a minimum field strength for which Ap-type characteristics are produced. This minimum strength appears to be of order the photospheric equipartition field (around 250 G for a main sequence A0 star). The remarkable detection rate obtained in our survey strongly suggests that all Ap stars having "magnetic" behaviour (Preston 1974, i.e., essentially all stars classified spectroscopically as Ap/Bp) actually harbour magnetic fields of at least a few hundred G. In other words, all Ap stars are magnetic stars and there may well be a threshold field strength for obtaining this behaviour.

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