Spectropolarimetry of Ca II 8542: Probing the Chromospheric Magnetic Field

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Abstract. We present spectropolarimetric observations of the chromospheric Ca II 8542 and photospheric Fe I 6302 lines obtained with the Interferometric Bidimensional Spectrometer (IBIS) at the Dunn Solar Telescope. The high spatial resolution over a large field of view (FOV) allows us to connect the observed profiles to the overall topology of the target region. After suitable calibrations we can extract Stokes profiles for each point in the FOV. The Stokes V profiles observed in the Ca II line show a large variety of shapes, indicating widely varying vertical behavior of the field strength, velocity, and temperature. We examine the center-of-gravity method for determining a representative field strength from the observed profiles and use it to directly compare photospheric and chromospheric magnetic fields.

1. Introduction

The measurement of the chromospheric magnetic field within individual atmospheric structures is a desirable but still challenging goal. Because of the non-LTE properties of the chromosphere, inversion models are not as well developed as for the photosphere. Pietarila et al. (2007) have recently performed inversions of the quiet Sun chromosphere but to our knowledge there are no inversions for active regions in the chromosphere. Therefore, we use a direct approach to determine the magnetic field strength by applying the center-of-gravity (COG) method, first described by Rees & Semel (1978). We compute the magnetic fields of simultaneous measurements in photospheric and chromospheric heights for an active region. While it is agreed upon that the field decreases with height, the magnitude of this decrease is still uncertain (see Solanki 2003).

2. Observations

IBIS is a two-dimensional spectropolarimeter (Cavallini 2006; Reardon & Cavallini 2008) located after a high-order adaptive optics system at the Dunn Solar Telescope, U.S.A. The data were obtained on Jan. 29, 2007 and Feb. 5, 2007 targeting AR 10940 and AR 10941, respectively. Repeated scans of two different lines (Fe I 6302.5 Å and Ca II 8542.1 Å) were acquired in a two-minute period while cycling through six polarization states ($I + Q, I + V, I - Q, I - V, I - U,$
$I + U$) at each wavelength. The spectral sampling was 18 mÅ for Fe and ranged from 37 mÅ (core) to 93 mÅ (wing) for Ca. The scans contained 26+41 (Fe+Ca) spectral points (Jan. 29) and 23+37 (Feb. 5). Data reduction included a correction for the blueshift resulting from the collimated mount of the Fabry-Perot etalons, destretching of the data to compensate for seeing changes in each exposure and a correction for telescope and instrumental polarization. Fig. 1 shows a set of the four derived Stokes parameters for one wavelength position in the blue wing of each of the observed lines. A weak flare is visible in the chromospheric intensity image. We found a wide range of $V/I$ profile shapes in the sunspots (see examples in Fig. 2), even reversals of $V/I$ resulting from apparent emission in the Ca ii 8542 line core (as also described by Briand & Vecchio 2003).

![Figure 1](image.png)

**Figure 1.** AR 10940 on Jan. 29, 2007 (heliocentric $\mu = 0.8$). The Stokes parameters are shown at one wavelength in the blue wing of Fe i 6302 (top) and Ca ii 8542 (bottom). The images are scaled to ± of their maximum polarization amplitude, meaning that neutral gray represents zero polarization.

### 3. Center-of-Gravity Method

The COG method applied to $I + V$ and $I - V$ can be used to calculate the line-of-sight (LOS) magnetic field strength in each point of the FOV. The COG wavelengths are defined by

$$
\lambda_{\pm} = \frac{\int \lambda [I_{\text{cont}} - (I \pm V)] d\lambda}{\int I_{\text{cont}} - (I \pm V) d\lambda}
$$

(1)
Figure 2. Examples of different profiles from AR 10941 on Feb. 5, 2007 (heliocentric $\mu = 0.93$). Top left: regular I (dashed) and $V/I$ (solid) profiles, as visible in most places of the FOV. Top right: Emission in the line core (dashed) and asymmetric profile shapes (solid) are common in Ca $\text{ii}$ 8542. The left scale of the plots refers to the $V/I$ amplitudes while the right scale gives $I$ normalized by the continuum intensity.

The wavelength difference of the COG of $I + V$ and $I - V$ is directly proportional to $B_{\text{LOS}}$.

$$B_{\text{LOS}} = \frac{\lambda_+ - \lambda_-}{2.0} \frac{4\pi m_e c}{e g L \lambda_0^2}$$

(2)

where $m_e$ is the electron mass, $c$ the speed of light, $e$ the electron charge, $g_L$ the effective Landé factor and $\lambda_0$ the wavelength of the line center. While the method is well applicable to the regular antisymmetric $V$-profiles in the photospheric Fe $\text{i}$ 6302 line, the widely varying shapes of the chromospheric Ca $\text{ii}$ 8542 $V$-profiles pose a problem. It was necessary to implement an area asymmetry criterion (Martinez Pillet, Lites, & Skumanich 1997) and omit all profiles that have an asymmetry exceeding a certain value (0.30 in this case). Fig. 3 presents a direct comparison between chromospheric and photospheric magnetic fields derived by the COG method. An average field value was calculated for 10 pixel (1.65$''$) wide concentric rings around the sunspot center that was defined by the COG of the intensity image (same center for both lines). The standard deviation of the averaged values is of the size of the line thickness and therefore not shown in the figure. As expected, the chromospheric field strength is lower than the photospheric field until a point close to the outer boundary of the penumbra where the relation inverts. This slower decrease of field strength in higher atmospheric levels is also mentioned by Solanki (2003).
4. Conclusions

We have shown that a measure of the line-of-sight chromospheric magnetic field can be derived with the COG method when it is used with caution. Further investigation of the data will allow not only a direct comparison of photospheric and chromospheric line-of-sight magnetic fields but also a determination of the transverse fields from $Q$ and $U$. This may lead to a better understanding of magnetic fields in chromospheric structures.

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References