Solar cycle evolution of the contrast of small photospheric magnetic elements

Ada Ortiz *

Department d’Astronomia i Meteorologia, Universitat de Barcelona, Martí i Franquès 1, E-08028 Barcelona, Spain

Received 27 October 2004; received in revised form 3 March 2005; accepted 3 March 2005

Abstract

Solar irradiance variations produced on the solar rotation time-scale are known to be driven by the passage of active regions while, during the last years, the origin of variations on the solar cycle time-scale has been under debate. Nowadays, there is an agreement that the magnetic network has an important contribution to these long-term variations, although it has not been fully quantified. This important role motivated us to study its physical properties along the solar cycle, such as contrast and population. We combine magnetograms and intensity images from the MDI instrument on board the SOHO spacecraft to analyze the radiative properties of small magnetic elements. We determine the contrast of faculae and network elements as a function of position over the disk, magnetic flux and time, finding that these elements exhibit a very different center-to-limb variation of the contrast. This implies that their contribution to irradiance variability is distinct. By extending this analysis through the rising phase of solar cycle 23, we conclude that the functional dependence of the contrast of small elements results to be time independent, implying that the physical properties of the underlying flux tubes may not vary with time. We decompose magnetograms into two structures identifying both faculae and network features and we examine their populations along the solar cycle.

© 2005 COSPAR. Published by Elsevier Ltd. All rights reserved.

Keywords: Solar irradiance variability; Solar cycle; Solar activity: faculae; Network

1. Introduction

The solar disk is a panoply where a whole spectrum of magnetic structures can be seen. Such concentrations of magnetic origin form a hierarchy with a wide range of sizes, field strengths and degrees of compactness (e.g., Schrijver and Zwaan, 2000). Here, I will mainly focus on the properties of small bright photospheric magnetic structures. By small magnetic structures I will refer in this work to elements with measured magnetic flux below 600 G, at the MDI/SOHO full-disk resolution of 4″. These structures may include network elements, active region (AR) faculae and probably micropores, all of which are in general brighter than the quiet photosphere.

Within active regions, faculae are tightly packed while the enhanced network appears more widely distributed. Outside active regions, the bright network patches form the quiet network, in close coincidence with supergranular boundaries. At high resolution faculae consist of conglomerates of many unresolved small bright points or facular points with diameters of about 100 km (Dunn and Zirker, 1973; Keil and Muller, 1983; Berger et al., 1995).

Two and a half decades of space-based monitoring of the total solar irradiance have revealed that it changes on time-scales ranging from minutes to the length of the solar cycle. Most of these variations arise from the changing presence and evolution of the aforementioned

* Present address: High Altitude Observatory, National Center for Atmospheric Research, P.O. Box 3000, Boulder, CO 80307-3000, USA.
E-mail address: ada@ucar.edu.
magnetic features. Variability on the solar rotation timescale is associated with the passage of sunspots and active region faculae across the solar disk (e.g., Foukal and Lean, 1986; Chapman, 1987; Lawrence and Chapman, 1990; Fligge et al., 2000; Solanki and Fligge, 2002). Irradiance records have also established a variation of about 0.1% of the irradiance in phase with the eleven year solar cycle, giving as a result a brighter Sun around activity maximum (Chapman, 1987; Willson and Hudson, 1988; Foukal and Lean, 1988; Fröhlich, 1994). During the last decade, the origin of this long-term irradiance variation has been under debate. The point was whether solar surface magnetic features alone could account for irradiance variations on the solar cycle timescale, or whether additional mechanisms of non-magnetic origin should also be considered, either based on temporal changes in the latitude-dependent surface temperature of the Sun (Kuhn et al., 1988), or based on spatial changes in the latitude-dependent non-magnetic origin should also be considered, either based on temporal changes in the latitude-dependent surface temperature of the Sun (Kuhn et al., 1988), or as a consequence of structural readjustments in the convection zone (Balmforth et al., 1996; Li and Sofia, 2001; Pap et al., 2002; Sofia, 2004). Recently, there seems to be a consensus that surface magnetic features can account for most, if not all, of the solar cycle irradiance variations (e.g., Fligge and Solanki, 2000; Solanki and Fligge, 2002; Krivova et al., 2003; Walton et al., 2003; de Toma et al., 2004). In particular, the magnetic network has been pointed out as an important contributor and some authors even tried to quantify the contribution of these small bright elements to solar variability. Foukal et al. (1991), for example, found an increase of 0.043% from minimum to maximum due to the network. They measured facular contrasts converting them into network contrasts, but did not consider the different contrast CLV presented by faculae and network. Ermolli et al. (2003), however, determined that the quiet network contributes ~0.03–0.04% during a solar cycle. Walton et al. (2003) found that faculae are responsible for 80% of solar cycle irradiance variations. Their identification methods were based on the area and latitude of the magnetic features. Nevertheless, characterizing quantitatively the network has proved extremely difficult.

Many of the models that reproduce the observed irradiance variations rely on the center-to-limb variation (CLV) of the facular contrast as a relevant input. However, the functional form of the CLV of the facular contrast remains poorly defined, being a major source of uncertainty in any estimation of the facular contribution. It is hard to evaluate the facular contrast CLV due to the complex morphology (conglomerates of unresolved bright points) and the low contrast of these features relative to the quiet Sun. In addition, their brightness signature is a function of their heliocentric angle, size, averaged magnetic field, wavelength and spatial resolution of the observation (e.g. Solanki, 1993, 1994). These difficulties have led to a widespread use of chromospheric proxies in order to represent photospheric magnetic features (such as Ca II K, Mg II k or He I 1083 nm radiation), since chromospheric plages have much higher contrast than white-light faculae (Chapman, 1987); but these layers are dominated by different physical processes than the photospheric layers. Moreover, observations are made at different wavelengths, spatial resolutions or field strengths, which makes the comparison between them difficult and contributes to the scatter between reported contrast measurements.

To circumvent some of these problems we have combined cospatial and cotemporal photometric images and magnetograms, in order to identify magnetic features more accurately by their filling factor, and to determine the contrast CLV of different structures sorting them by their magnetic field. Previous works were essentially photometric studies, that did not distinguished features by their magnetic flux (Libbrecht and Kuhn, 1984; Wang and Zirin, 1987; Lawrence, 1988; Lawrence and Chapman, 1988; Steinegger et al., 1996; Walton et al., 2003; Ermolli et al., 2003); these works may suffer a bias towards brighter features. Relatively few contrast investigations including the magnetogram signal can be found in the literature: for example Frazier (1971); Foukal and Fowler (1984); Topka et al. (1992, 1997); Lawrence et al. (1993) or Ortiz et al. (2002). We are aware that our definition of small bright features – faculae and network – differs from the definitions used in other works (e.g., Harvey and White, 1999; Turmon et al., 2002; Ermolli et al., 2003; Walton et al., 2003), since our definitions are based on the magnetic flux properties and position of the features (see Section 3.2). This leads to different results, since nomenclature problems come from the different techniques used in order to identify bright features (using either intensity images, magnetograms or a combination of both). As a result, area coverage of these features and changes over the cycle depend on the selection criteria.

As has been mentioned, the magnetic network can play an important role in the solar cycle irradiance variations, however, quantifying its relative contribution to these variations is difficult since these elements are hard to detect. This important role motivated us to study its physical properties along the solar cycle, such as their contrast and population. We therefore analyze the evolution of these magnetic elements through the rising phase of cycle 23 (from 1996 to 2001). In order to study the temporal evolution of these elements we will: (1) analyze the solar cycle evolution of the facular and network contrast and (2) quantify their populations. We use data from the MDI instrument on board SOHO (Scherrer et al., 1995). Their main advantages are that seeing effects are avoided (therefore a well-defined and constant spatial resolution is obtained), a large and homogeneous data set is available, and magnetograms and intensity images are obtained regularly by the same
instrument. The main disadvantages of the MDI data are their relatively low spatial resolution (with a pixel size of $2'' \times 2''$), the relatively high noise level of the full disk magnetograms (14 G for 1-min measurements, see Ortiz, 2003) and the single-wavelength measurements.

In Section 2, we introduce the data sets and the analysis procedures. Section 3 describes the obtained results. Finally, we discuss the results and give our conclusions in Section 4.

2. Data and analysis procedure

The SOI/MDI instrument on board the SOHO spacecraft provides, among other observables, longitudinal magnetic field measurements in full disk (FD) and high resolution modes, and continuum intensity images (see Scherrer et al., 1995, for details). The FD magnetograms are usually obtained every 96 min. Magnetograms do not measure the true magnetic field strength inside a flux tube, but its line-of-sight component averaged over the resolution element; for simplicity, we hereafter refer to this measurement as $B$.

We have analyzed a data set of MDI observations consisting of nearly simultaneous FD magnetograms and continuum intensity images, belonging to 60 days spanning from the 1996 minimum to 2001. The main characteristics of these data can be found in Ortiz (2003).

We have employed averages over 5 single consecutive intensity images, taken at a cadence of 1 per minute, in order to avoid p-mode oscillations in the intensity. Each intensity image was firstly corrected for limb-darkening effects (see Ortiz et al., 2002); then, each image was rotated to co-align it with the corresponding magnetogram before averaging. Care has been taken to use intensity images obtained as close in time to the magnetograms as possible (23 out of the 60 image pairs are exactly simultaneous). The final data set is formed by pairs of co-aligned averaged magnetograms and averaged intensity images.

Fig. 1. Sample full-disk MDI magnetograms (left columns) and their corresponding derived contrast masks (right columns), for 1997 (minimum activity) and 2000 (maximum activity). Note that only features lying above the given thresholds, i.e., selected by the masks, are indicated as black pixels.
continuum intensity images, for each of the 60 selected days, that can be compared pixel-by-pixel.

We have determined the 1-σ noise level of the MDI magnetograms and continuum images as a function of position over the CCD array, essentially following the procedure described in Ortiz et al. (2002) (see Ortiz, 2003 for more details). A fundamental aspect of this work is to perform a careful study of the temporal dependence of the MDI sensitivity and stability. This is a key point, as we intend to detect magnetic signals and intensities which are only slightly higher than the signal-to-noise ratio. Therefore, we have determined the noise levels for each year between 1996 and 2001 independently, in order to check the performance of the instrument with time (thus, not making any a priori assumption about it). The average resulting standard deviation is 8 G for the 5-min averaged magnetograms, in agreement with Meunier (2003), with a possible systematic increase smaller than 8% over the six years (she finds an increase of around 10% for the same period). This small trend, if any, means that the sensitivity of the detector remains almost constant with time. Moreover, this variation of the instrumental noise could be even smaller because the calculated standard deviations may still contain some noise of solar origin (solar magnetic fields could change significantly within a few minutes).

We have analyzed the time evolution corresponding to the mean and standard deviation of the quiet Sun intensity, $\langle I_{qs} \rangle$ and $\sigma_{qs}$, respectively, where the subscript qs denotes “quiet Sun”. Pixels with an absolute magnetic signal value below 0.5 times $\sigma_{mag}$ (where $\sigma_{mag}$ is the yearly magnetogram standard deviation) have been considered as quiet Sun pixels.

The surface distribution of solar magnetic features with a bright contribution to irradiance variations is identified by setting two thresholds to every magnetogram-intensity image pair. The first threshold looks for magnetic activity of any kind, while the second threshold masks out sunspots and pores (see more details in Ortiz et al., 2002; Ortiz, 2003). Then, for each selected day, we construct a mask that indicates the surface distribution of bright magnetic activity present over the solar disk at a given moment, as well as its associated contrast $C_{fac}$, defined for every pixel $(x,y)$ as

$$C_{fac}(x,y) = \frac{I(x,y) - \langle I_{qs} \rangle(x,y)}{\langle I_{qs} \rangle(x,y)}.$$  \hspace{1cm} (1)

Fig. 1 shows an example of FD magnetograms and their derived contrast masks for two years on the rising phase of solar cycle 23. Only features lying above the given thresholds are pinpointed as black pixels. The increase of magnetic activity during solar cycle maximum can be clearly seen. For each pixel in these masks, we derive the contrast, magnetic field strength averaged over the pixel, and its position (represented by the heliocentric angle $\mu = \cos \theta$).

3. Results

In Ortiz et al. (2002) we studied, using data from 1999, the contrasts of AR faculae and the network as a function of position over the disk, $\mu$, and magnetic signal, $B/\mu$. By sorting the magnetogram signal into different bins we were able to distinguish between the contrasts of different photospheric magnetic features. We found that the CLV of the contrast changes gradually with magnetic signal, so that elements lying at the lower and higher ends of the magnetic range – network elements and AR faculae, respectively – exhibit a different contrast CLV. These differences imply that such elements need to be treated separately when reconstructing variations of the TSI. We also obtained an empirical expression which predicts the contrast of different magnetic features as a function of both $\mu$ and $B/\mu$. Now, we consider one more variable, time, and we will analyze the evolution of these elements through the rising phase of solar cycle 23. We do it by analyzing the solar cycle evolution of the facular and network contrast and by quantifying the different small scale magnetic feature populations.

3.1. Evolution of the facular and network contrasts

This analysis is similar to that performed in Ortiz et al. (2002), except that now it extends in time. We have binned $B/\mu$ values into four intervals that range from the threshold level, set at $3\sigma_{mag}$ (where $i$ refers to each year from 1996 to 2001), to 500 G. Thus, we distinguish between the contrast CLV of magnetic features with different filling factors, by sorting the magnetic field strength into different bins.

Fig. 2 represents the contrast, $C_{fac}$, as a function of $\mu$ for different $B/\mu$ intervals during a period of solar minimum (1997, left panels) and a period of solar maximum (2000, right panels). For each interval a second degree polynomial has been fitted to guide the eye. The number of pixels in each bin is indicated in the upper left corner of each plot. The complete series, from 1996 to 2001, can be found in Ortiz (2003).

These figure reveals a clear evolution of the behaviour of the contrast between intervals. Network features (top panels) show a lower contrast, almost independent of $\mu$, while AR faculae (bottom panels) present a very pronounced CLV. Intermediate cases show a gradual increase of the contrast towards the limb, as well as an increasingly pronounced CLV. Small $B/\mu$ values (<200 G) always report a positive contrast everywhere, while it becomes negative around disk center for $B/\mu \geq 200$ G. Just looking at the number of pixels involved, it is easy to notice the increase of solar activity along the rising phase of the cycle. While the highest $B/\mu$ bins at solar minimum just contain a few points, plots are overcrowded at solar maximum (see Fig. 2).
This is a direct consequence of the growing number of active regions present over the solar disk as solar maximum approaches.

We have performed a multivariate analysis in order to obtain an empirical expression for the contrast of photospheric features, $C_{\text{fac}}(\mu, B/\mu)$, following the method detailed in Ortiz et al. (2002). Grid dimensions are $0.1 \leq \mu \leq 1$ and $24 \text{ G} \leq (B/\mu) \leq 630 \text{ G}$. The fitting applied in Ortiz et al. (2002) has shown to be still valid, as expected. The fitted function is, therefore:

$$C_{\text{fac}}(\mu, B/\mu) = \sum_{i,j} a_{ij} \mu^i \left(\frac{B}{\mu}\right)^j,$$

where $i$ runs from 1 to 3, $j$ runs from 0 to 2 and $a_{ij}$ are the coefficients of the fit. The result of these fits, for each of the six years, are surfaces of second order in position over the disk and third order in magnetic signal. As can be seen, the contrast has been constrained to go through zero when $B/\mu = 0$, the expected behaviour for the quiet Sun. Quadratic functions have already been used by other authors (e.g., Foukal, 1981) to fit the dependence of the facular contrast on position over the disk, although most of them use a function of the form $C_{\text{fac}}(\mu) = b(1/\mu - a)$ (Chapman, 1980). A quadratic function agrees quite well with the CLV proposed by the hot wall model. A cubic function has been used...
for fitting the dependence of the contrast on magnetic flux. In this case we do not have a physical reason, only the goodness of the fit with respect to other bivariate functional dependences tried and the requirement to force the contrast through zero for a disappearing magnetic signal. The fit does not encompass the same range of $B/\mu$ values each year, due to a lack of features with high magnetogram signals during the period of low solar activity. This fact can be seen in Fig. 2 by just looking at the number of pixels counted in the lower panels (indicative of strong AR faculae). Fig. 3 shows, as an example, the best-fit surface for 2000, where solar activity was reaching its maximum. We have to bear in mind that this expression is only applicable to the range of MDI parameters, such as wavelength and spatial resolution ($6768$ Å and $4''$, respectively). Other values of these parameters would result in different contrast dependences.

When comparing contrast plots derived for different years (as in Fig. 2), it can be seen that the observed contrast of small bright features does not change with time. Fig. 4 clearly illustrates this point. In this figure we have superposed cuts along the $\mu$-axis of the yearly $C_{\text{fac}}(\mu, B/\mu)$ surfaces, for every $B/\mu$ interval; different types of lines indicate different years. The curves in each $B/\mu$ interval are not arranged in any specific temporal order neither follow any pattern; therefore, we infer that there is not any temporal trend for the contrast

![Fig. 3. Polynomial surface of second order in $\mu$ and third order in $B/\mu$ obtained for a period of maximum activity (2000) from multivariate fits performed to the grid of contrasts. Dashed vertical lines project the corners of the plotted surface onto the $\mu - B/\mu$ plane.](image)

![Fig. 4. Superposition of cuts along the $\mu$-axis of the yearly $C_{\text{fac}}(\mu, B/\mu)$ surfaces, for four $B/\mu$ intervals. Thick solid lines stand for 1996 results, thin solid lines for 1997, dotted for 1998, dashed for 1999, dashed dots for 2000 and dashed dot dot are representative of 2001 results. No temporal trend for the contrast CLV may be inferred from these sets.](image)

Thus, the empirical model defined by Eq. (2) for the contrast of bright magnetic features – shortly, $\mu^2 B^3$ model – is valid for different phases of the present solar cycle and degrees of solar activity. Since the nature of the contrast CLV is related to the structure of the flux tubes making up the magnetic elements, our results suggest that the facular flux tube physical properties may not vary with time, in particular with the solar cycle.
3.2. Image decomposition and magnetic feature populations

In order to inspect the contributions to irradiance variability by specific types of small solar surface magnetic structures, we have decomposed our 60 magnetograms in two structures, namely, active regions and quiet Sun areas. For this, we have proceeded following the work of Harvey (1994); accordingly, active regions are identified in the magnetograms by evaluating the amplitude of the variations of the magnetic signal. Performing that way, we take advantage of the fact that inside an active region the magnetic field presents great fluctuations; Fig. 5 shows the result of applying this separation method to a sample magnetogram, where the contours separate the active region component from the quiet Sun component. We use this magnetogram decomposition in order to quantify the evolution of the network and facular populations. The aim of quantifying these populations is to compare their roles in the long-term irradiance variations.

As mentioned in Section 1, our definition of faculae and network differs from previous definitions used by other authors, and is based on the magnetic flux and position of the features. As a starting point we use the contrast masks, $C_{\text{fac}}(x,y)$, that identify the surface distribution of small bright magnetic features over the solar disk (see Section 2). As a result, we select magnetically active pixels which produce a bright contribution. This selection may include network elements, AR faculae of all sizes or even micropores (Topka et al., 1997). By superposing the result of these contrast masks with the corresponding magnetogram decomposition, we obtain bright magnetic features located either in active regions or in quiet Sun regions. After this separation, we consider as “network” pixels all those active bright pixels located in the quiet Sun region, in addition to those pixels within the active region component that have $B/\mu < 90$ G, in order to also take into account the enhanced network. Those pixels inside the active region component with $B/\mu \geq 90$ G have been defined as “faculae”. Therefore, pixels are classified into “network” or “faculae” depending on their magnetic flux as well as on their position over the disk. According to these definitions, network pixels are likely to correspond to weaker features spread among the solar disk, while faculae are likely to correspond to features with a higher magnetic flux, generally concentrated in the solar activity belts. This can be seen in Fig. 6, where masks showing pixels classified as “network” (marked as N) or “faculae” (marked as F) are shown for two sample days during minimum (top) and maximum (bottom) of solar cycle 23. For comparison, the corresponding magnetograms and $C_{\text{fac}}(x,y)$ masks are also

Fig. 5. Example of application of the decomposition method for separating active regions from QS areas within a given magnetogram (20 November 1999).
shown. Note that during that particular day of solar minimum in 1997, no faculae were detected by our identification technique.

Fig. 6. Top, clockwise: MDI FD magnetogram, corresponding mask showing the distribution of small bright magnetic features over the disk, mask identifying facular pixels (marked as F) and mask identifying network pixels (marked as N), for April 22, 1997 (solar minimum); bottom: same as top but for May 17, 2000 (solar maximum). Note the particular lack of facular pixels during that day in 1997, and the increase in activity from 1997 to 2000.

Fig. 7 shows the evolution of the absolute number of network pixels (●) and facular pixels (○) detected for each of the 60 selected days. The amount of facular
pixels increases from almost zero at minimum to about $2 \times 10^4$ around solar maximum, while network pixels increase from about $1 \times 10^5$ to less than $3 \times 10^5$ at maximum, showing therefore a slower growing rate. Note that network pixels are present throughout the solar cycle, while that is not the case for faculae. In addition, the number of network pixels always outnumbers those classified as faculae. This is true even at the period of maximum activity, and in spite of having a lower increase rate relative to that of faculae.

4. Discussion and conclusions

According to Pap and Fröhlich (2002), it is not known whether the center-to-limb variation of the network contrast changes as a function of wavelength, position on the disk and during the solar cycle. This is precisely the topic addressed in this work. We have seen that the contrast of small flux tubes that produce a bright contribution to the TSI depends on their position on the visible disk and on the magnetic flux, but do not vary with time. This temporal invariability had often been assumed in the past – there is no theoretical argument that implies that small magnetic features should have a different structure at solar minimum than at maximum – but had never before been verified. Ermolli et al. (2003), using Rome-PSPT images, analyze the quiet network pattern along the current solar cycle and report a network contrast change of about 0.05% along that period of time. A possible explanation for the different results is that their identification method differs substantially from ours (they only use photometric intensity images, while we combine magnetograms and intensity images), yielding different definitions for the network. In particular, the contrast change identified by these authors can be due to a change in the distribution of elements within the network component with the solar cycle.

Ortiz et al. (2002) show how the contrast CLV varies gradually with magnetic flux from network to AR faculae and to larger micropores. In fact, a 2-dimensional function has been derived that predicts the contrast of these features. The $\mu B^3$ description for the facular and network contrast is valid for different phases of the present solar cycle and degrees of solar activity, and can be introduced as an input into physical models that reproduce the spectral irradiance of faculae. To our knowledge, this is the first time such a systematic multivariate analysis to model the contrast of bright features has been made.

One of our aims was to quantify the evolution of the network and facular populations, in order to compare their roles in the long-term irradiance variations. We are aware that other workers have probably used more elaborated image decompositions, and that the results depend on the definitions of what constitutes network or faculae, which at the same time depends on the selection criteria. For example, Walton et al. (2003) defined features according to their size and latitudinal distribution in an exclusively photometric study (which may suffer from a bias towards brighter features), while Harvey and White (1999) identifies structures from magnetograms and Ca II K images, based on magnetic flux strength, contiguity, filling factor and association with sunspots. Our network definition is probably quite broad as compared to other definitions, as even elements within active regions are considered as faculae. One advantage of our method is that identifying the magnetic features is quite straightforward, but some physical properties such as lifetime or geometry are not considered here. Our results show that the network pixels outnumber facular pixels throughout the solar cycle. This is true at least for the period included in the observations, and in spite of their lower increase rate relative to that of faculae.

The ratio between the number of magnetic features at maximum relative to that at minimum increases with $B/\mu$, or alternatively with the size of the structure. For example, from Ortiz (2003) and Fig. 2, features with $B/\mu < 90$ G increase by a factor of 2.5 from minimum to maximum, while features in the 400–500 G range show a ratio of around 15 from minimum to maximum. Meunier (2003) finds a factor of 2.9 in number for fluxes below $3 \times 10^{19}$ Mx, which approximately correspond to the network, and factors between 13 and 19 for structures with stronger fields. From Fig. 7, pixels classified as network increase by a factor of 2.25 and facular pixels
by a factor of 10.5, considering that in that figure pixels are classified depending on their magnetic flux and on their position over the disk.

Meunier (2003) also investigated the properties of small magnetic elements and their dependence with size and solar activity. In that work, network patches have a corresponding magnetic flux below \(3 \times 10^{19} \text{ Mx}\). This quantity is in good agreement with the limit of 90 G chosen to separate the network from facular elements, if we consider the MDI pixel size and a filling factor of roughly 10\% for the network. We are aware that 90 G is an arbitrary value and other values could have been chosen. She finds that, at first order, structures of all types exhibit a similar increase in number with the solar activity level. The comparison with our results (see Fig. 7) is not direct, but nevertheless the variations of the number of structures versus time look quite similar, except that in our case, the network pixels always outnumber those classified as faculae.

To conclude, we want to stress that a careful analysis of the temporal response of the detector is imperative in any study of the long-term contributions of small features to irradiance variations. Of special importance is the determination of the image noise levels and of the quiet Sun intensity backgrounds.

Acknowledgements

I acknowledge financial support from the DURSI (Generalitat de Catalunya) Grant 2001 TD0C00021, from the MCyT (Spanish Ministry of Science and Technology) Grant AYA-2001-3304, and from E. Ortiz and S. Carbonell. I thank Drs. Blai Sanahuja and Vicente Domingo for their warm support and scientific guidance during my Ph.D. work.

References


