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The Height Dependence of the Magnetic Vector Field in Sunspots

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Abstract. A complex active region was observed simultaneously with the solar telescopes VTT and THEMIS on Tenrife in May 2005. Spatial scans across the sunspot group were performed at both telescopes. The full Stokes-vector was recorded in several photospheric spectral lines, i. e. at the VTT in a group of iron and silicon lines in the near infrared and at THEMIS in iron and chromium lines in the visible. Inversions were carried out independently for the different lines in order to derive the magnetic field strength, its inclination and azimuth together with the temperature stratification. Thus we obtained the three-dimensional structure of the magnetic field. Selected locations in the penumbra and in light bridges were considered in detail. We find a general tendency that the magnetic field is weaker and less inclined in higher layers.

1. Introduction

The height dependence of the magnetic field in sunspots and active regions is still a controversial topic. Most investigations find a decrease of the magnetic field strength with height, but the rapidness of this decrease is under discussion (see Balthasar 2006). In the outer penumbra, Orozco Suarez, Lagg, & Solanki (2005) found a positive gradient of the field strength and Jurčak, Martínez Pillet, & Sobotka (2006) reported an increase of the field strength for light bridges. Balthasar & Bommier (2007) could not confirm such increases for most locations inside the spot, but many magnetic features outside spots and pores exhibited a higher field strength in higher layers.

In this contribution, we investigate several spectral lines originating from different atmospheric layers. Deriving magnetic gradients from the inversion code might be misleading in case of discontinuities as it was discussed by Martínez Pillet (2000). We avoid that problem by inverting the lines individually assuming a constant magnetic field for the height range from which the single line originates. Results from the different lines yield the height dependence of the magnetic field.

2. Observations and Data Reductions

Observations of active region NOAA 10767 with two telescopes, i. e. the Vacuum Tower Telescope (VTT) and the Télescope Héliographique pour l'Étude du Magnétisme et des Instabilités Solaires (THEMIS) on Tenerife, were performed

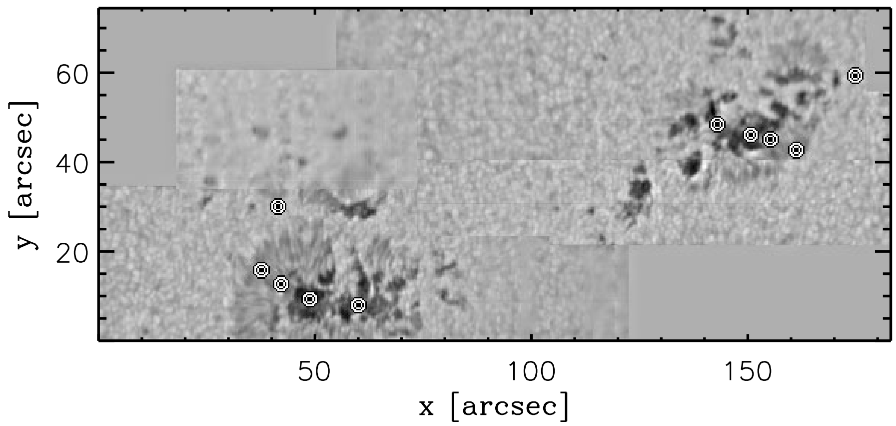

Figure 1. Recombined intensity map of the spot from VTT–data near 1078 nm with enhanced contrast. Points selected for the line graphics below are marked. West is to the right, North to the top, and disk center to the upper left. In this group, the leading spot has a less compact structure than the follower.

on May 29, 2005, simultaneously in different photospheric lines. The central position of the sunspot group was 8° South and 23° West. We used the Tenerife Infrared Polarimeter (TIP) at the VTT and the MulTi-Raies-mode (MTR) at THEMIS. At the VTT we recorded one spectral lines from the lower photosphere and one from the higher photosphere in the quiet sun and from almost the same layers in the umbra. At THEMIS we observed a pair of Fe I lines which originate for most areas between the VTT-lines and one line coming from very deep layers. Part of these data have already been investigated by Balthasar & Bommier (2007). Now we include two more lines, all lines are listed in Table 1.

Table 1. The used spectral lines, their Zeeman splitting factor, and formation heights in model atmospheres for quiet sun and umbra.

Element	λ [nm]	Telescope	$g_{\rm eff}$	$h_{\rm QS}$ [km]	$h_{\rm U}$[km]
Cr I	578.31	THEMIS	2.00	125	130
Fe I	1078.3	VTT	1.50	175	130
Fe I	630.25	THEMIS	2.50	270	165
Fe I	630.15	THEMIS	1.67	325	200
Si I	1078.6	VTT	1.50	335	130

Fig. 1 shows a combined intensity map of the active region, obtained at the VTT. Because of adaptive optics corrections, VTT images are of higher quality, and VTT-results were degraded for this investigation. Inversions of the Stokes profiles were done with the SIR-code (Stokes Inversions bases on Response functions) of Ruiz Cobo & del Toro Iniesta (1992). In contrast to our

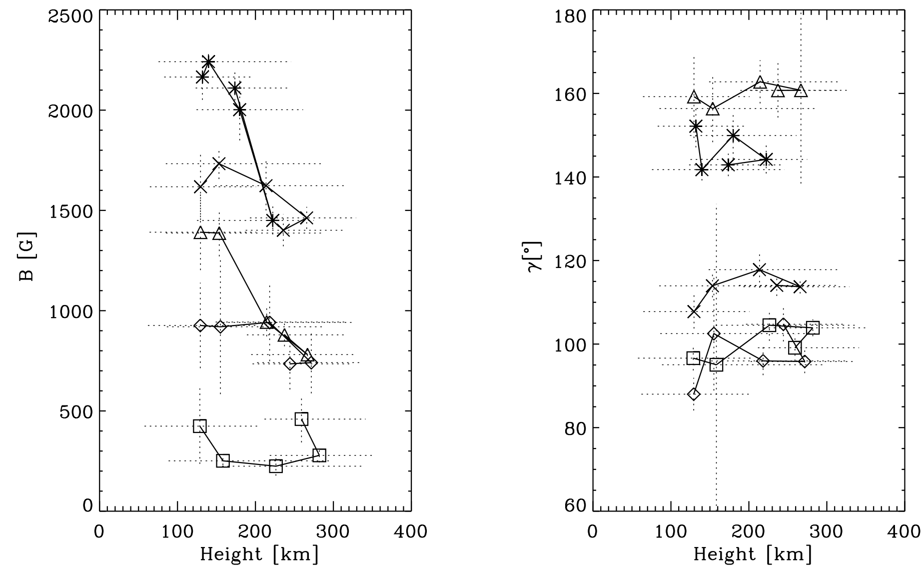

Figure 2. Height dependence of magnetic field strength (*left*) and inclination to the LOS (*right*) for the preceding spot. Following the connection lines the spectral lines are Cr 578.3 nm, Fe 1078.3 nm, Fe 630.2 nm, Fe 630.1 nm and Si 1078.6 nm. Asterisks denote the umbra, triangles the light bridge, crosses the inner penumbra, diamonds the outer penumbra and squares the canopy point outside the spot. Dotted lines indicate the error bars.

previous investigation (Balthasar & Bommier 2007), we now restrict ourselves to use only the total magnetic field strength and magnetic inclination with respect to the line–of–sight (LOS), because we have doubts that we could solve the azimuth ambiguity in a consistent way for all five lines. Formation heights are interpolated between an umbra and a quiet sun atmospheric model using the temperature map at the continuum layer. Error bars for the formation heights correspond to the half-width of the depression contribution functions.

3. Results

We selected five points in and next to the leading spot and another five points for the following spot. These points are marked in Fig. 1. The magnetic field strength and inclination derived from the five spectral lines are shown in Figs. 2 and 3. From the iron lines we deduce a decrease of the magnetic field strength with height inside the spot independent of the fine structure. The silicon line weakens strongly in the umbra where it is formed in deeper layers. Therefore its results are consistent with those from the iron lines. Only the chromium line delivers a smaller field strength than the infrared iron line. For this reason, it does not fit to tendency of a decreasing magnetic field strength with height. Outside the spots there are locations with an opposite trend.

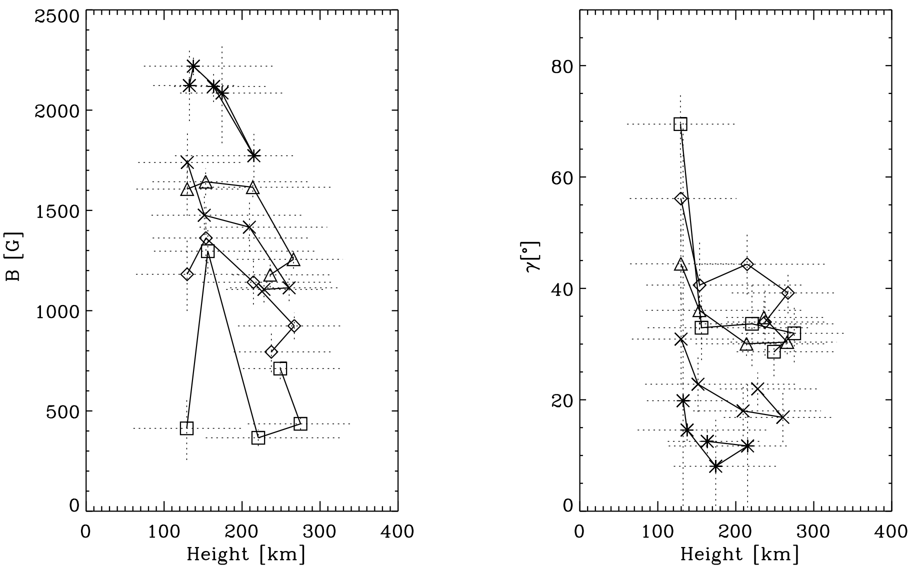

Figure 3. Height dependence of magnetic field strength (*left*) and inclination to the LOS (*right*) for the following spot, otherwise the same as Fig. 2.

The direction of the magnetic field is typically less inclined in higher atmospheric layers. We encounter this tendency for all locations, although sometimes one or two of the spectral lines deviate from the general trend.

4. Conclusions

We see a general tendency that the magnetic field strength decreases with height although this is not statistically significant everywhere and the Cr line does not fit in all cases. Again as a general tendency, magnetic field lines are less inclined in higher layers. Problems might arise from different image quality of the two telescopes and different spectral resolution.

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