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Zeeman effect measuring devices in the spectrometers of the BTA Nasmyth foci

I.D.Najdenov, V.E. Panchuk

Special Astrophysical Observatory of the Russian AS, Nizhnij Arkhyz 357147, Russia

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Abstract. Performance of two multipurpose devices designed for measurements of the longitudinal and transverse Zeeman effects is described. The devices are operated in combination with the stationary apparature placed at the Nasmyth foci of the 6 m telescope. At the Nasmyth–1 focus measurements are made with the scanner, at the Nasmyth–2 with the Main stellar spectrograph and a high resolution echelle spectrometer.

Key words: stars: Zeeman effect measurements – instruments

1. Introduction

Measurements of the Zeeman effect at the 6 m telescope have been made since the time the circular polarization analyzers (Glagolevskij et al., 1978) were introduced on the Main stellar spectrograph (MSS) (Vasil'ev et al., 1977) installed at the Nasmyth focus (F:30). The bulk of data was obtained by photography with the Schmidt camera (F:2.3). The information capacity of this method was defined by the number of magnetosensitive lines recorded simultaneously on a spectrogram of about 1000 Å length.

Later on a photoelectric magnetometer based on the long–focus camera of the MSS (F:12) was put into operation. The high slit width of the technique was provided by the use of a scanning Fabry–Perot etalon (Glagolevskij et al., 1979). In this case the spectral range recorded simultaneously was determined by the width of the point spread function of the etalon, i.e. this technique was at a disadvantage of 4 orders in relation to the photographic method. This apparatus was used for the investigation of stars down to 4^m, and the highest accuracy of magnetic field determination (up to 10 Gs) was attained. It should be mentioned that such a high accuracy in a single line measurement was achievable with long–time signal acquisition.

For the prime focus of the 6 m telescope a hydrogen magnetometer was developed (Shtol et al., 1985). The scope of problems serviced by this device is restricted by the range of spectral resolutions of the spectrograph UAGS with a supplementary objective F: 6.6. The low slit width of this combination is made up for only by loss of spectral resolution. In this case a numerous class of narrow–line objects is left out.

On the whole photoelectric techniques, used at the 6 m telescope with a few channels (2–3) recorded simultaneously could not force out the photographic method for magnetic field measurements which was the only method employed at the 6 m telescope in the late 1980. At that time only the longitudinal Zeeman effect was measured. At the present time the polarization and phase–shifting characteristics of the optics in combination with solid–body multielement light detectors allowed multipurpose spectrophotometric pieces of aparatus to be designed with the advantages of the former generation devices retained.

2. Scanner measurements with medium spectral resolution

In 1987 an instrumental system was manufactured (Borisov et al., 1989) which was intended to investigate the Zeeman effect with the 6 m telescope scanner (Drabek et al., 1986). The technology of the 1980s permitted only the creation of narrow–band specialized Zeeman effect measuring devices. That is why a narrow spectral region (4690±150 Å) apparatus was used until recently for measuring the longitudinal Zeeman effect component. Present–day achromatic plates enabled a new wide–band (4000 – 9000 Å) device, which is shown schematically in Fig. 1, to be made. Let us describe the performance of the device under the condition of measuring the transverse Zeeman effect component. Characteristically, the splitted spectral components for the transverse Zeeman effect are linearly polarized. That is why it is sufficient for the measurement to analyze the Stokes parameters U and Q. This can be obtained theoretically by recording spectra when the axis of the entrance phase–shifting plate is at 0° and 45°. To allow for the

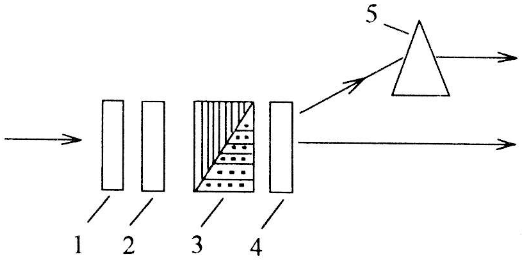

Figure 1: *Optical arrangement of the device for measuring the Zeeman effect at the N1 focus. Designations: 1 – phase plate λ/4, 2 – second phase plate λ/4, 3 – Roshon prism, 4 – outlet phase plate λ/4, 5 – compensation wedge.*

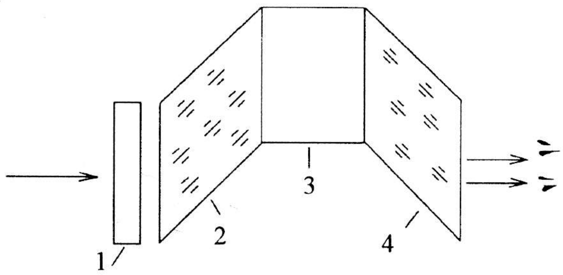

Figure 2: *Optical arrangement of the device for measuring the Zeeman effect at the N 2 focus. Designations: 1 – phase plate λ/4, 2 – entrance Fresnel rhomb, 3 – iceland spar crystal, 4 – outlet Fresnel rhomb.*

instrumental effect, four successive spectra need to be taken at the following angles of the entrance plate orientation: $-45°, 0°, +45°, +90°$. While measuring the longitudinal Zeeman effect, the plate is removed from the device. At a given S/N ratio the spectral resolution and the limiting magnitude are determined by the scanner characteristics (with allowance made for a decrease in magnitude by $1\overset{m}{.}5$ due to losses with the optical elements of the analyzers and creation of two images. Specimens of spectra taken with the scanner under the conditions of measuring the longitudinal and transverse Zeeman effect are available in (Borisov et al., 1989).

3. Measurements with the Main stellar spectrograph

For measuring the transverse Zeeman effect with the Main stellar spectrograph an achromatic circular polarization analyser based on the Fresnel rhomb (Najdenov, Chuntonov, 1976) is used. In this device an achromatic phase plate of $\lambda/4$ with the axes located at $-45°, 0°, +45°, 90°$ is placed in front of the Fresnel rhomb (Fig. 2), and the recording of spectra is done in the indicated positions of the plate. To record the longitudinal Zeeman effect a special construction which rotated the analyzer through 180° about the optical axis of the telescope was manufactured. The instrumental errors could thus be allowed for. We gave preference to a Schmidt camera F:2.3 having redesigned it for a CCD to be used. A CCD chip of 530 × 580 pixels of $18 \times 24 \mu m^2$ in size is used (Borisenko et al., 1991). When operating with a grating of 600 gr/mm in the second order and the narrow side of the pixel being aligned with the dispersion direction, the spectral interval registered simultaneously totals 120 Å. The short–wavelength border of spectral range (4200–9000 Å) is caused now not by the transmission and quality of the optics but by the spectral sensitivity of the CCD.

Three exposures as a minimum should be made to reconstruct the whole magnetic field vector from the spectrograms.

- The angle of the quarter-wave plate with respect to the iceland spar crystal axes is 0°. With such an orientation the splitted Zeeman components of the spectral line are observed, which are due to the longitudinal magnetic field, and linear polarization is analyzed. It is characteristic of the Zeeman effect that two splitted components have the same polarization, while the non–splitted component is orthogonally polarized. That is why on one spectrum strip two components are observed, on the other – the medium component.
- The orientation of the quarter–wave plate makes an angle of 45° with the iceland spar crystal axis. Here again linear polarization is analyzed, whose vector makes an angle of 45° with the crystal axes.
- A spectrum obtained without the entrance quarter–wave plate is registered under the condition of circular polarization measurement. To eliminate instrumental errors, another three spectra can be registered at angles of 90° and −45° of the quarter–wave plate axis with the crystal axes, and with the analyzer turned about the telescope optical axis by 180°.

The spectrum range registered simultaneously is 81, 120 and 240 Å in the third, second and first diffraction orders, respectively. The upper limit of spectral resolution achieved in this case is 0.3, 0.5 and 1 Å. The separation between the components of stellar image on the slit amounts to 5 arcsec. Losses on the optics of the analyzer caused by the creation of two images do not exceed two magnitudes. In Fig. 3 is presented a calculated curve of magnitudes in the V colour normalized by original observations. We developed this

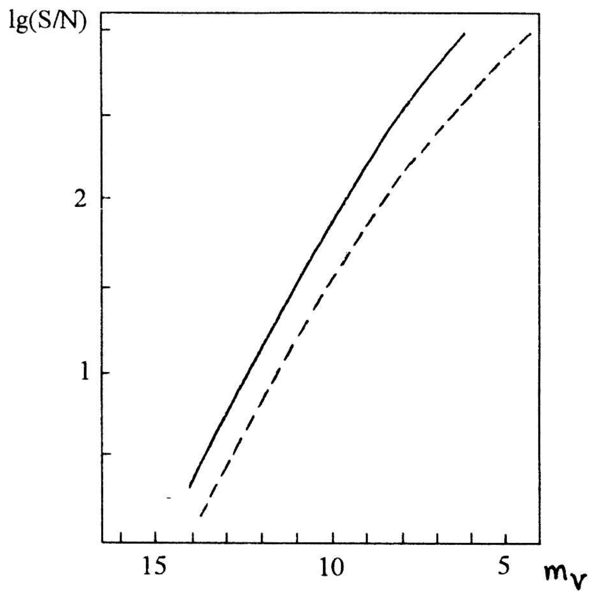

Figure 3: *Relationship between the S/N at λ 5500 Å and the recorded magnitude m_v at a seeing of 2.5″ and 1-hour exposure. Solid line – MSS, dashed line – echelle spectrometer Lynx.*

technique in 1994 and in that year it was first used in observations. Fragments of the first spectra obtained by this technique are shown in Fig. 21 of the SAO Report 1993–1994. An example of using this method is the paper of Romanyuk et al. (1995). Unfortunately Romanyuk et al. reffers in their paper to a publication of 1988, where the description of this method is missing.

4. Measurements with the echelle spectrometer Lynx

The replacement of the photographic plate by the CCD decreases the spectral interval registered simultaneously (for the camera F:2.3 of the MSS with a particular CCD the decrease is over 10 times), the number of simultaneously registered magnetosensitive spectral lines is reduced roughly by the same factor. Because of this the accuracy of magnetic field measurement drops by a factor of 3–4. The measurement error of the line shifts is in inverse proportion to S/N, therefore the substitution of the CCD for the photographic plate will retain the accuracy of magnetic field measurement provided that the gain in S/N is 3–4-fold (i.e. in the case the camera F:2.3 of the MSS is used, photographic spectra with the S/N = 30 correspond to the CCD spectra with the S/N=90–120). Further improvement of the accuracy can be ensured by increasing the number of magnetosensitive lines registered simultaneously, i.e. by using of the echelle spectrometer. With this in mind the echelle spectrometer Lynx (Klochkova, 1995) was equipped with a cross-dispersion unit of 600 gr/mm. With a 5-arcsecond separation of the polarized components of a stellar image and an echelle of 37.5 gr/mm this allows the Zeeman echelle spectra at $\lambda > 4500$ Å to be obtained, while with a cross-dispersion grating of 300 gr/mm one can operate at $\lambda > 6400$ Å.

The Main stellar spectrograph and the echelle spectrometer Lynx have a common preslit unit. That is why in observations with the echelle spectrometer the above described circular and linear polarization analyzer, turned about the optical axis of the Nasmyth focus by 90° with respect to its former position, is used (when working with the MSS), and the set of the exposures remains the same. The principal characteristics of the technique are as follows: the working spectral range is 4500–9000 Å, the range registered simultaneously is 500–1000 Å, the spectral resolution R=25000, the separation of polarized components on the slit is 5″. In Fig. 3 is displayed a calculated magnitude curve in the V colour normalized to original observations. In Fig. 4 are presented fragments of the first echelle spectrum registered with the circular and linear polarization analyzer in the process of testing the technique.

5. Conclusion

Analyzers of circular and linear polarization in combination with the spectral instrumentation fixed on the 6 m telescope allow fulfillment of spectropolarimetric programs. These systems in conjunction with the simplicity in operation have essentially new characteristics: possibility of measuring in a wide wavelengths range, photoelectric accuracy with a large number of spectral elements measured simultaneously, possibility of investigating faint objects. To facilitate the operation, work is being done to make the analyzers remotely controlled. The authors are certain that extensive use of universal multipurpose wide-band polarization analyzers combined with multichannel spectral systems will raise drastically the level of investigation of stellar magnetism at the 6 m telescope.

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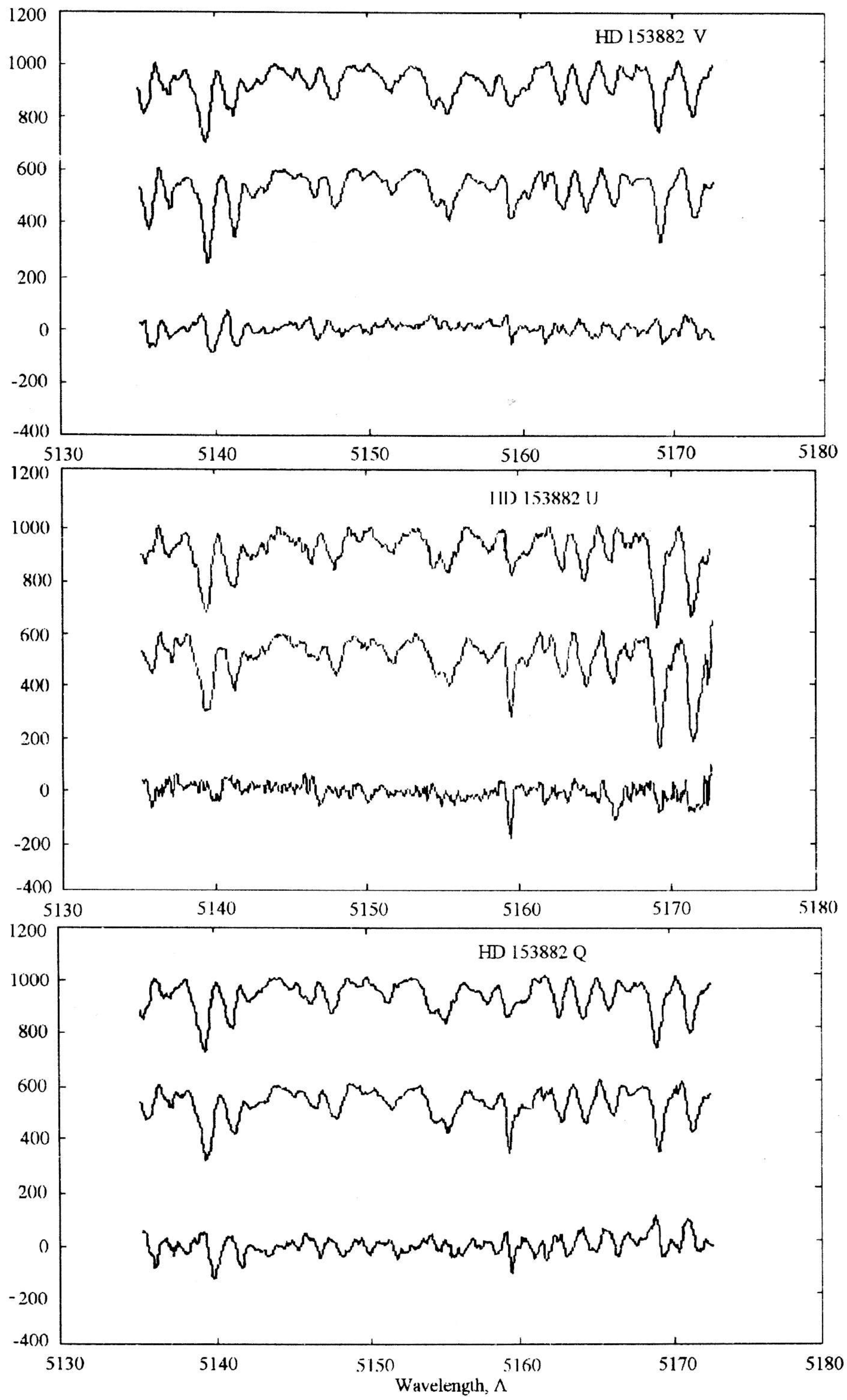

Figure 4: *Fragments of one of 10 spectral orders of echelle spectra of HD153882 recorded on 14/15.03.96 at different states of the circular and linear polarization analyzer. Recording of Stokes parameter V, U, Q. Below are presented the differences of residual intensities.*

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