On the Magnetic Field of a Sunspot Penumbra

H. BALTIASAR, W. SCHMIDT (Kiepenheuer-Institut für Sonnenphysik, Freiburg)
A. HOFMANN (Sonnenobservatorium Einsteinturn, Potsdam)
T.D. TARBELL, Z. A. FRANK (Lockheed Palo Alto Research Laboratory)

We observed a medium size sunspot located outside disc centre (at \( \cos \theta = 0.9 \)) during good seeing conditions. We obtained spectra of the Fe I line 630.25 nm and the Ti I line 630.38 nm. The two lines were recorded on a CCD camera with 0.4 pm spectral and 0.19 arcsec spatial pixel size at 15 raster positions covering an area of 4.5 x 90 arcseconds. Stokes I and Stokes V maps were derived from I+V and I-V filtergrams, recorded simultaneously on a single CCD camera. The filtergrams were taken at different wavelength positions around the centre of the Fe 630.25 line using a narrow-band (7.2 pm) tuneable filter. The observations were made at the Vacuum Tower Telescope on Tenerife in June of 1991.

The V filtergrams were corrected for scattered light and instrumental polarisation. We had measured the I- and V- related parts of the Mueller-Matrix of the whole instrument during the observations. The filtergrams were converted into longitudinal magnetograms applying a suitable calibration procedure.

The spectra were taken simultaneously with the filtergrams. Magnetic field strengths were derived by fitting synthetic I profiles to the measured ones, or, for larger fields, by measuring the Zeeman splitting of the components of the Fe line. The Doppler shifts of both the Fe and the Ti line were measured to determine the line-of-sight component of the penumbral flow.

From our analysis of the spectrograms and magnetograms we find

(i) a clear (anti-) correlation between the brightness variation of penumbral structures and the longitudinal component of the magnetic field.

(ii) that the magnetic field inclination in dark structures is several degrees larger than in bright features.

(iii) no variation of magnetic field strength across dark and bright structures at constant spot radius.

(iv) a maximum field strength of 2900 G at the darkest part of the umbra, decreasing to about 2000 G at the inner penumbral boundary. At the outer penumbral edge the field strength is 800 - 1000 G and drops sharply towards the photosphere within 1 arcsecond.

(v) line-of-sight velocities in the penumbra up to 2 km/s with a rapid decrease at the outer penumbral boundary. The Ti line shows larger Doppler shifts due to the lower height of formation.

These results remove much of the uncertainty associated with the magnetic field structure in sunspot penumbrae. It has often been argued that dark penumbral structures have stronger magnetic field than bright ones. The mostly negative result of corresponding observations was addressed to insufficient spatial resolution. We find no variation even at a resolution of half an arcsecond.