The A-Star Puzzle
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Measuring magnetic fields in CP stars using a multiline approach

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Abstract. We have developed a new code for measuring stellar magnetic fields by calculation using fast transforms of the Fourier cross-correlation function from spectra with reciprocal circular polarization. To test the code, spectra of stars with previously measured magnetic fields were used. In some cases, discrepancies between the field strength obtained by Babcock's classical technique and using our code occur.

Keywords. Polarization, stars: chemically peculiar, stars: magnetic fields, methods: numerical

1. Introduction

An algorithm for magnetic field measurements using the cross-correlation function was suggested by Donati *et al.* (1997). This procedure named LSD has been successfully employed for measuring the magnetic fields of the Sun and various types of stars.

We have made an attempt to implement the correlation method of magnetic field measurement in CP stars by computing the cross-correlation function of polarized components of Zeeman spectra. As a simplifying supposition we assumed the magnetic field to have the same effect on all the lines used. Since the values of Landé factors of spectral lines differs only sligtly, and the spectral range used is not larger than 150 Å, such a simplification can be considered to be quite plausible.

Further it is believed that: 1) the spectral line profiles in different polarizations are equal and differ in the value of the shift due to the external magnetic fields, and 2) the level of the continuum is drawn accurately. Thus the peak of the cross-correlation function must indicate the value of the shift of all the lines used. Further, by using Babcock's usual formula, one can find magnetic field.

2. Results of testing the code

To calculate the cross-correlation function we have written a code using fast Fourier transforms (Press *et al.* 1992). For analyzing the possibile applications of the method, we used the spectra with different characteristics: with narrow and wide lines, with strong and weak magnetic fields. Filtering of the spectrum is produced by the line depths. Application of a mathematical mask is possible.

To test the code, the spectra obtained with the Main stellar spectrograph of the 6-m telescope with the Zeeman analyzer were used. The first step of the processing was performed in the standard manner (Kudryavtsev 2000). Further, our code was used to calculate the cross-correlation function. The field strength was determined by the shifts of its peaks. We have investigated the degree the shape of the correlation function depends on the line profile and concluded that the approximation of the peaks is best performed by a Gaussian function.

For our analysis we selected 4 stars with magnetic fields of different magnitudes and

Table 1. Results of magnetic star measurements by classical and our correlation techniques.

Star	$B_{\rm classic} \pm \sigma$ (G)		$B_{\rm correl} \pm \sigma$ (G)	
HD 18078	950	±50	1030	±30
HDE 293764	3860	±220	2541	±30
HD 110066	−130	±28	−87	±10
52 Her	520	±60	460	±20

2 null stars. The spectrum were measured by the classical technique, i.e. by measuring individual lines (Kudryavtsev 2000) and then by the correlation method of our code. Results of these determinations are listed in Table 1.

We find good agreement of the measurements made by both techniques in stars with no fields and with weak fields. For HDE 293764 with a strong magnetic field considerable differences arose.

With a weak magnetic field the cross-correlation function has a very symmetric shape and, as a consequence, the value of the shift is measured with a very high accuracy. When the field is strong, the line profiles in different polarizations are considerably different and have a complex structure. Thus the simplification we have developed as to their identity has proven to be incorrect.

The accuracy of measurements is essentially affected by the choice of the method of approximation of the correlation function. Although the approximation of the peaks was performed by a Gaussian function, in some cases the approximation should be executed by function different from Gaussian, which is determined in the Fig. 1 (left).

The linear interpolation (on the right in the Fig. 1) allows the shape of the correlation function to be improved and to measure the field with a higher accuracy. The portion of the spectrum of the star HD 18078 is presented in the Fig. 2. In the case of very narrow lines the cross-correlation function is very symmetric and the shift can be measure with a high accuracy (Fig. 3).

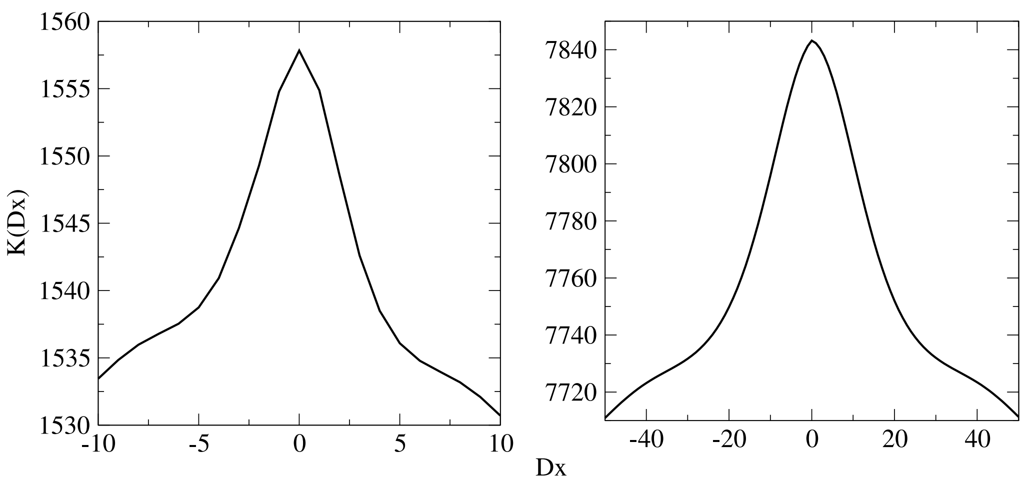

Figure 1. Cross-correlation function for HD 18078

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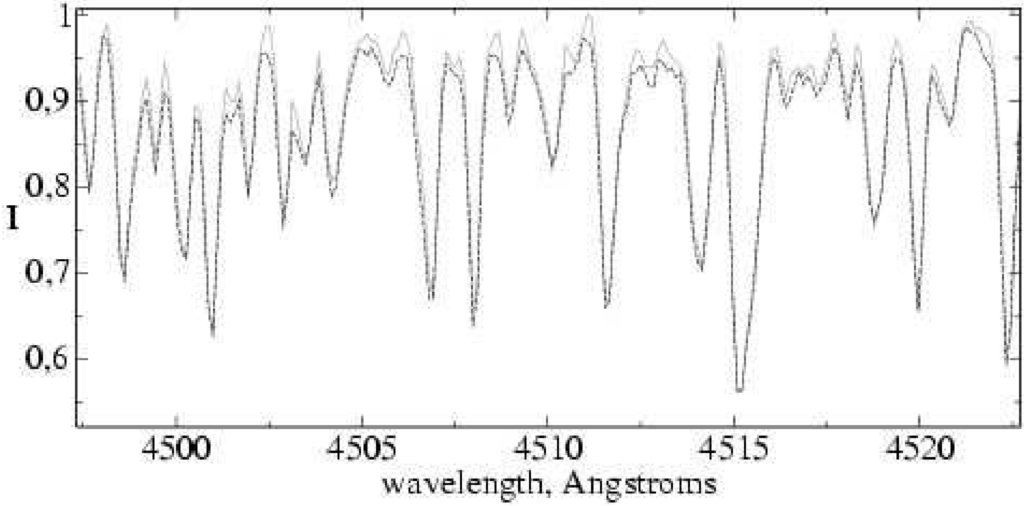

Figure 2. Portion of the spectrum of HD 18078

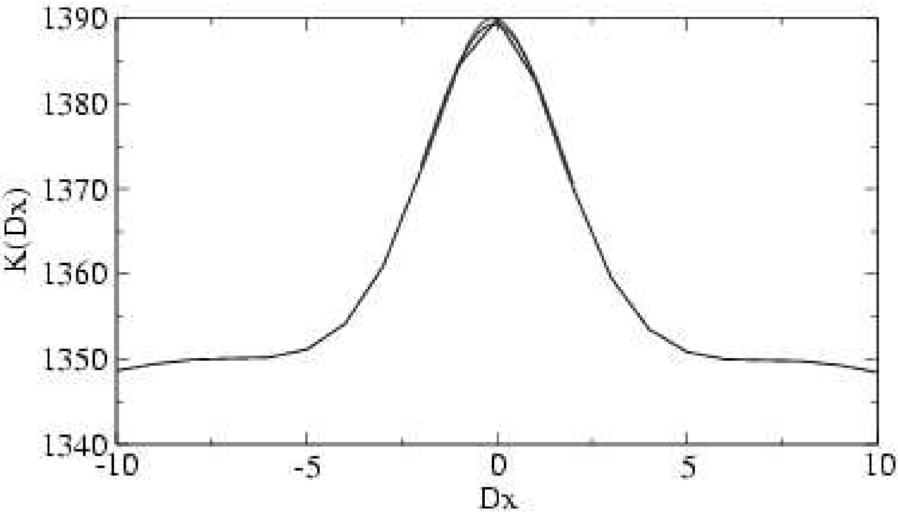

Figure 3. Cross-correlation function for “null star” o UMa

3. Conclusions

We have written a code and tested it, which showed that it can be applied to measuring magnetic field of stars by correlation method. There is a certain disagreement between our results and those obtained by traditional method from measuring individual lines. To a considerable degree, this is associated with the inaccuracy of the approximation of the peaks by the cross-correlation function. It was shown that the use of the Gaussian function is not always justified, sometimes it is useful to employ other functions (for instance, Lorentz function).

Besides some physical causes can give rise to such differences. In the classical method of measurements the weighted mean by the Landé factors line shift is measured. In using the cross-correlation the weighting takes place by their intensities as well. To remove the contribution of noise it is necessary to use masks.

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