ON THE CONTRAST OF FACULAE AND SMALL MAGNETIC FEATURES

A. Ortiz[1], S.K. Solanki[3], M. Fligge[4], V. Domingo[1,2], and B. Sanahuja[1,2]

[1]Dept. Astronomia i Meteorologia, Universitat de Barcelona, E-08028 Barcelona, Spain, +34-93-4021122, fax +34-93-4021133, aortiz@am.ub.es

[2]Institut d'Estudis Espacials de Catalunya, E-08034 Barcelona, Spain

[3]Max-Planck-Institut für Aeronomie, 37191 Katlenburg-Lindau, Germany, solanki@linmpi.mpg.de

[4]Institute of Astronomy, ETH-Zentrum, CH-8092 Zürich, Switzerland, fligge@astro.phys.ethz.ch

ABSTRACT

Sunspots, faculae and the magnetic network contribute to solar irradiance variations. The contribution due to faculae and the network is important for understanding solar irradiance variations, but suffers from considerable uncertainty. We focus our study on the faculae and the network which produce an increase in the irradiance. Data from the Michelson Doppler Interferometer (MDI) are employed. Starting from the surface distribution of the solar magnetic field we build a mask to detect bright features and study their contrast dependence on limb angle and magnetic field. By sorting the magnetic field strength into different bins we can distinguish between different associated bright features. We find that the contrast of active region faculae and the network exhibits different centre to limb variations, implying that they need to be treated separately when reconstructing variations of the total solar irradiance.

Key words: solar activity; irradiance variations; faculae; network.

1. INTRODUCTION

There is increasing evidence that the solar surface magnetic field is the most important driver of solar irradiance variations on time scales of days up to the solar activity cycle length (Fligge & Solanki, 2000). The photospheric magnetic field is bundled into discrete elements (flux tubes) whose diameter ranges from a hundred kilometers to several thousand. The brightness signature of these magnetic features is a strong function of their limb angle and their size (the large sunspots are dark while small flux tubes are generally bright) (Solanki, 1993). Our knowledge of the brightness of small scale magnetic features (groups of which form faculae and the network) is very incomplete (e.g. Solanki, 1994). We focus our study of the contrast dependence of faculae and the (enhanced) network on limb angle and magnetic field because:

- their contribution is important when modelling irradiance variations on time scales of years, but is not well known,
- it can be used as a test for flux tube models (Spruit, 1976; Deinzer et al., 1984a,b; Knölker & Schüssler, 1988),
- previous measurements usually have not distinguished features by magnetic flux, with a few exceptions. See Topka et al. (1992) and Topka et al. (1997) for examples.

In our analysis we use data from the MDI instrument (Scherrer et al., 1995) on the SOHO spacecraft; their main characteristics are:

- their continuity and uniformity (no seeing fluctuations),
- data from the magnetograms have a low noise level.
- the characteristics of the instrument and the data are well known.

2. DATA AND ANALYSIS PROCEDURE

We have used MDI/SOHO full disk magnetograms and continuum intensity images taken at $\lambda = 676.8$ nm for the period February to October, 1999. Intensity has been corrected for limb-darkening effects as suggested by Neckel & Labs (1994). The employed

Proc. 1st Solar & Space Weather Euroconference, 'The Solar Cycle and Terrestrial Climate', Santa Cruz de Tenerife, Tenerife, Spain, 25-29 September 2000 (ESA SP-463, December 2000)

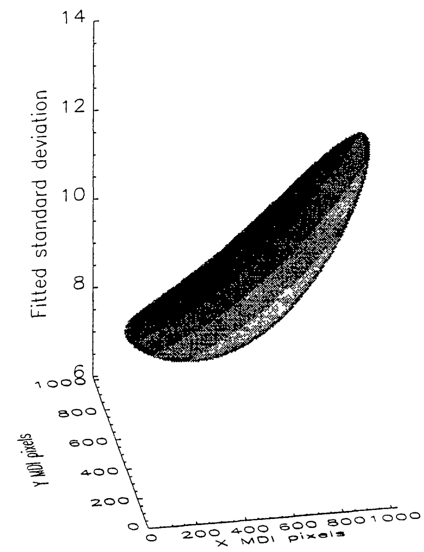

Figure 1. Standard deviation of the 5-minute averaged MDI magnetograms.

magnetograms are averages over 20 single magnetograms (taken at a cadence of 1 per minute). Intensities are standard 1-minute images; these images have been rotated to co-align with the corresponding average magnetogram. Care has been taken to use intensity images obtained as close in time to the magnetograms as possible. In almost all cases the two types of images were recorded within 30 minutes of each other. Therefore, features over the solar disk superpose on both the magnetogram and the intensity image.

We have carefully determined the noise level of MDI magnetograms and continuum images as a function of position. The standard deviation for the magnetic signal has been calculated using a running 100x100 pixel box over the solar disk, with the exception of the limbs. A surface is then fitted to the result and extrapolated to the whole solar disk. The resulting noise level shows an increase towards the SW limb probably due to velocity signal leakage. Figure 1 shows the calculated standard deviation (1 σ_{mag}) for the 5-minute averaged magnetograms. The procedure to determine the standard deviation and average of the quiet Sun intensity is similar.

Bright magnetic features are identified by setting a threshold of $3\sigma_{mag}$ for magnetic activity ($\approx$ 18 G) and $3\sigma_{Iqs}$ below the average intensity to avoid sunspots. Using both thresholds we build a mask of the contrast of bright features for each day. In each pixel, the contrast C_{fac} is defined as:

$$C_{fac}(x,y) = \frac{I(x,y) - I_{qs}(x,y)}{I_{qs}(x,y)}, \qquad (1)$$

where the subscript qs means the quiet Sun.

Pixels above the thresholds for each selected day are put together into a vector of about 6 10^5 elements, which gives good statistics of the facular and network behaviour. Contrasts, as well as limb angle $\mu = \cos(\theta)$ and magnetic flux are calculated for each point.

3. RESULTS

Figure 2 shows an example of the contrast mask mentioned above for October 12, 1999. The magnetogram (top) and continuum image (middle) show the activity present on the solar disk. The mask (bottom) shows the detected bright features. For example, sunspots near the NE limb are not evident in the mask, although it takes into account the faculae surrounding those sunspots. Smaller features belonging to the network are also pinpointed outside of the active regions.

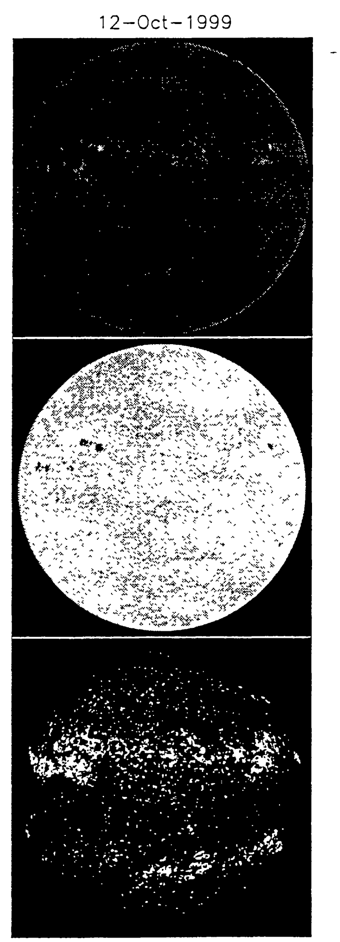

Figure 2. Top: averaged MDI magnetogram; middle: MDI intensity image; bottom: contrast mask for October 12, 1999.

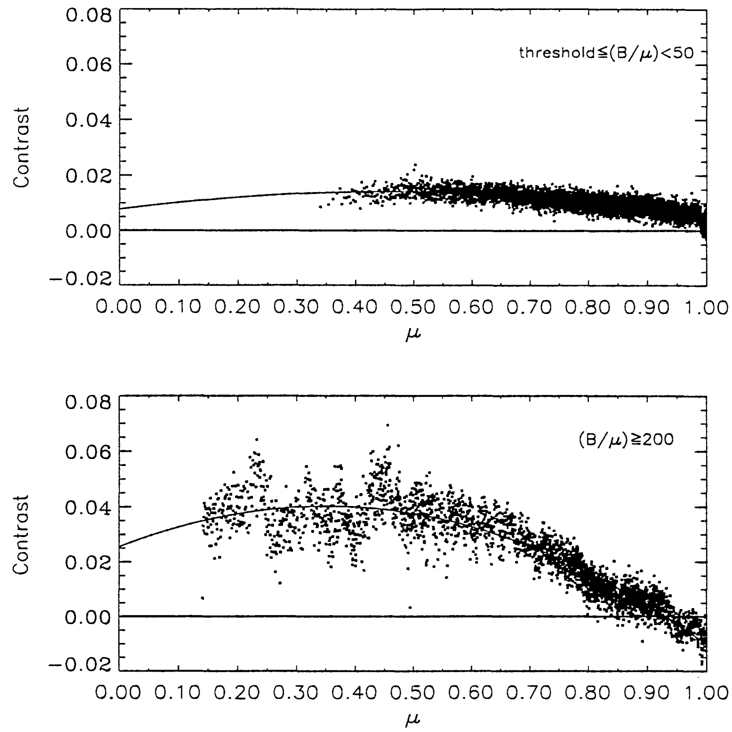

Figure 3. Facular and network contrast as a function of μ for low (top) and high (bottom) magnetic fields.

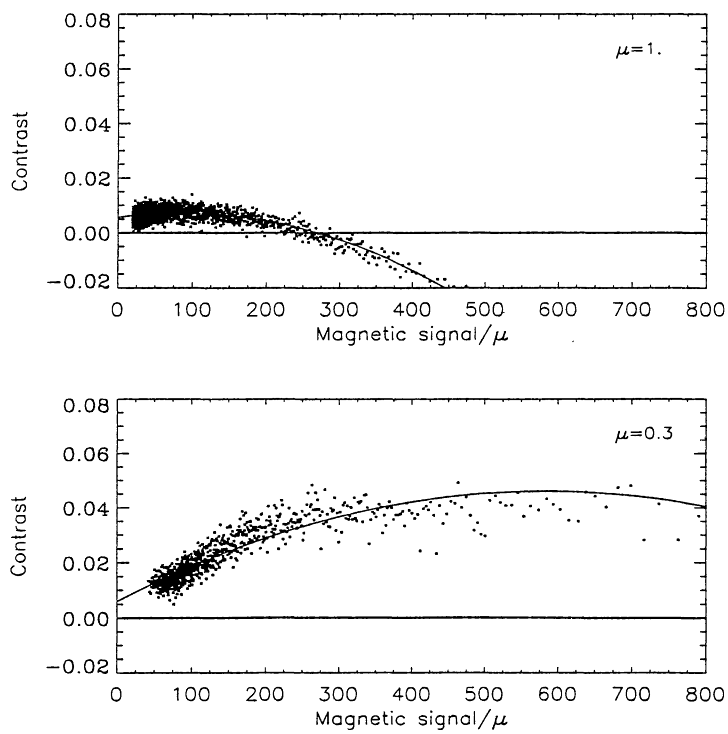

Figure 4. Contrast of "bright" features (contrast > -0.02) as a function of B/μ for $\mu = 1$ (top) and $\mu = 0.3$ (bottom).

We present the contrast dependence on μ, for different bins of B/μ, and on B/μ, for different positions on the solar disk. Representing B/μ takes account of the foreshortening effects that cause the magnetic signal to decrease to the level of the background noise at the very limb (even if regions with strong magnetic field are present). Finally, to represent this amount of data they are binned into groups of 40 pixels before plotting.

The B/μ values are binned in five intervals that range from threshold level ($\approx$ 18 G) to more than 200 G. In figure 3 we present the contrast as a function of μ, for both the lowest and highest B/μ intervals. A second order polynomial has been fitted to guide the eye and a line indicating $C_{fac} = 0$ has been added for clarity.

There are clear differences between the behaviour of the contrast in both cases, one showing features with the lowest magnetic flux per pixel (top), probably the network, the other showing features with the highest magnetic signal (bottom), probably faculae. Clearly, features within the network show a low and almost constant contrast compared to that shown by active region faculae which have a very pronounced center-to-limb variation (CLV). Note also the negative contrast around disk center seen for faculae, that becomes positive when looking at the network.

Figure 4 shows the contrast dependence on B/μ, for positions at disk center (μ=1) and at the limb (μ=0.3). The fits are also second degree polynomials. The contrast at the limb is considerably higher than at disk centre. At the limb, higher contrasts are associated with higher magnetic fields, whereas at μ=1 faculae with high fields appear dark, as in Figure 3.

4. CONCLUSIONS

The magnetic network provides an important contribution to irradiance variations that has to be taken into account in irradiance models. By binning into different magnetic fields we can distinguish between different associated bright features. The contrast of active region faculae and of the network exhibits different CLV, implying that they need to be treated separately when reconstructing variations of the total solar irradiance.

Stronger magnetogram signals (corresponding to wider flux tubes on average, see Grossmann-Doerth et al., 1994) appear dark at disk centre, but very bright at the limbs, while the weakest signals (narrowest flux tubes) are equally visible at disk centre and at the limb. This result is in good agreement with the observational results of Topka et al. (1997) and with the predictions of theoretical flux-tube models (Deinzer et al., 1984a,b; Knölker et al., 1988; Knölker & Schüssler, 1988) if there is a distribution of flux-tube sizes present on the Sun. The advantage of the present investigation relative to that of Topka et al. (1997) is that by using full disk MDI data we have a result for a well-defined spatial resolution, so that any models derived on the basis of these results can be directly used for reconstructing total and spectral solar irradiance measered by VIRGO (Fröhlich et al., 1995) without further adjustment.

REFERENCES

Deinzer et al., 1984a, Astron. Astrophys. 139, 426.

Deinzer et al., 1984b, Astron. Astrophys. 139, 435.

Fligge M., Solanki S.K., 2000, J. Astrophys. Astr., in press.

Fröhlich, C. et al., Sol. Phys. 162, 1995, 101

Grossmann-Doerth et al., 1994, Astron. Astrophys. 285, 648.

Knölker M., Schüssler M., 1988, Astron. Astrophys. 202, 275.

Knölker M. et al., 1988, Astron. Astrophys. 194, 257.

Neckel H, Labs D., 1994, Solar Phys. 153, 91.

Scherrer P. et al., 1995, Solar Phys. 162, 129.

Solanki S.K., 1993, Space Sci. Rev. 61, 1.

Solanki S.K., 1994, in *The Sun as a Variable Star: Solar and Stellar Irradiance Variations*, (ed. J.M. Pap, C. Fröhlich, H. Hudson and S.K. Solanki), Cambridge Univ. Press IAU Coll. 143, p. 226

Spruit H.C., 1976, Solar Phys. 50, 269.

Topka et al., 1992, Astrophys. J. 396, 351.

Topka et al., 1997, Astrophys. J. 484, 479.