The very strong and complex magnetic field of the helium-strong star HD 37776

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Abstract. We report progress in our attempt to model the magnetic field of the He-strong star HD 37776 from circular spectropolarimetry obtained at the 6 m telescope. We present preliminary reductions and analysis of our 31 new circular polarization spectra. These results are fully consistent with a strong and complex field topology, such as that described by Bohlender's (1988) model.

1 Introduction

Magnetic fields have been discovered in more than 100 A and B stars. The line-of-sight components of the magnetic fields (the *longitudinal fields)* of most of these stars exibit a smooth sinusoidal variation with rotational phase. This indicates that the magnetic field configurations are (in most cases) approximately dipolar. When we examine the disk-integrated mean magnetic field strength (the *mean magnetic field modulus*[1]) of these stars, we find its magnitude is not usually more than about 10 kG. However, Babcock (1960) inferred a mammoth 34 kG mean field modulus for the A-type star HD 215441. Clearly, a stellar atmosphere permeated by such a strong magnetic field offers us a very special laboratory in which one can study the physics which prevails in such a rare environment.

The longitudinal magnetic field of HD 37776 was first measured by Borra and Landstreet (1979) who reported a field about 2 kG from photoelectric circular polarization measurements. Subsequently, double-wave longitudinal field variability was discovered by Thompson and Landstreet (1985) with a period of 1.53869 ± 0.00007 days. The longitudinal field curve of HD 37776 (Bohlender, 1988) is shown in Fig. 1. Thompson and Landstreet concluded that HD 37776 has a magnetic field geometry which is essentially quadrupolar and differs strongly from the classical dipolar field configuration. Bohlender (1988) and Bohlender and Landstreet (1990) have met with success modelling the longitudinal field variations of HD 37776 using an axisymmetric multipolar magnetic field. The maximum value of the mean field modulus attained by this model is about 60 kG. This is very significant since, if this model were confirmed, HD 37776 would surpass HD 215441 as the star with the strongest magnetic field.

Kopylova and Romanyuk (1992) found strong differences between photographic Zeeman spectra of opposite circular polarization, supporting the idea of very strong, complex magnetic field. Unfortunately, the signal-to-noise ratio (SNR) of these spectra was insufficient to allow them to be used for modeling purposes. Therefore no firm spectropolarimetric test of Bohlender's model has been achieved.

1 This quantity is also known as the *surface field,* and is obtained from measurements of Zeeman splitting in unpolarized spectra. See Mathys et al. (1996) for more details.

Table 1: Journal of magnetic field observations of HD 37776 obtained from displacement measurements of the core of He I λ5876 in left– and right–circular polarization spectra. Phases are calculated from the ephemeris cited in the text.

JD-240 0000	Phase	B_{core} (kG)
49641.471	0.543	+22.0
49641.600	0.627	–
49642.471	0.193	–
49736.304	0.176	+ 9.5
49736.325	0.189	+ 9.1
49738.262	0.449	+ 0.8
49788.183	0.892	+ 9.5
49788.208	0.905	+ 9.2
50056.521	0.288	+ 3.7
50056.542	0.301	+ 1.3
50057.288	0.784	- 5.0
50057.308	0.797	- 1.2
50057.488	0.914	+12.8
50057.508	0.927	+ 9.2
50059.388	0.148	+ 7.1
50059.408	0.159	+ 8.6
50060.312	0.744	-18.6
50060.325	0.758	- 7.7
50060.525	0.888	+12.2
50060.546	0.902	+12.5
50087.371	0.335	- 8.5
50087.396	0.352	- 9.3
50088.271	0.920	+ 9.5
50090.338	0.263	+ 7.9
50090.358	0.277	+ 3.7
50118.179	0.357	-14.3
50118.195	0.368	-18.3
50119.166	0.999	- 6.1
50119.187	0.012	-13.8
50119.425	0.167	- 4.1
50121.275	0.369	- 9.9

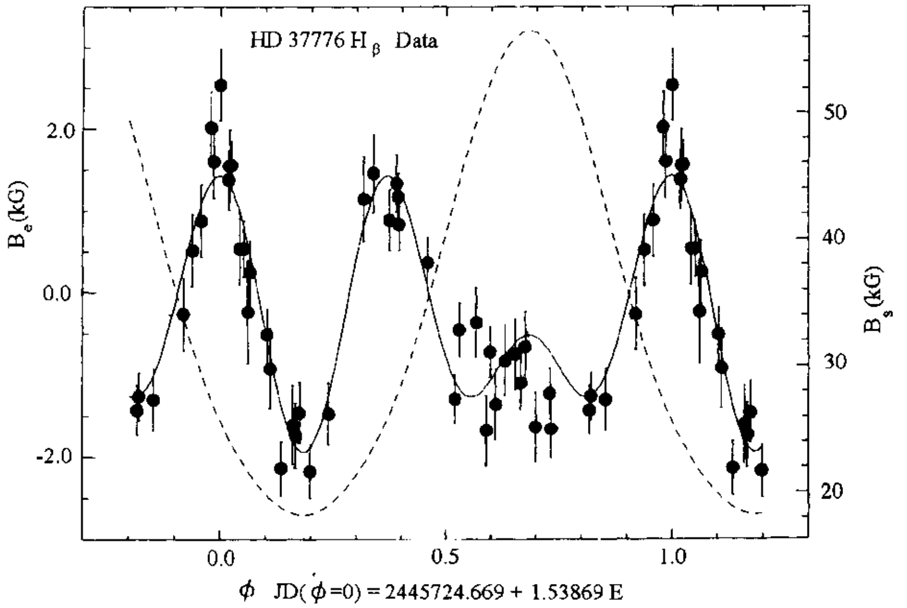

Figure 1: The longitudinal field of HD 37776 and model field variations (Bohlender, 1988). The solid curve is the longitudinal field variation produced by the model and the dashed curve is the mean field modulus variation produced by the model.

We presented the first spectropolarimetric confirmation of the quadrupolar magnetic model (Bohlender, 1988) for HD 37776 in our 1995 paper (Romanyuk et al., 1995). Herein we describe our most recent observations, reductions and analysis.

2 Observations

Our series of left- and right-circularly polarized Zeeman spectra were acquired (simulateneously) using the Zeeman analyzer and the spectroscopic CCD (Borisenko et al., 1991) on the 6 m telescope of the Russian Academy of Sciences. The reciprocal linear dispersion of the Main Stellar Spectrograph is 14 Å/mm. Spectra were taken during 1994 October — 1996 January. Observations were, acquired in the two spectral ranges: 5820 — 5940 Å, which contains He I λ5876, and 6520-6640 Å, which contains H_α. The SNR for each spectrum was about 150, and exposure times were all about 30 minutes. The observing techniques for magnetic measurements are more thoroughly described by Bychkov et al. (1988).

Reduction of the spectra was performed using the DECH and DECH-20 image and spectral reduction packages developed at the SAO by Galazutdinov (1992).

3 Preliminary results and conclusions

Some preliminary magnetic field measurements, obtained by measuring the displacement of the *core* of He I λ5876 in the left and right circular polarization spectra, are presented in Table 1 and shown in Fig. 2. The phases are calculated according to the ephemeris JD = 2445724.669 + 1.53869 E of Thompson and Landstreet (1985). These data are presented only for illustrative pur-

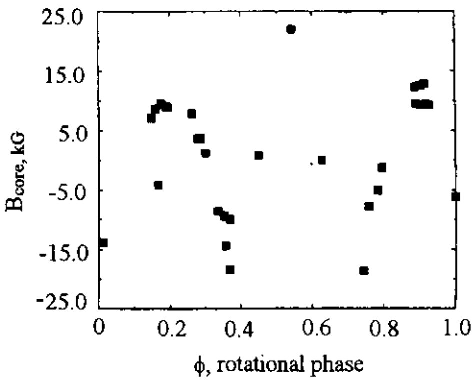

Figure 2: Preliminary magnetic field data inferred from measurements of the shift of the core of He I λ5876 in left and right circular polarization spectra.

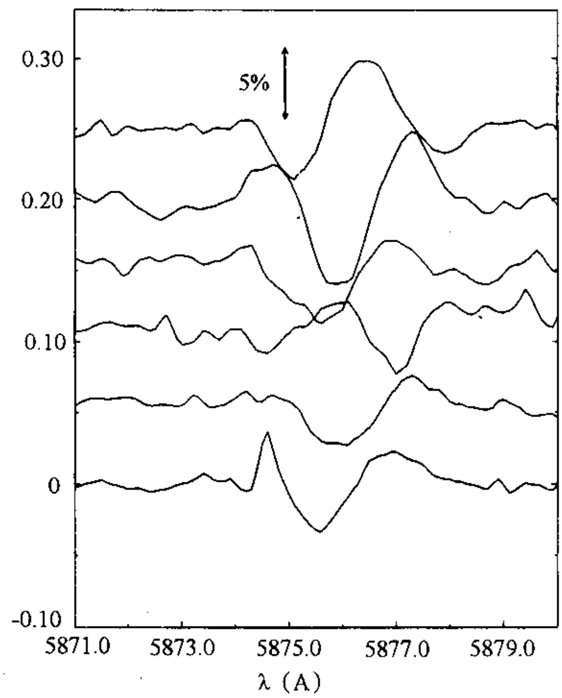

Figure 3: Some preliminary Stokes V profiles for He I λ5876 in our spectra of HD 37776.

poses; while the shape of their variation is approximately the same as that found in the longitudinal field measurements (which will be obtained by measuring the displacement of the line *centre-of-gravity)* neither their mean value nor their amplitude are the same as the longitudinal field values. While approximate, these measurements still show that the magnetic field of HD 37776 is both very strong and distinctly non-dipolar.

The principal goal of this programme is to construct a magnetic model for this star by modeling the Stokes I and V profiles which we are extracting from these spectra. This should constitute one of the best-constrained magnetic models yet constructed. Some preliminary Stokes V profiles calculated from these spectra are shown in Fig. 3. The peak-to-peak amplitude of the profiles can be greater than 10%, and it is clear that the SNR of the Stokes V profiles is adequate for modeling.

It has been previously concluded (Brown et al., 1991) that the Stokes I and V profiles contain inadequate information for a full reconstruction of a low-order multipolar magnetic field. We will therefore attempt to construct our magnetic model using the Stokes I and V profiles to fit a multipolar field distribution to the data, and then to model the *departures* of the magnetic field from this configuration. The programme ZEEMAP, which we are currently developing, is designed for such a purpose. We hope to have our first results within the year.

Acknowledgements. We are grateful to the Time Allocation Committee of the 6 m telescope for continuing support of this programme. This work was partly supported by RFBR grant: 94-02-06584.

References

Babcock H.W.: 1960, Astrophys. J., **132,** 521.

Bohlender D.A.: 1988, Ph.D. Thesis.

Bohlender D.A., Landstreet J.D.: 1990, Science News, Jan. 27.

Borisenko A.N., Markelov S.V., Ryadchenko V.P., 1991, SAO report, **76.**

Borra E.F., Landstreet J.D.: 1979, Astrophys. J., **228,** 809.

Brown S.F., Donati J.-F., Rees D.E., Semel M.: 1991, Astron. Astrophys., **250,** 463.

Bychkov V.D., Glagolevskij Yu.V., Elkin V.G., Gazhur E.B., Nazarenko A.F., Najdenov I.D., Romanyuk I.I., Chuntonov G.A., Shtol' V.G., 1988, In: Magnetic stars, Eds.: Yu.V. Glagolevskij, I.M. Kopylov, Leningrad, Nauka, 12.

Galazutdinov G.A., **1992,** SAO Report, **92.**

Kopylova F.G.,Romanyuk I.I.: 1992, In: Stellar magnetism, Eds.: Yu.V. Glagolevskij, I.I. Romanyuk, St.Petersburg, Nauka, 54.

Mathys G., Hubrig S., Landstreet J.D., Lanz T., Manfroid J.: 1996, Astron. Astrophys.(in press).

Romanyuk I.I., Elkin V.G., Schtol' V.G.: 1992, In: Stellar magnetism,,St.Petersburg, 57.

Romanyuk I.I., Elkin V.G., Wade G.A., Landstreet J.D.: 1995, In: Stellar Surface Structure, IAU Symposium 176, 153.

Thompson I.B., Landstreet J.D.: 1985, Astrophys. J., **289,** L9.