

CONTENTS

1 Introduction	1
1.1 Proposed Research	1
1.1.1 Science Plan	3
1.1.2 Specific Research Tasks	3
REFERENCES	5

The Fine Structure of Active Regions and Weak Magnetic Fields from MDI Images

PI: Judit M. Pap, Co-I: W. Dean Pesnell, Collaborator: Roger Ulrich

1 Introduction

The subject of this work is related to the LWS 2006 TR&T Focused Science Topic “*Solar Origins of Irradiance Variations*”. Measurements of solar irradiance over the solar spectrum have now established conclusively that solar irradiance varies on time scales from minutes to the solar activity cycle. Considering the solar physics and climate implications of irradiance variations, considerable efforts have been put forward to model and predict the observed irradiance changes, however, their physical origin is not yet well-understood. This research effort addresses the following three fundamental problems to better understand the physical processes by which solar magnetic activity causes these variations:

1. Origin and evolution of sunspots, active regions, and activity complexes
2. Energy balance of active regions
3. Detection and parametrization of weak magnetic fields outside of active regions

To achieve these goals, we will work with the full disk and high resolution images taken by the “Michelson Doppler Imager” (MDI) experiment on SOHO (Scherrer *et al.*, 1995). Total irradiance observations are available from the SOHO/VIRGO (Fröhlich *et al.*, 1997), SORCE/TIM (Lawrence *et al.*, 2000) and ACRIM III (Willson and Mordvinov, 2003) experiments. Solar spectral irradiance from the UV to infrared has been measured by the SIM experiment on SORCE in the 200 nm to 2,700 nm range (Harder *et al.*, 2000; 2005), while the VIRGO experiment spans the solar spectrum at selected narrow band wavelengths at 402, 500, and 862 nm (Fröhlich *et al.*, 1997). Measurements of UV irradiance are provided

by the UARS/SOLSTICE and SUSIM experiments and from various NOAA platforms.

Although the main objective is to reveal the physical origin of irradiance variations based on the three targeted research areas, this work will also help to further develop and complement currently available methods (as described by Turmon *et al.*, 2002), to analyze MDI images. In addition, it will also lead to new tools to analyze the images to be obtained by the “Heliosesimic and Magnetic Imager” (HMI) investigation on SDO, the first satellite in the series of the forthcoming LWS missions.

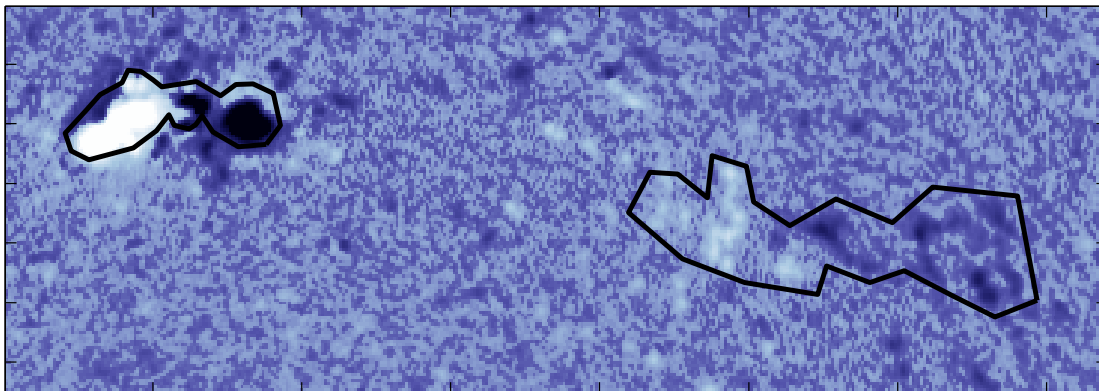
1.1 Proposed Research

When decomposing MDI images, StarTool, developed specifically to analyzing MDI images, uses both full-disk (1024^2 pixels) magnetograms (level 1.5, about 15 per day), and quasi-white-light photograms (level 2.0, about 4 per day). It handles image preprocessing, synchronization, and registration. Note that we recognized that analyzing magnetograms alone is not sufficient to correctly recognize sunspots and faculae since magnetic field values between 25 and about 400 Gauss in MDI unit may cause either sunspots or faculae (Turmon *et al.*, 2002).

In analyses to date, we have concentrated on *three specific structures: sunspots (umbra and penumbra), faculae, and background (the so-called quiet-Sun/network)*. These structures are relatively easy to identify consistently in sample images, which facilitates model selection. Figure 1 illustrates how this is done. Results of this image decomposition and irradiance changes are presented in Figure 2.

However, with the current version of StarTool and using the full disk MDI images, the weak magnetic network structures cannot be identified well, and these weaker structures are

Preprocessed Magnetogram: Detail



Preprocessed Photogram: Detail

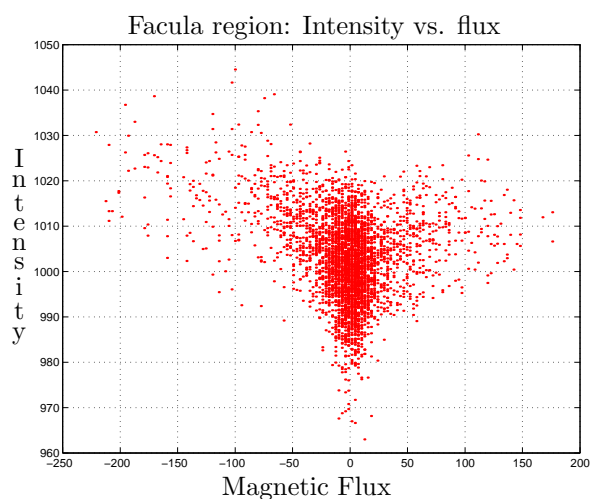
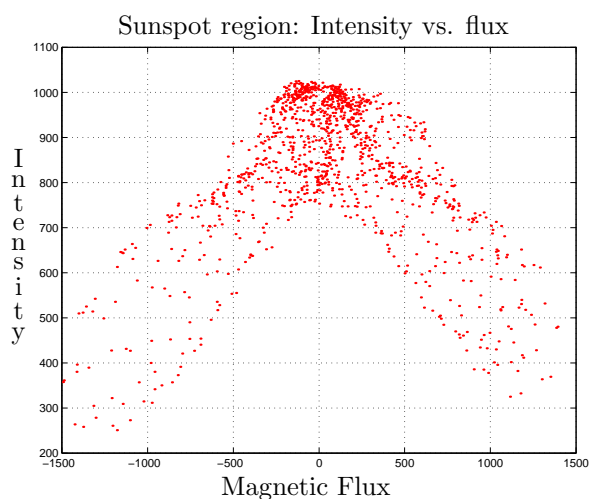
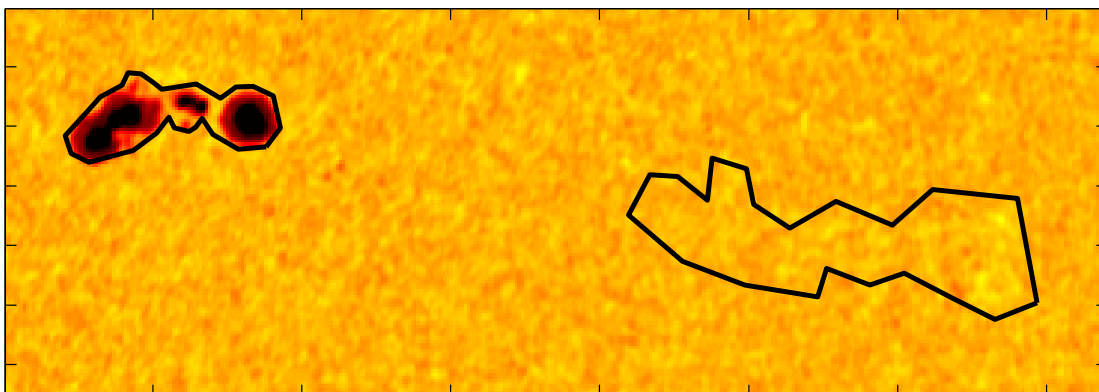


Figure 1: Synchronized full disk magnetogram and photogram, with scatter plots of sites within the two indicated regions. The top two panels are details from a magnetogram and a photogram; the photogram was taken at 17:58 UTC on September 7, 1997 and preprocessed to remove various instrumental effects; the magnetogram has been synthesized from bracketing one-minute magnetograms taken at 6:24 and 19:11 UTC on that day. The selected regions are “255×725”. The scatter plots of data for the two indicated subregions are in the bottom panels. The bipolar spot (left panel) shows clearly as having lower intensity, and the penumbra is visible at the knee of the plot. Most encouraging, the brightness enhancement of the decayed facula (right panel), far from the limb at $\mu = 0.81$, is clearly visible, increasing with magnetic flux strength. The maximum brightness enhancement amounts to about 3-4% of the nominal intensity level. They also show how various region types, here faculae and sunspots, may be identified on the basis of the joint observables, but not either alone. Plot is updated from Turmon *et al.* (2002).

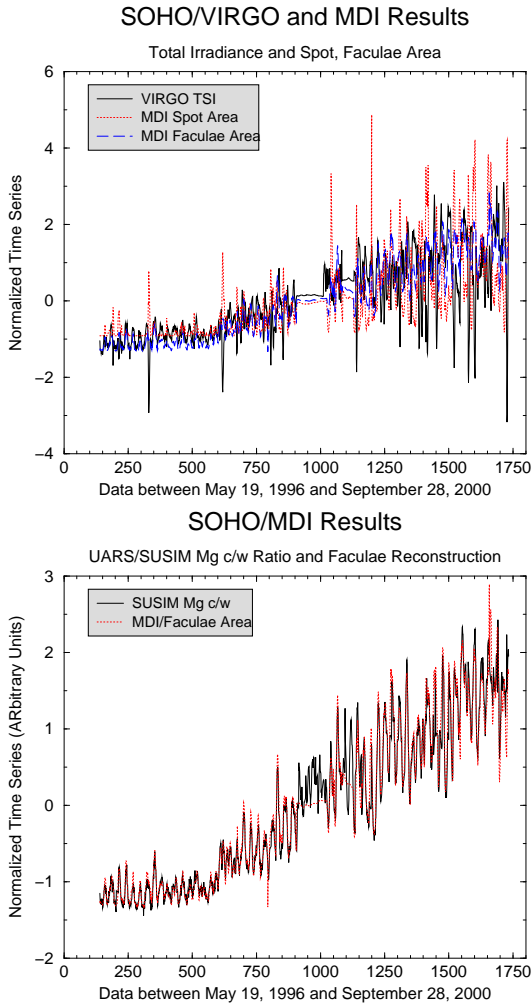


Figure 2: The upper panel shows the VIRGO total irradiance and the area of sunspots and facula; the lower panel shows the SUSIM Mg c/w and the facular areas derived from the MDI images. As can be seen, the sunspots correspond well to the temporary dips in total irradiance. Both the rotational and solar-cycle-related variations of the MDI faculae are in good agreement with those of the Mg c/w ratio, which is considered as a good indicator of the UV irradiance variability (Heath and Schlesinger, 1986; Floyd *et al.*, 2002). These results indicate that the StarTool automated image processing software provides a powerful tool to extract and characterize sunspots and faculae from the MDI images.

classified into the quiet Sun or background structures. To identify and characterize the weak network magnetic components, as a first step we need to properly define and identify the quiet Sun values. For this purpose, we apply the results gained from the “standard instrument distribution curve” technique – as used to analyze to Mt Wilson magnetograms (Ulrich *et al.*, 2002). Since StarTool uses both the magnetograms and the intensity images to extract features from the MDI images, these “*standard instrument distribution curves*” need to be derived from the continuum images as well. In this way, we can derive the necessary parameters for the quiet Sun values from the high resolution MDI images and these parameters, together with the currently available parameters for faculae and sunspots, would define the MDI weak field structures. Technically, the weak field parameters will be determined by the maximum magnetic field and intensity values of the instrument distribution curves and the minimum values for the already identified faculae.

1.1.1 Science Plan

1.1.2 Specific Research Tasks

Research Task 1: Origin and Evolution of Sunspots, and Active Regions, and Their Relation to Spectral Irradiance Variations

Within this research task, we examine the effect of sunspots and faculae on spectral irradiance at different portions of the solar spectrum as measured by SORCE/SIM, and will compare these variations to those of observed in total irradiance.

As part of the work, we will identify the sunspot-related dips and the faculae-related enhancements in the SIM spectral irradiance at various wavelength bands and will compare the amplitude of these dips relative to each other and also relative to TSI. Since radiations at various wavelengths are emitted from various parts of the photosphere and chromosphere, this in-

vestigation will give us information about the energy deficit caused by sunspots at various photospheric/chromospheric heights.

As a next step, we will examine whether and to what extent evolutionary effects play a role in the observed irradiance changes. Further, we will examine the facular areas around spots with different magnetic configurations and related irradiance dips; and we will compare the facular/spot area ratio with the amplitude of the dips as a function of wavelengths. This information will give us a further insight about the relation between the active regions evolution and related irradiance dips.

Research Task 2: Energy Budget of Active Regions and Spectral Irradiance Variations

Work on this research task will be built on the results achieved within the above-described research efforts. Study of the intensity of sunspots and faculae based on the MDI continuum intensity maps will allow us to directly compare the energy deficit due to sunspots and irradiance enhancements due to faculae. The intensity values of each sunspot and faculae within the same active region will be recorded and their energy deficit and excess flux will be calculated to estimate the energy balance of active regions. The deficit and excess flux values will be compared during the different evolutionary stage of active regions.

Integration of the sunspot deficit and facular excess flux over the lifetime of an active region will also help to clarify whether the energy blocked by sunspots is re-radiated by the faculae (Chapman, 1987) or are additional mechanisms at work to store the energy deficit due to sunspots. Therefore, study of the energy budget of active regions will provide important information about the mechanism of the formation of active regions and related irradiance changes.

Research Task 3.: Detection and Parametrization of Weak Magnetic Field Structures and Spectral Irradiance Variations

The detection and parametrization of the weak magnetic fields from the MDI images will follow the method developed by Ulrich *et al.* (2002) using the Mt. Wilson images. The actual magnetic field on the solar surface is highly inhomogeneous and the Mt. Wilson system measures only one specific function which depends on spatial averages of this field. Although the Mt. Wilson system does not attempt to achieve high enough spatial resolution for a direct measurement, this system has a high photon flux due to the large size of its critical optical elements that permits the detection of very weak magnetic fields by their diluted effect within the resolution pixel. In fact the sensitivity is such that the addition or removal of a single magnetic flux tube with properties deduced by Keller (1993) produces a detectable change in the magnetic field measured by the Mt. Wilson system. The MDI images will be analyzed in a similar fashion.

We note that according to former plans, we have combined the MDI and Ca K images from the PSPT instrument in Rome to identify the network component. Specifically, the network itself would have been identified from the PSPT (or any) Ca II K images (i.e., Ermolli *et al.*, 2003), and the Ca K network would have been extrapolated back to MDI. As a next step, the total network area and pixel intensities would have been calculated from the MDI images. Although this method is feasible (see also Ortiz *et al.*, 2002), it has a limitation, due to the fact that at this point of time we have to compare the space-borne MDI images with ground-based Ca K images which are subject to the atmospheric transparency changes, not only over time, but in many cases even during the observational sequence.

The method based on the *standard instrument distribution curves* as a reference to ideally quiet-Sun conditions, provides a completely different approach. However, cross-comparison of the results achieved by the two techniques will be necessary and it will help to validate results of other image processing programs when the network component is esti-

mated from Ca K images (e.g., Ermolli *et al.*, 2003), and will also help to clarify to what extent the method proposed here is capable to recognize and parametrize the weak network component.

References

- [1] Chapman, G.: 1987, *Ann. Revs. Astron. Astroph.* **25**, 633.
- [2] Ermolli, I., Berrilli, F., and Florio, A.: 2003, *Astron. Astrophys.* **412**, 857.
- [3] Floyd, L., Prinz, D.K., Crane, P.C., and Herring, L.C.: 2002, *Adv. Space Res.* **29**, 1957.
- [4] Fröhlich, C. and Lean, J.: 1998, In *Proceedings of IAU Symposium 185*, (ed.: F.L. Deubner), Kluwer Academic Publishers, p. 98.
- [5] Harder, J., G. M. Lawrence, G. Rottman, and T. Woods: 2000, *Metrologia*, **37**, 415.
- [6] Harder, J. W., Fontenla, J., G. Lawrence, T. Woods, and G. Rottman: 2005, *Solar Phys.*, **230**, 169–204, DOI: 10.1007/s11207-005-1528-1.
- [7] Heath, D.F. and Schlesinger, B.M.: 1986, *J. Geophys. Res.* **91**, 8672.
- [8] Keller, C.: 1993, in *The Magnetic and Velocity Fields of Solar Active Regions*, eds. H. Zirin, G. Ai and H. Wang, *Astron. Soc. Pacific*, 1993, p. 3.
- [9] Lawrence, G.M., G. Rottman, J. Harder, and T. Woods: 2000, *Metrologia*, **37**, 407, 2000.
- [10] Ortiz, A., Solanki, S.K., Domingo, V., Fligge, M., Sanahuja, B.: 2002, *Astron. Astrophys.* **388**, 1036.
- [11] Scherrer et al.: 1995, in *The SOHO Mission*, eds. B. Fleck, V. Domingo and A. Poland, Kluwer Academic Publishers, p. 129.
- [12] Turmon, M., Pap, J., and Mukhtar, S. 2002, *Astrophysical J.*, **568**, 396.
- [13] Ulrich, R., Evans, S., Boyden, J., and Webster, L.: 2002, *Ap.J., Supp. Series*, **139**, 259.
- [14] Willson, R.C. and Mordvinov, A.V.: 2003, *Geophys. Res. Lett.*, **30**, 3-1.