Cool Stars, Stellar Systems, and the Sun, Eighth Cambridge Workshop
ASP Conference Series, Vol. 64, 1994
Jean-Pierre Caillault (ed.)

A SEARCH FOR SUNSPOT CANOPIES USING A VECTOR MAGNETOGRAPH

M. ADAMS
Solar Science Branch, NASA/Marshall Space Flight Center, AL 35812

S.K. SOLANKI
The Institute for Astronomy, Zurich, Switzerland

M.J. HAGYARD AND R.L. MOORE
Solar Science Branch, NASA/Marshall Space Flight Center, AL 35812

ABSTRACT Using a magnetograph, we examine four sunspots for evidence of a magnetic canopy at the outer penumbra boundary. The penumbra edge is determined from the photometric intensity and is defined to correspond to the value of the average photospheric intensity minus twice the standard deviation from the average. From a comparison of the location of this boundary with the location of contours of the vertical and horizontal components of the magnetic field, we conclude that the data are best represented by canopy-type fields extending from all four sunspots. The observations suggest that the magnetic canopy of a sunspot begins at its outer penumbral boundary with an inclination of 5° - 15° with respect to the horizontal.

INTRODUCTION

In the early eighties, Giovanelli (1982) used observations of W.C. Livingston to infer a magnetic canopy which overlies a non-magnetic photosphere. Giovanelli's model, based on observations of active regions close to the solar limb, describes a canopy base which extends back into the sunspot penumbra. The purpose of this study is to constrain answers to the following questions: (1) Can the superpenumbral magnetic canopy of sunspots be seen in visible lines near the center of the solar disc? (2) If so, what is the inclination of the magnetic field in the canopy? (3) Does the canopy continue into the penumbra?

OBSERVATIONS AND ANALYSIS

The data were acquired with the MSFC vector magnetograph, composed of a 30 cm (f/13) Cassegrain telescope, polarizing optics, Lyot birefringent filter, and CCD camera. The field of view in 1980 was 5 x 5 arc min with a resolution of 2.4 arc sec per pixel. Data from 1985 had a field of view of 6 x 6 arc min with 2.81 arc sec pixels. The Zeeman sensitive spectral line at Fe I 5250.2 Å, may be tuned

by ±8 Å on either side of the line. More details of the instrument may be found in Hagyard et al. (1982) and Hagyard, Cumings, and West (1985). A summary of the observations of three active regions is given in the table below. All data were treated for projection effects and transformed to heliographic coordinates.

Table I Summary of Active Region Observations

Date	Active Region	Location	Magnetic Class	Time (UT)	Field Strength
Apr 6, 1980	2372	N12 E08	δ	21:10	2400 G
Sep 23, 1980	2684	N22 W18	βp	15:00	2100 G
Jun 9, 1985	4660	S14 E12	β	13:37	2200 G

According to Giovanelli's observations, the vertical component of the magnetic field disappears near the penumbra/photosphere boundary of a sunspot; however, these observations are based on a qualitative, visual impression of the penumbra edge. We have quantified the location of the border of each sunspot by calculating the mean value of the un-spotted photospheric intensity (within the field of view) and subtracting 2σ. Thus, the location of the edge of the penumbra is assumed to be the locus of points for which the value of the intensity is equal to $\bar{I}$ - 2σ and the sunspot itself is defined to be the locus of points for which the value is less than $\bar{I}$ - 2σ.

Next, a black and white mask of the sunspot is made such that all intensity values less than the mean photospheric value minus 2σ are painted black; all higher values are painted white (see Figure Ib). The resulting image is a completely black sunspot with white photosphere. Parts c and d of Figure I show the results and include the vertical and horizontal components of the field so that pixels with values of the vertical component above 30 Gauss and horizontal values above 200 Gauss which are coincident with the location of the mask, are displayed as white. Any residual field greater than the cutoff values outside the mask, appears in black encircling the outer penumbra.

CONCLUSIONS

Contribution functions show that Fe I 5250.2 Å is sufficiently sensitive to detect magnetic canopies in the middle and upper photosphere. The ratio between the vertical and horizontal B values of the field (from Stokes $V/\sqrt{Q^2+U^2}$) therefore, reliably gives the inclination angle of the field in the magnetic canopy. Our results may be summarized as follows:

1. There is an almost horizontal canopy of field encircling sunspots.
2. The base of the canopy corresponds roughly to the height of formation of the line.
3. The vertical component of the field does not drop to zero at the penumbra edge.
4. The inclination of the field in the canopy lies between 5° and 15° just outside the penumbra.

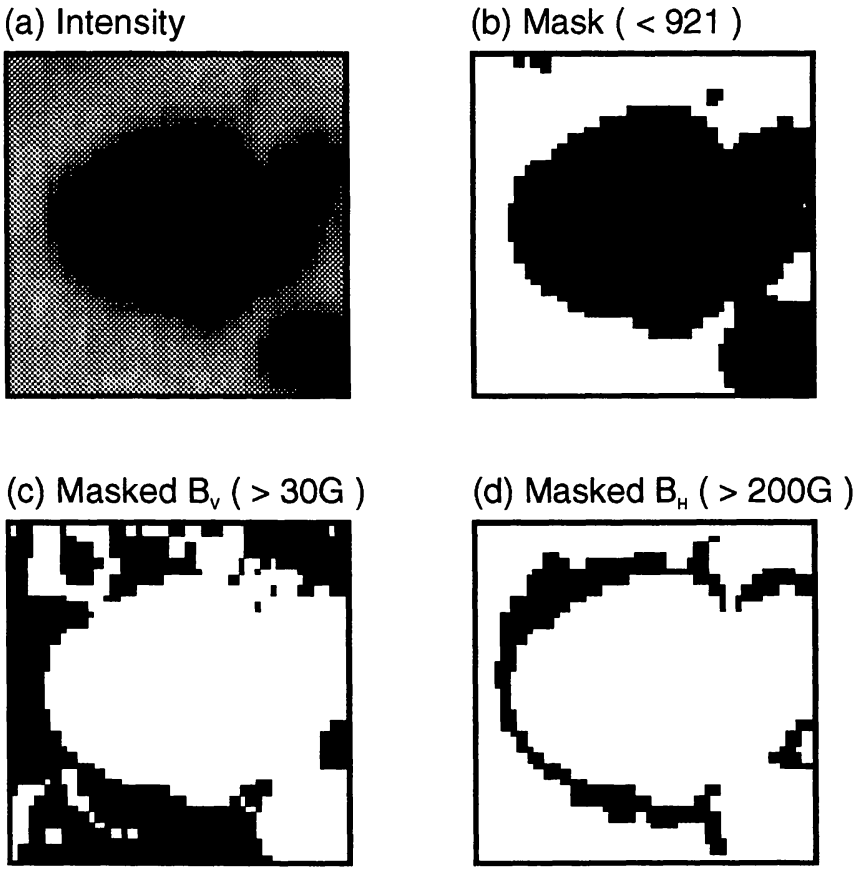

FIGURE I Masks and Overlays of AR 2372 the Follower Spot. (a) Grey-scaled white light image of the spot. (b) Black pixels have intensity values < 921 ($\bar{I}$ - 2σ). (c) The central white region of the spot represents the coincidence of the vertical component of the field > 30 G and the intensity < 921. Black areas represent field strength > 30 G and intensity values > 921. (d) Similar to (c), except black pixels represent horizontal component values > 200 G and intensity values > 921.

REFERENCES

Giovanelli, R.G. 1982, Solar Phys., *80*, 21

Hagyard, M.J., Cumings, N.P., West, E.A., and Smith, J.E. 1982, Solar Phys., *80*, 33

Hagyard, M.J., Cumings, N.P., and West, E.A. 1985 in *Proceedings of Kunming Workshop on Solar Physics and Interplanetary Travelling Phenomena*, eds. C. de Jager and C. Biao, Science Press, Beijing, 179