The A-Star Puzzle
Proceedings IAU Symposium No. 224, 2004
J. Zverko, J. Žižňovský, S.J. Adelman, & W.W. Weiss, eds.

DOI: 10.1017/S1743921305009397

Seeking the progenitors of the magnetic Ap stars: A search for magnetic fields in Herbig Ae/Be stars with FORS1 at the ESO VLT

D. Drouine[1], G.A. Wade[1], S. Bagnulo[2], J.D. Landstreet[3], E. Mason[2] and D.N. Monin[4]

[1]Department of Physics, Royal Military College of Canada
[2]European Southern Observatory, Chile
[3]University of Western Ontario, Canada
[4]Université de Moncton, Canada

Abstract. We describe an ongoing programme using the FORS1 spectropolarimeter on the ESO-VLT to search for magnetic fields in Herbig Ae/Be stars. Our aim is to identify the pre-Main Sequence progenitors of magnetic Ap stars, and to trace the evolution of their magnetic fields at the earliest possible stages.

Keywords. Methods: data analysis, techniques: spectroscopic, stars: magnetic fields, stars: individual (HD 94660, HD 94509)

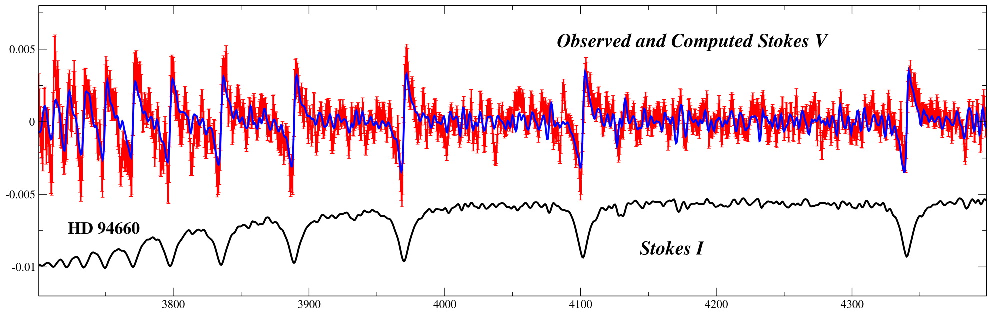
1. Overview

About 10% of Main Sequence A and B-type stars exhibit organised magnetic fields with typical strengths of a few kG. It is unknown when the magnetic field of these stars appears, e.g., during star formation, during the pre-Main Sequence phase, or early during Main Sequence evolution. Recent studies show that magnetic Ap stars exist at the earliest stages of main sequence evolution (essentially as soon as these stars reach the ZAMS; Bagnulo et al. 2003, 2004, Pöhnl *et al.* 2003). It is therefore natural to attempt to verify if magnetic fields also exist during the pre-Main Sequence stages of intermediate-mass stars. The progenitors of Main Sequence A and B stars are the Herbig Ae/Be (HAEBE) stars. They are observable optically, but which have not yet reached the ZAMS. HAEBE stars are sufficiently young that they are still surrounded by gas-dust envelopes. These envelopes induce significant extinction and produce spectral emission lines, contaminating the photospheric spectrum and hampering magnetic field diagnosis. HAEBE stars are also rapid rotators ($v \sin i \sim 200$ km s^{-1}), making them poorly suited for study with metallic-line spectropolarimeters. This poster describes an investigation using the low-resolution spectropolarimeter FORS1 at the ESO VLT to perform Balmer-line circular polarisation spectropolarimetry of a small sample of HAEBE stars, in an attempt to detect magnetic fields in their photospheres.

2. Observations

FORS1 is a multi-purpose instrument attached at the 8-m VLT unit Antu. In spectropolarimetric mode, it allows one also to obtain Stokes $IQUV$ profiles at low resolution (up to $R = 2000$) in about 2500 Å wavelength intervals between 3500 and 9000 Å.

Circular polarisation can be relatively easily detected in metallic lines for stars that rotate up to a few tens of km s^{-1}, provided that the magnetic field is organized on a global



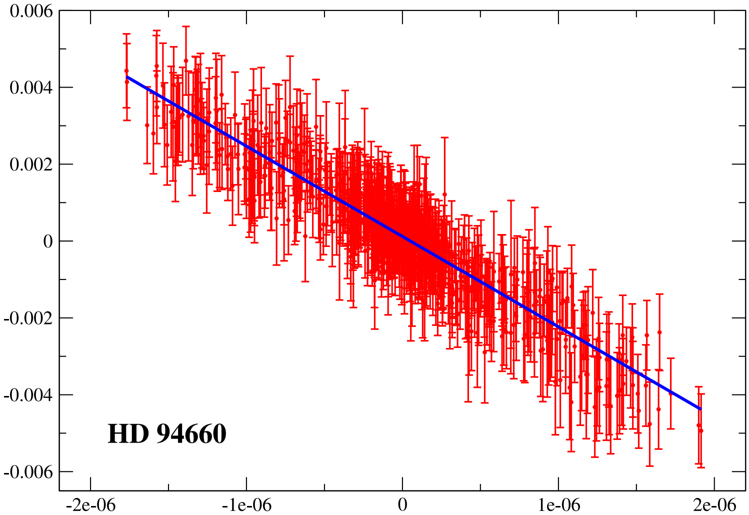


Figure 1. The magnetic standard Ap star HD 94660: *Upper frame:* Stokes I and V spectra with best-fit model spectrum according to Eq. (3.1). *Lower frame:* Regression according to Eq. (3.1). Both diagnose a longitudinal magnetic field of about -2 kG; abscissa: $-4.67 \times 10^{-13}\lambda^2/\mathrm{I}\ \mathrm{dI}/\mathrm{d}\lambda$, ordinate: V/I.

scale and with a mean longitudinal field of at least 100-200 G. However, the sensitivity is a strong function of rotation. Such studies require high-resolution spectropolarimetric data ($R > 10000$).

Spectral resolution requirements can be considerably relaxed for polarimetric observations of hydrogen Balmer lines (e.g., Bagnulo *et al.* 2002). Unlike metallic lines, rotational broadening of H lines is essentially negligible. Circular polarisation due to the Zeeman effect can be detected at low resolution ($R \sim 1000$) and in stars that rotate with $v \sin i$ up to 300 $\mathrm{km\,s^{-1}}$.

During our first observing nights at the VLT for this programme, we obtained Stokes I and V spectra in a wavelength range from 3500 - 5500 Å for 14 HAEBE stars. These stars were selected based on their Southerly positions, their apparent magnitudes, and their confident identification as pre-Main Sequence A or B type stars.

3. Results

In addition to the programme stars studied, magnetic and non-magnetic standards were observed to evaluate the nominal functioning of FORS1.

HD 94660 is a well-known magnetic Ap star (Bagnulo *et al.* 2002) which was observed

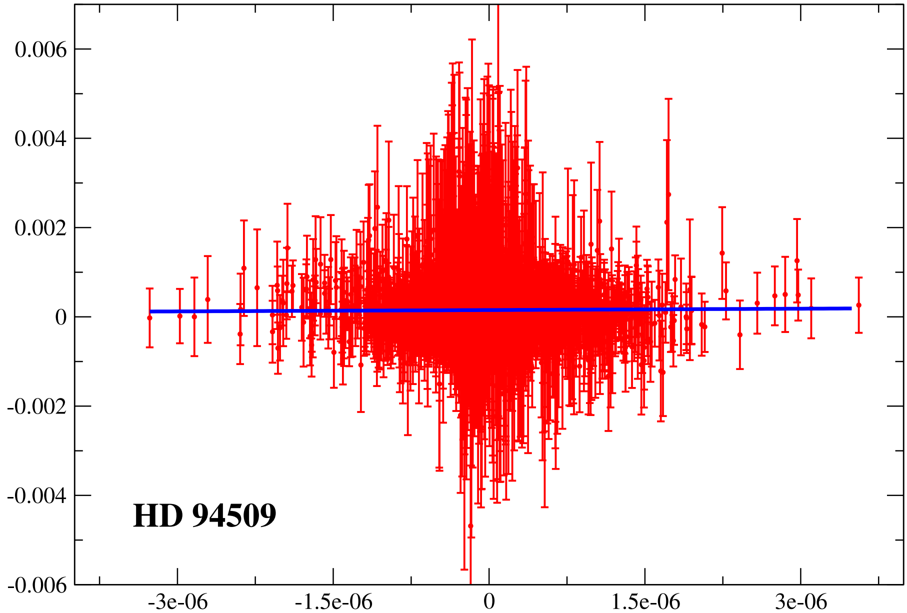


Figure 2. The HAEBE programme star HD 94509: Regression according to Eq. (3.1), diagnosing a (null) longitudinal field of 10 ± 13 G; abscissa: $-4.67 \times 10^{-13} \lambda^2$/I dI/d$\lambda$, ordinate: V/I. Note the extremely high precision of the measurement.

as a magnetic standard to verify the observational technique. Previous work has shown that HD 94660 displays a mean longitudinal magnetic field $\langle B_z \rangle$ of about -2 kG. Here, we illustrate the diagnosis of $\langle B_z \rangle$ from the FORS1 spectra.

Spectropolarimetry of H Balmer lines can be quantitatively interpreted in terms of the mean longitudinal magnetic field $\langle B_z \rangle$ according to the relationship:

$$V/I = -4.67 \times 10^{-13} z \frac{\lambda^2}{I} \frac{dI}{d\lambda} \langle B_z \rangle, \tag{3.1}$$

where z is the Landé g factor of the line, and λ is the wavelength in Å (Bagnulo *et al.* 2002).

The longitudinal field can be inferred via linear regression or by direct fitting of the Stokes V spectrum (Fig. 1). For HD 94660, we obtain a mean longitudinal field of about -2200 G.

The search for magnetic fields in the 14 observed HAEBE stars was performed using the same method employed for the magnetic standard HD 94660. If HAEBE stars are the direct progenitors of Main Sequence A and B stars, we expect to detect strong magnetic fields in 5-10% of all HAEBE stars.

So far, our analysis of the Stokes spectra has led to no obvious strong magnetic fields, although we have obtained one very promising 3σ detection of a weak field. In most cases we detect no longitudinal magnetic field, with typical upper limits of about 90-120 G (3σ). HD 94509 is one such star. In Fig. 2 we show the regression used to infer a (null) magnetic field of 10 ± 13 G based on all observed Balmer lines and metallic lines. Compare to the results for HD 94660 in Fig. 1.

https://doi.org/10.1017/S1743921305009397 Published online by Cambridge University Press

4. Conclusion

We cannot yet draw any firm conclusions about the magnetic nature of pre-Main Sequence A and B stars, but further observing runs are already scheduled. At this point, we can reconfirm the strong magnetic field of HD 94660, the ability to diagnose magnetic fields at the sub-100 G level using FORS1, and the absence of strong (kG) fields in any of the HAEBE stars studied. Further observations should allow us to obtain firm constraints on the characteristics of magnetic fields in a statistically significant sample of HAEBE stars.

Acknowledgements

References

Bagnulo S., Szeifert T., Wade G.A., Landstreet J.D., Mathys G., 2002, *A&A* 389, 191
Bagnulo S., Landstreet J.D., Lo Curto G., Szeifert T., Wade G.A., 2003, *A&A* 403, 635
Bagnulo S., Hensberge H., Landstreet J.D., Szeifert T., Wade G.A., 2004, *A&A* 416, 1149
Pöhnl H., Maitzen H.M., Paunzen E., 2003, *A&A* 402, 247