

**The Fine Structure of Active Regions and Weak Magnetic Fields from MDI Images
(NASA Grant NNX07AT83G)**

LWS First Year Report and 2nd Year Working Plans for Dr. Judit Pap and Dr. Luca Bertello

**by Judit M. Pap, Principal Investigator and Luca Bertello, Co-Investigator,
July 16, 2008**

Goddard Earth Sciences and Technology Center, University of Maryland Baltimore County –
Goddard Space Flight Center, Code 671.0, Greenbelt, MD 20771; Department of Astronomy,
University of California at Los Angeles, CA 90095.

The main objective of the proposed research is to carry out a comprehensive study of solar total and spectral irradiance variations, observed by the “Variability of Irradiance and Gravity Oscillations (VIRGO)” experiment in the entire spectrum and at wavelengths of 402, 500, and 862 nm. The research involves the investigation of long-term irradiance variations and activity indices as observed over the last three-decade. For this reason we have used the PMOD and ACRIM total irradiance composites, the composite Mg c/w ratio, the long-term Kitt Peak full disk magnetic field and CaK measurements, 10.7 cm radio flux and the sunspot number. In addition to the VIRGO experiment, the SOHO/SEM instrument has provided data in the 1 to 50 nm broad-band and at 30.4 nm spectral line. Additional spectral data are available from the Solar Irradiance Monitor (SIM) on SORCE. The research has been a collaborative effort between UMBC, UCLA and the SORCE team through Dr. Judit Pap (PI, UMBC), Professor Roger Ulrich (Collaborator, UCLA), Dr. Luca Bertello (Co-Investigator, UCLA) and Dr. Jerry Harder (Collaborator, LASP, University of Colorado at Boulder), SORCE/SIM instrument scientist. The research has also built upon results gained on the PI’s former SOHO/GEST investigator program on evaluating MDI images and efforts at UCLA to compare the MDI and Mt Wilson magnetograms.

Specific science questions of the project involve to (1) study the evolution of sunspots, active regions and activity complexes; (2), the energy balance of active regions; and (3) detection and parametrization of weak magnetic fields outside of active regions. Science question number (3) has gained of high interest considering the peculiar solar cycle 23 and the behavior of solar irradiance both at the maximum and minimum of the weak solar cycle 23 compared to the previous two cycles. Specifically, it has been found that both total and UV irradiances were high during the maximum of weak cycle 23 when both the number and size of active regions (sunspots and faculae) were smaller than during the last cycles, pointing to the role of additional mechanisms/features contributing to irradiance variations. We note that the Mg c/w ratio, derived from the observations at the 280 nm UV wavelength, has been considered as a good proxy to describe the effect of UV irradiance variations in the 165 to 300 nm as well as a good proxy for the effect of faculae and the bright network on total irradiance. The SIM measurements, however, have shown that the behavior of spectral irradiance at 250 and 304 nm is different from that of the Mg c/w ratio. Furthermore, the PMOD total irradiance continued to decrease toward the minimum of cycle 24 below the value of the last two minima, while the ACRIM composite still shows a slight increase (0.004%) from the minimum of cycle 21/22 toward the minimum of cycle 23/24. We also note that in the ACRIM composite, specifically in the ACRIM III data, there is a strong yearly variation which is not present in other datasets.

Similar to the behavior of the PMOD total irradiance, the combined KPVT and SOLIS full disk magnetic field data have shown a very deep decrease toward the minimum of cycle 24, while all other

indices like the CaK index, Mg c/w ratio and sunspot number did not reach their minimum level. While in total irradiance the decrease seems to be real rather than instrumental; the question whether the low magnetic field strength data toward the minimum of cycle 24 is instrumental and/or real solar effect is still subject of investigation. In addition to the different behavior of various activity indices during the maximum of cycle 23 as compared to the former cycles, the weak cycle 23 produced highly active regions during the declining portion of cycle 23, producing the largest observed dip in total irradiance with an amplitude of 0.5%. The peculiar behavior of solar indices and irradiances at both the maximum and minimum of cycle 23 has shown that new ways and new indices are necessary for modeling total irradiance.

Study of relations between sunspots with complex structure (delta and gamma/delta configurations) and irradiance variations started as well. The PI's former analyses showed that the temporary dips in total irradiance are related to the occurrence of sunspots with complex structures (gamma-delta and delta magnetic configurations). Analysis of the SORCE/SIM data also show that certain sunspots cause deeper dips in both total and spectral irradiances (Fontenla, private communications). It has been established that these particular spots, especially with delta magnetic configuration, produce X-ray flares pointing to their importance to space weather studies. Since 1996-98 period is the minimum and the rising portion of cycle 23, this interval is of particular interest of locating individual sunspots causing the temporary dips in total and spectral irradiance.

Part of the first year effort was to outline and set up the research collaboration between different groups. The first LWS NASA-group meeting took place in December 2007 at the AGU meeting, where the PI and scientists from the San Fernando Observatory developed a coordinated research effort to execute the proposed research. These results were presented at the first independent LWS focus team meeting in Boulder, Colorado, July 22-23, 2008 (as presented on the website <http://solar.physics.montana.edu/irradiance/>). Working plans have been finalized with scientists from University of California, Los Angeles and LASP/University of Colorado (Drs. Jerry Harder and Juan Fontenla). As part of this effort, Dr. Luca Bertello of UCLA will be part of the research team as Co-Investigator and the allocated funding in the approved proposal will be sub-contracted to him through the University of Maryland system. These efforts, on one hand, will improve the calibration of the MDI images and target research question (3), i.e., to identify and estimate the role of the network in the long-term variations in total irradiance. On the other hand, comparison of the SIM and VIRGO irradiances at the overlapping wavelengths will be important for data validation as well as to extend the spectral irradiance times series at the VIRGO wavelengths back to 1996. We note that within the first year, the PI organized and carried out the "Solar Variability, the Earth's Climate and Space Weather" workshop at Bozeman, Montana, June 1-6, 2008, which was funded by LWS, SCOSTEP/CAWSES and IHY. The PI has worked also on the design of a book entitled "Solar Variability and the Sun-Earth System", to be published by Cambridge Univeristy Press. The PI had presented two poster papers at the LWS Workshop in Boulder, CO, September 2007 and at the AGU 2007 meeting on total and spectral irradiance variations as well as spectral irradiance variations including the SEM EUV data. The PI also contributed to one of the SDO Data Center proposal and during the first year period she has become a NASA-approved Co-I on HMI. Related to this project, seminars have been presented at the National Solar Observatory at Kitt Peak, Goddard Space Flight Center and UCLA. A review paper, based on this material is being completed.

Work Plans for the 2nd year:

Following the structure of the original proposal, the second year's work will also be divided into technical and science parts.

(a) Technical Part:

The MDI instrument provides, among other products, a series of high-spatial resolution (1024×1024) magnetic images once every 96 minutes with unprecedented temporal coverage. Although the MDI system producing the magnetogram series has a number of excellent qualities: high temporal continuity, high spatial resolution and regular temporal cadence, the magnetic field determination is based on filtergrams that cannot treat all spatial points in the same way. The spectral line displacement for differing states of polarization is measured from four samplings of the line profile making it possible for there to be cross-talk between overall line velocity and the derived magnetic field strength. The solar physics group at UCLA has performed an extensive comparison between MDI and the well calibrated Mount Wilson Observatory (MWO) magnetograms.

This study at UCLA has provided a solar disk position-dependent scale factor converting the MDI magnetograms to the MWO $\lambda 5250\text{\AA}$ scale. In particular, we found that the MDI magnetograms gauss levels are systematically lower than the MWO $\lambda 5250\text{\AA}$ by a factor of about 1.7. This study has also shown that, while this scale factor is quite stable over time, it does show a slight dependence on the center-to-limb angle with a difference in the scale factors between the west-side and the east-side. This distortion may come from the angle dependence of the Michelson filters in the MDI instrument, with an additional contribution from scattered light. Although the current analysis is able to produce a spatial mask that can be applied to the MDI magnetograms to correct for these effects, some steps in this calibration process need to be re-addressed. In particular, the application of a saturation factor to the MWO magnetograms used for the calibration of MDI has been recently questioned.

Within the *second year of the effort* we will investigate the nature of this correction, which significantly affect the proper calibration of the MDI magnetograms. We note that comparing the MDI sunspot area data with the sunspot area data derived at the Heliophysical Observatory at Debrecen, Hungary, has also shown that there is an east-west asymmetry in the derived sunspot data, and the used image analysis program (StarTool, Turmon, Pap, and Mukhtar, 2002) tends to mix facular and sunspot pixels close to the solar limb. We expect that the above-described calibration procedure will improve considerably StarTool. This investigation will be conducted using new observations and a detailed analysis of the line shape effects produced by the magnetic field. This analysis will include also the proper determination of the zero point offset in the MDI magnetograms, which is critical for the determination of the weak magnetic field distribution.

(b) Science Investigation, 2nd Year

- (1) Comparison of the derived sunspot and facular areas as used in the former work with the sunspot and facular areas after calibrating the MDI images as described above (by J. Pap, L. Bertello).
- (2) Continuation of the relation between irradiance variations and morphology of active regions (by J. Pap, J. Harder, J. Fontenla).

Within this task we will separate the gamma/delta and delta spots for the SOHO time interval, and study relations between the occurrence of these spots and dips in both total and spectral irradiance as measured by VIRGO and SIM. During the LWS Focus Team meeting in Boulder (July 22-23, 2008), Jerry Harder and Judit Pap developed a plan to compare the corresponding SIM and VIRGO spectral irradiances.

- (3) Parametrization of active regions (sunspots and faculae) will also be part of the study of the second year of the project. Our former results (1st year of this project and the SOHO Guest

Investigator Program) have shown that the threshold for faculae when extracting them from the MDI images were quite different for the period of 1996-1998 than for 1996-2003. These results point out that we need to distinguish between various phases of the solar cycle when processing images and identifying active regions. This effort will include the study of the change of contrast of both sunspots and faculae as a function of (1) their position, (2) evolution, and (3) phase of the solar cycle. While the MDI images does not allow this analysis, the images taken at the San Fernando Observatory will allow the study of changes of facular and sunspot contrast. This particular part of the proposed research will be a collaborative effort with Dora Preminger of SFO through a group proposal of Dr. Dibyendu Nandi of Montana State University (Dora Preminger being Co-I on that proposal). Exchange of image and time series analysis programs will take place after the Boulder Group Meeting in July 2008.

(4) Work on the network identification will start in the 2nd year after the proper correction of the MDI images and correction for the zero level of the images as outlined in the original proposal (by L. Bertello and J. Pap).

(c) Work Responsibilities

The *2nd year of work* will be a collaborative effort between Dr. Judit Pap, Dr. Luca Bertello as well as collaborative effort with various groups within the NASA LWS Focus Team, led by Dr. J. Klimchuk. In the original proposal, we have included a research associate and after the lifted budget constraints University of Maryland will subcontract the allocated amount (as included in the original proposal approved by NASA) to Dr. Bertello at UCLA. The UCLA Budget and Dr. Bertello's commitment are attached.

Dr. J. Pap, will be responsible for the overall project and will work on the tasks as shown above. The calibration of the MDI images will be the responsibility of Dr. Bertello, and he will also be participating in various specific tasks as outlined above.