6 Summary and future perspectives

We have analyzed in detail the intensity contrast of small photospheric magnetic elements and their contribution to solar irradiance variability. Our interest focused on the dependence of the facular and network contrast on the position over the solar disk, the magnetic field strength and on its solar cycle evolution. We used photometric and magnetograph data provided by the VIRGO and MDI instruments on board the SOHO spacecraft. These data covered the rising phase of solar cycle 23, from 1996 to 2001. To perform this work, we have had to develop original procedures for data reduction because the detectors are not accessible and they continuously degrade due to bombardment by space radiation. We have derived an analytical expression that predicts the contrast of a bright feature given its position and magnetic strength. This expression is then used to resconstruct the spectral facular irradiance. We have demonstrated – at least for the analyzed period – that the contrast functional dependence on the heliocentric angle and the magnetic signal is time independent, inferring that the physical properties of the photospheric flux tubes are also time independent. We have investigated the role of the network and facular contributions to the long-term solar irradiance variations, quantifying both populations along the solar cycle.

Specifically,

Data analysis (Chapters 2, 4 and 5)

1. We have reduced data from the LOI/VIRGO and SPM/VIRGO detectors, as well as from the SOI/MDI instrument by applying our own procedures since there was no standard protocol developed for data reduction. In particular,

it is worth mentioning: an alternative method to correct the limb darkening variation with distance for LOI data, the Polar Pixel Normalization algorithm to correct data from instrumental degradation, and the procedures to calculate the noise level maps for MDI magnetograms and intensity images.

Excess facular emission from NOAA AR 7978 (Chapter 3)

2. We have evaluated the angular distribution of the excess radiance of the isolated active region NOAA AR 7978 during six solar rotations. The aging of this active region is reflected in its equivalent extent, the number of magnetic structures above a given threshold and the limb-brightening presented by its angular distribution. By means of a simple phenomenological model we have derived the angular distribution for this facular region. From this model we deduce the emission from individual facular elements.

3. Assuming a cylindrical symmetry for the facular emission of AR 7978, we calculated the total excess emission by this active region, which is $0.8\,10^{-4}$ times that of the solar luminosity at 500 nm, with the same order of values for 402 nm and 862 nm. The spectrum derived for the facular emission supports the theoretical spectrum derived by Unruh et al. (1999).

4. We have applied the function $C_{\rm fac}(\mu, B/\mu)$, derived in Chapter 4, that predicts the contrast of photospheric bright features to the case of AR 7978. We have reconstructed the relative spectral irradiance for the entire life of this region; the results show an excellent agreement with VIRGO observations, when there are no sunspots.

The contrast of photospheric faculae and network elements (Chapter 4)

5. We have used high-quality data from MDI to built up a set of ten pairs of nearly-simultaneous full-disk magnetograms and continuum images, between February and October 1999. Then, we have analyzed the dependence of the facular and network intensity contrast on the heliocentric angle and the magnetic signal. The results indicate that the CLV of the continuum contrast of these features changes gradually with the magnetic signal, such that the contrasts of AR faculae and the network exhibit a very different CLV. This result is in good agreement with the predictions of the hot wall model for flux tubes.

6. Performing a multivariate analysis of the data set, we have been able to derive an analytical expression for the facular contrast, $C_{\rm fac}(\mu, B/\mu)$, equation 4.3.

No similar work has been done before. This result is important because it is then possible to predict the contrast of a bright feature, from network and small tubes to faculae of different sizes, given its position and magnetic strength. Such expression puts also constraints on the models for flux tubes and it is now being used to improve the modelling of solar irradiance.

7. Another important result derived from this statistical analysis is that network elements are bright over the whole solar disk and that they have a high specific contrast; they dominate at at disk center, while features with increasingly B/μ dominate closer to the limb. Therefore, we conclude that their contribution to irradiance variations is significant and needs to be taken into account when reconstructing variations of the total solar irradiance.

Solar cycle evolution of small magnetic elements (Chapter 5)

8. We have analyzed a set of sixty pairs of nearly-simultaneous full-disk magnetograms and continuum intensity images spread during the rising phase of solar cycle 23, from 1996 to 2001. The study of the facular contrast shows that its functional dependence on the heliocentric angle and the magnetic signal is time independent. Therefore, we infer that the facular flux tube physical properties do not vary with time, an hypothesis until now assumed but not observationally verified.

9. Network elements increase by a factor 2.5 from minimum to maximum, while faculae increase by a factor 70. Positive variations of the solar irradiance are a direct consequence of the growing of the bright feature populations when approaching the solar maximum.

10. To derive solid conclusions about the contribution of bright small magnetic structures to solar variability, it is absolutely necessary a good and accurate determination of the quiet Sun intensity background.

11. The distribution of network, faculae and micropores can be fitted by a double power-law (below and above 250 G) as N(B/μ) $\propto (B/\mu)^{-\alpha}$. Below 250 G (low magnetic signal), α decreases as solar activity increases; for $B/\mu \geq 250$ G, the shape of the power-law does not change much with the solar cycle (i.e., α is constant). Along the solar cycle, the dominating population of small magnetic features is the network, even though the facular increase rate is much larger than the increase rate of network elements.

12. We decomposed the sixty magnetograms within the data set in two components, namely, active regions and quiet Sun network. The contrast CLV of these populations does not change with the solar cycle and is the same whether located in active regions or in the quiet Sun, probably indicating a unique physical structure of the flux tubes.

There are open issues, derived from our studies, about the contribution of faculae and network to solar variability; we plan to broach them in the next future, for instance:

- Check the validity of equation 4.3, obtained from 1999 data, through the whole rising phase of cycle 23, and use it to restore the facular spectral irradiance for any time along the solar cycle.
- Combine this analysis with the image decomposition, and restore separately the facular excess irradiance for active regions and quiet Sun network.
- Refine the method for structure separation and find a better mechanism to identify the network.
- Extend the performed analysis to the study of sunspots.