

Observations of the joint Action of the Hanle and Zeeman Effects in the D₂ Line of Ba II

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Abstract. We show a selection of high-sensitivity spectropolarimetric observations obtained over the last few years in the Ba II D₂-line with the Zürich Imaging Polarimeter (ZIMPOL) attached to the Gregory Coudé Telescope of IR-SOL. The measurements were collected close to the solar limb, in several regions with varying degree of magnetic activity. The Stokes profiles we have observed show clear signatures of the joint action of the Hanle and Zeeman effects, in very good qualitative agreement with the theoretical expectations. Polarimetric measurements of this line show to be very well suited for magnetic field diagnostics of the lower solar chromosphere, from regions with field intensities as low as 1 gauss to strongly magnetized ones having kG field strengths.

1. Introduction

In a recent paper, Belluzzi, Trujillo Bueno, & Landi Degl'Innocenti (2007) concluded that the modeling of spectropolarimetric observations in the Ba II D₂-line at 4554 Å could be a very useful diagnostic tool to obtain empirical information on the spatial fluctuations of the magnetic field vector in the lower solar chromosphere. This line is indeed particularly interesting because its emergent linear polarization has contributions from different isotopes that have a different behavior in the presence of a magnetic field.

With the observations reported in the present paper we aim at experimentally verifying the theoretical model predictions on the magnetic sensitivity of the Ba II D₂ line.

2. Observations

A set of 28 spectropolarimetric measurements were obtained at several regions close to the solar limb during 9 different days from June 2005 to March 2007 with the 45 cm Gregory-Coudé Telescope (GCT) at the Istituto Ricerche Solari

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Locarno (IRSOL). The observations were obtained at different latitudes, from the equator to the solar poles, and in both quiet and active regions. A high polarimetric sensitivity free from seeing induced effects could be achieved thanks to the ZIMPOL polarimeter (Povel 1995; Gandorfer et al. 2004). The solar image was rotated with a Dove prism set after the polarization analyzer in order to keep the limb parallel to the spectrograph slit. A limb tracker was used to keep a constant distance from the limb: typically 10 arcsec. Calibration observations such as polarimetric efficiency measurements, dark current, flat field, and instrumental polarization measurements were taken regularly before and/or after the observations. The instrumental polarization was carefully corrected for applying the procedure described in Ramelli et al. (2006).

3. Results

The observations exhibit a very good qualitative agreement with the basic theoretical predictions of Belluzzi et al. (2007). We report here a few significative examples.

The measurement reported in Fig. 1 was obtained close to the heliographic North Pole. Two spatial regions along the spectrograph slit are selected and the corresponding profiles shown on the right panel. In the region corresponding to the dotted lines, there is a small decrease of the Q/I signal in the line core while

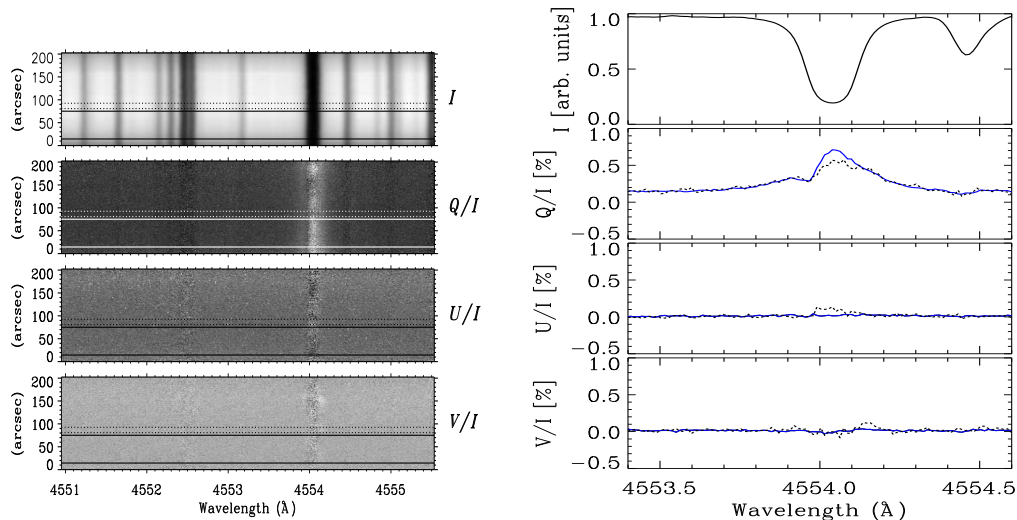


Figure 1. Full-Stokes observations taken on August 15, 2006 close to the heliographic North Pole with the spectrograph slit at about 10 arcsec from the limb. Two spatial regions are selected by the solid and dotted horizontal lines on the Stokes images reported in the left panel. The corresponding Stokes profiles around the Ba II D_2 line are shown on the right panel by the solid and dotted lines. The latter exhibit the typical behavior expected for a weak horizontal magnetic field with a significant longitudinal component (~ 1 gauss). The exposure time was 800 s.

the line wings remain unaffected. In the same region a small feature appears in U/I in the line core. The V/I profile shows a small antisymmetric signal. This is the typical behavior expected for a horizontal magnetic field with a longitudinal component of the order of 1 gauss (compare with fig. 10 of Belluzzi et al. 2007).

In the left panel of Fig. 2 we show a measurement of Stokes I , Q/I and V/I taken near the west limb (AR 10904) very close to a sunspot (see the slit jaw image on the right panel of Fig. 2). The corresponding profiles obtained in two selected spatial regions A and B along the slit are displayed in Fig. 3. Region A corresponds to a region with an intermediate field strength. Here we see again in the Q/I profile a decrease of polarization in the line core while the line wings stay almost unaffected: the typical behavior expected for a horizontal magnetic field with a strength smaller than 100 Gauss (compare with the left panels of fig. 10 of Belluzzi et al. 2007). Region B is selected just above the sunspot where the Stokes V/I Zeeman signals reach the maximum amplitude. In this case one observes a strong decrease of Q/I in the line wings due to the transverse Zeeman effect. This is well expected for a magnetic field whose horizontal component perpendicular to the line of sight is larger than 100 gauss (see the right panels of figs. 7 and 9 in Belluzzi et al. 2007).

Finally we show the results of a long exposure measurement (4400 s) taken at about 8 arcsec from the limb, just above the active region AR 10946 on March 13, 2007 (Fig. 4). Due to the high photon statistics it is possible to obtain several good quality profiles, with low level of noise, integrating over small portions of

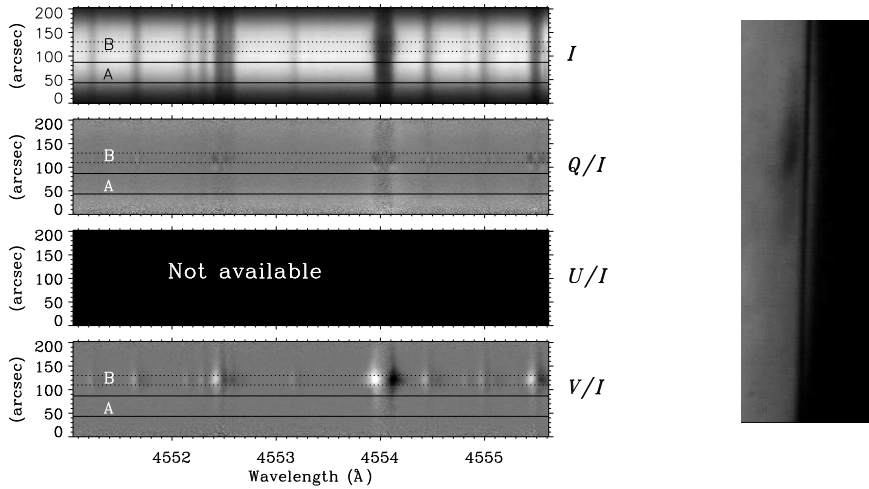


Figure 2. Observations taken on August 21, 2006 at about 3 arcsec from the limb, very close to a sunspot. The left panel shows the observed I , Q/I and V/I images. Two spatial regions A and B are selected. The corresponding profiles are shown in Fig. 3. In Region A there is a magnetic field of intermediate strength. Region B is selected where the magnetic field strength is at the maximum, close to the sunspot. A cropped low resolution slit-jaw image taken during the measurement is shown on the right. The total exposure time was 1200 s.

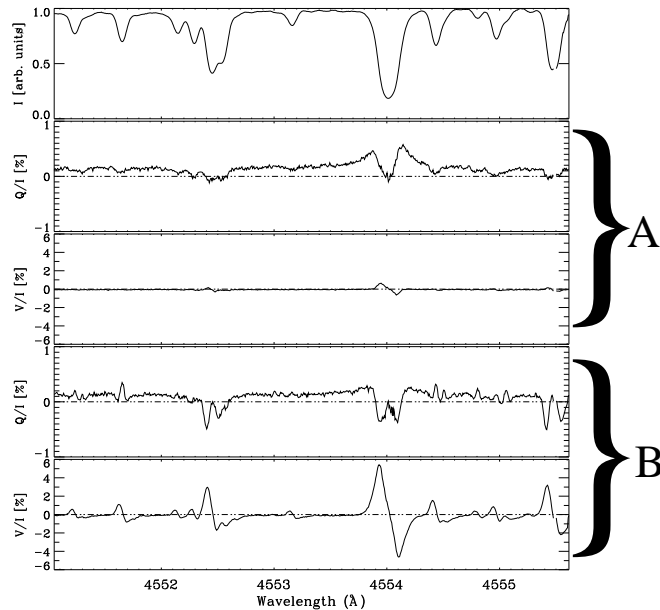


Figure 3. I profile, Q/I profile and V/I profile of regions A and B selected in Fig. 2

the spectrograph slit. Starting from the top of the image we select several contiguous regions of about 15 arcseconds (10 pixels) down to the region with the highest Stokes V/I signal. The resulting Q/I and V/I profiles are shown in Fig. 5. This illustrates quite well a transition from a weakly magnetized region to a substantially more active one. In V/I there is a gradual increase of the amplitude of the antisymmetric Zeeman pattern. In Q/I one sees first a clear decrease of polarization in the line core and then, where the field becomes stronger, also a decrease in the line wings. One notes also an overall decrease of Q/I on the whole spectral range. The larger overall value of Q/I in the top of the image is due to the fact that we are closer to the limb than in the center of the image because of the limb curvature.

The profiles obtained in this observation were fitted with the theoretical profiles predicted by the optically-thin model of Belluzzi et al. (2007), which is however very detailed from the atomic physics viewpoint. An example of the result of the fit is shown in Fig. 6. Obviously, the goodness of this fit does not imply at all the validity of the optically thin assumption, which was used on purpose by Belluzzi et al. (2007) in order to focus on understanding the magnetic sensitivity of the emitted spectral line polarization. Since the Ba II D_2 line is strong, any quantitative modeling of the present observations will have to include the effects of radiative transfer in realistic atmospheric models.

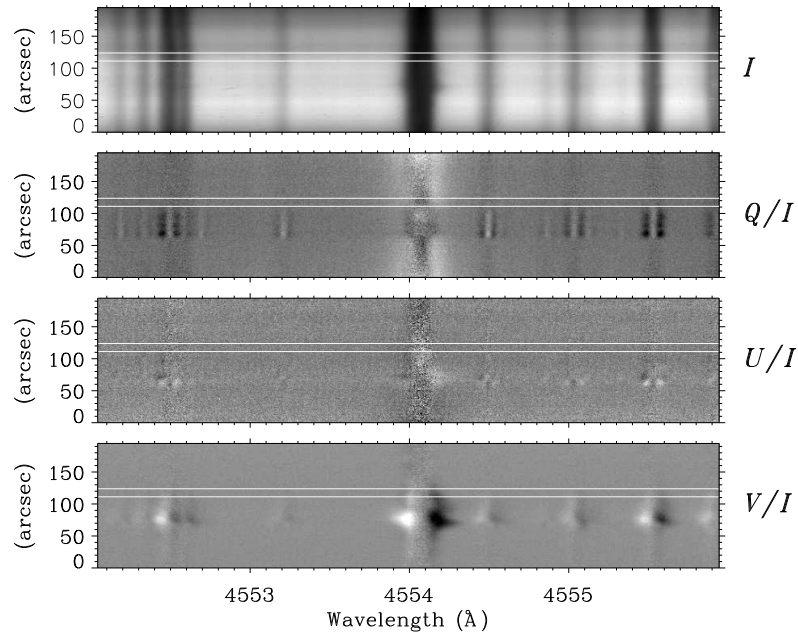


Figure 4. Full-Stokes observations taken on March 13, 2007 in an active region with the spectrograph slit set at about 8 arcsec from the limb. The exposure time was 4400 s. Profiles obtained in different portions of the slit are reported in Fig. 5. The profiles obtained in the interval between the two horizontal lines present in each Stokes image are reported in Fig. 6

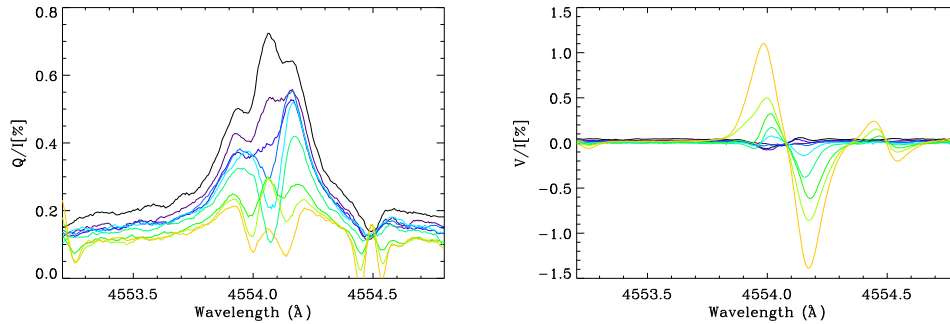


Figure 5. Stokes Q/I and V/I profiles of different contiguous spatial regions of about 15 arcseconds each, selected from the top of the image shown in Fig. 4 down to the region with the strongest Stokes V/I signal. In the transition from the top of the image to the latter position, the Stokes Q/I signal reduces gradually its amplitude while the antisymmetric Zeeman pattern in V/I increases its amplitude.

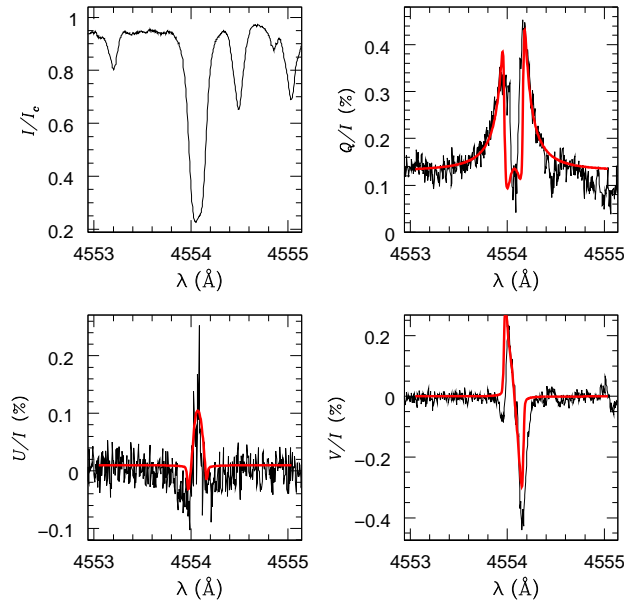


Figure 6. An example showing the profiles obtained in the 15 arcseconds region included between the line pairs shown in Fig. 4. The files are fitted with theoretical profiles predicted by the model of Belluzzi et al. (2007) corresponding to a magnetic field of 28 Gauss with an inclination $\Theta_B = 63^\circ$ with respect to the local vertical and an azimuth $\chi_B = 98^\circ$ (for the angle definitions see the corresponding paper).

4. Conclusions

The high-sensitivity spectropolarimetric observations reported in the present paper are in good qualitative agreement with some of the theoretical predictions of Belluzzi et al. (2007) on the magnetic sensitivity of the Ba II D₂ line. This reinforces their conclusion that spectropolarimetric measurements of this line provide a very promising mean for magnetic field diagnostics in the solar photosphere and chromosphere for a wide range of field strengths. Particularly interesting results may be expected with two-dimensional spatial polarimetric imaging techniques using Fabry-Perot interference filters.

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