Precise measurements of the longitudinal magnetic fields of chemically peculiar stars

S.L.S. Shorlin[a], J.D. Landstreet[a], G.A. Wade[b], J.-F. Donati[c]

[a] Department of Physics and Astronomy, The University of Western Ontario, London, Ontario, Canada N6A 3K7
[6] Astronomy Department, University of Toronto at Mississauga, Mississauga, Ontario, Canada L5L 1C6
[c] Observatoire Midi-Pyrenees, 14 Avenue Edouard Belin, 31400 Toulouse, Prance

Abstract.
Precise longitudinal magnetic fields of Ap stars have been measured using circularly polarised spectra analyzed using the Least-Squares Deconvolution (LSD) procedure. The uncertainties associated with these measurements are significantly better than those typically achieved using other methods, and effectively redefine the standard of measurements of the longitudinal magnetic field. No significant longitudinal field has been measured for any of 23 Am and HgMn stars, including several stars in which strong, complex magnetic fields have previously been claimed. The implication is that either some Am and HgMn stars exhibit magnetic fields which are qualitatively different from those detected in any other class of stars, or that the previous detections are spurious.

Key words: magnetic fields, Ap and Bp stars

1. Introduction

The chemically peculiar A and B type stars have long been classified into two general groups: the magnetic and nonmagnetic subtypes. Strong, ordered magnetic fields have been found and measured in the Ap SrCrEu, Ap Si, He-weak SiSrTi and He-strong stars, while fields have not generally been detected in the ApHgMn, Am, He-weak PGa and λ Boo stars. However, probable detections of strong, complex magnetic fields in several Am and Ap HgMn stars (Mathys & Lanz, 1990, Bikmaev et al., 1998, Mathys & Hubrig, 1995, Hubrig et al., 1999) have recently been reported. The fields are suggested to be perhaps more like those of active late-type stars than those of the classical magnetic A and B stars.

2. Observations

Circularly polarised (Stokes *V)* and unpolarised (Stokes J) spectra were obtained in February 1997 and 1998, and January 1999 using the MuSiCoS echelle spectropolarimeter attached to the 2 m Bernard Lyot Telescope at Pic-du-Midi observatory. This apparatus allows the acquisition of a stellar spectrum throughout the range 450 to 660 nm with a resolving power of about 35000. Observed stars include 14 magnetic Ap stars, 16 Am stars, seven ApHgMn stars and one λ Boo star. Up to eighteen spectra were obtained for each Ap star, while Am, HgMn and λ Boo stars were observed up to four times each.

3. Measurement of longitudinal magnetic fields

Least-Squares Deconvolution (LSD) is a cross-correlation technique which takes advantage of the similar shapes of spectral lines and their polarisation features to compute average intensity and polarisation profiles from a stellar spectrum. The use of all the lines in a spectrum greatly improves the signal-to-noise ratio (S/N) in the star's deconvolved Stokes *V* profile. The mean longitudinal magnetic field B_e may be inferred from the mean Stokes *V* profile (e.g. Donati et al., 1997). High S/N polarisation profiles provide one with the opportunity to measure the longitudinal fields of magnetic stars with very high precision, as well as to set stringent upper limits on the fields of nonmagnetic stars. The technique is most applicable for stars with many spectral lines, which increase the effective S/N of the polarisation profile. However, the technique is not limited to sharp-lined stars and may be used over a broad range of *vsini* (Wade et al., 1999, Shorlin et al., 1999).

4. Results

4.1. Magnetic Ap stars

The longitudinal field measurements obtained for the cool Ap star 49 Cam, phased according to the 4.3 d rotational period and compared with earlier Balmer-line Zeeman Analyzer observations, are shown in Fig.l. The improvement in precision is evident. The uncertainty in our new measurements represents more than an order of magnitude improvement over those made with the Balmer-line Zeeman analyzer. The reader is referred to Wade et al. (1999) for the details of field measurements for individual magnetic Ap stars.

The distribution of standard errors associated with longitudinal field measurements for our sample of magnetic Ap stars is shown in Figure 2. This distribution implies a median B^e uncertainty of 48 G and a standard deviation of 38 G. One-hundred fourteen of the 129 Ap star field measurements have uncertainties smaller than 100 G. This should be compared with the typical 1σ uncertainties of between 200 and 300 G obtained using other modern longitudinal field measurement techniques.

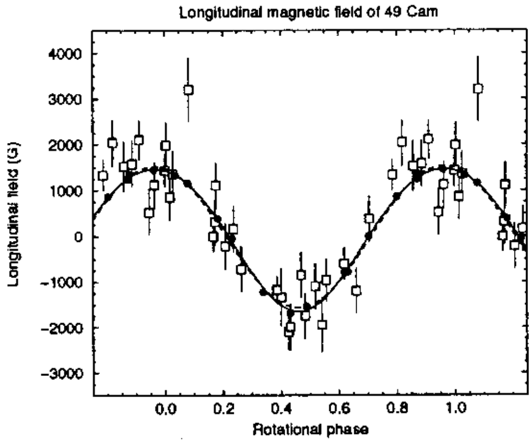

Figure 1: ***Longitudinal magnetic field variation of 49 Cam. Open squares: unpublished Hβ B_ℓ measurements by the authors. Filled circles: B_ℓ from LSD profiles (Wade et al., 1999). The dashed curve is a first-order Fourier fit to the LSD measurements, while the solid curve is a second-order fit.***

4.2. Am and Ap HgMn stars

No significant longitudinal magnetic field has been detected for any of the 23 Am or HgMn stars studied here (see Table 1), including HD 29173, HD 195479 and *o* Peg (HD 214994) for which complex fields have previously been claimed based on field detections obtained using other techniques (Lanz & Mathys, 1993, Mathys & Lanz, 1990). The median of the 1sigma uncertainties associated with B^e measurements for the Am stars is 17 G and the standard deviation of the distribution is 16 G. The median standard error for the HgMn stars is 84 G and the standard deviation is 46 G. The median uncertainty is somewhat higher for the HgMn star due to the lower line density in their spectra and a fainter average magnitude, as well as perhaps uncertainties in the abundance table which was used to create HgMn line masks.

Among the non-magnetic stars the least successful case was ρ Vir, the single λ Boo star observed. Its spectrum has very few lines which are all quite broad. LSD was only marginally successful in extracting mean profiles for this star.

Not only do these results provide the best field measurements for individual Am and HgMn stars, they furthermore provide the strongest statistical evidence for the absence of significant ordered magnetic fields in Am stars. The strongest dipole fields statistically compatible with the Am star data (with polar strengths of around 50 G) are weaker than the equipartition threshold (of order 100 G), and thus have minimal impact on the structure and dynamics of their atmospheres.

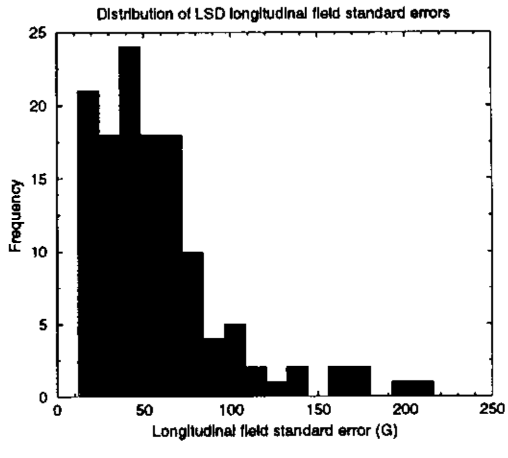

Figure 2: ***Distribution of standard errors associated with longitudinal magnetic field measurements of magnetic Ap stars using LSD profiles (Wade et al., 1999).***

5. Conclusions

LSD Stokes *V* profiles may be used to infer very precise longitudinal magnetic fields for magnetic Ap stars. Such precision allows one to determine the detailed shapes of field variations and precise rotational periods for magnetic Ap stars. The details of the determinations are discussed by Wade et al. (1999).

The non-detection of the longitudinal fields of any of 23 Am or HgMn stars is certainly significant. Since

Table 1: *B_ℓ measurements of Am and HgMn stars (Shorlin et al., 1999). The projected rotational velocities are those reported by Abt and Morrell (1995)*

HD designation	$B_\ell \pm \sigma$ (G)	$v \sin i$ (km s^{-1})	HD designation	$B_\ell \pm \sigma$ (G)	$v \sin i$ (km s^{-1})
		Am stars			
29173	-40 ± 58	18	110951	-9 ± 14	28
48915	5 ± 12	15		8 ± 16	
	14 ± 8		112412	6 ± 17	10
78209	17 ± 10	33	126661	-33 ± 34	33
78362	-4 ± 4	13	141675	19 ± 26	61
	-10 ± 5		141795	8 ± 15	38
90277	-5 ± 18	33		-16 ± 15	
95608	3 ± 28	13		8 ± 18	
108642	-17 ± 15	13	159560	33 ± 34	58
	9 ± 17		195479	15 ± 53	18
108651	-62 ± 62	18	214994	-32 ± 20	10
		HgMn Stars			
27295	16 ± 84	10	78316	-9 ± 67	10
63975	240 ± 170	20	129174	-27 ± 56	30
75333	-120 ± 170	20		-114 ± 91	
77350	55 ± 63	< 10	144206	-24 ± 49	< 10

very complex fields are detected in late-type stars using the LSD technique (Donati, 1998), our results appear inconsistent with the claims of strong, complex magnetic fields in the photospheres of the Am and HgMn stars. In particular, our results corroborate neither the detections of fields in HD 29173 and HD 195479 by Lanz & Mathys (1993) nor the detection in *o* Peg by Mathys & Lanz (1990). Their detections were based on measurements of the subtle Zeeman broadening and desaturation of *unpolarised* spectral lines in the presence of a magnetic field.

However, all observations can probably be reconciled if we assume that the fields of the Am stars are highly complex (more complex than the solar field, resulting in very efficient cancellation of the longitudinal field over the stellar surface) while at the same time very strong (several kG in strength, in order to be consistent with the observations of Lanz κ Mathys (1993) and Mathys κ Lanz (1990)). On the other hand, it is important to keep in mind that the detection of weak magnetic fields using unpolarised spectra is somewhat ambiguous, and susceptible to systematic errors (particularly due to line blends). Therefore our new observations, which are by themselves consistent with the absence of fields in Am stars, may well provide instead an independent evaluation of the effectiveness of unpolarised techniques. We would therefore advise a degree of caution be adopted when interpreting field detections obtained using these methods.

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