ISSI International Research Team Proposal on:

"Relationship between Solar Magnetism and Irradiance"

Abstract

The relationship between elements of the photospheric magnetic field and photospheric irradiance is the basis of most studies of solar irradiance variability, but in spite of much published work and many workshops on solar variations there is not yet a consensus on the experimental phenomenology. On the theoretical side considerable progress has been achieved, but there are still many open questions. The major open question is the relative contributions of surface magnetic variability and global changes to irradiance variations on various time scales. Since understanding the drivers of solar irradiance is a fundamental to interpreting the paleoclimate models which indicate climate change on the Earth, establishing the proper relation between solar magnetism and irradiance is one of the highest priorities in solar research. The ISSI research team, composed of instrument scientists, data analysis experts, and solar theorists, will produce a coherent description of the influence of the photospheric magnetic field on the solar irradiance, based on our best present knowledge. Now that Nimbus-7, several ACRIM, and VIRGO measurements have been carried out for over two and a half solar cycle and the new SORCE mission has become operational, this is a perfect time for such an initiative. The different data analysis methods historically applied to irradiance imaging and magnetograms (image processing, parameter calculations) will be compared and consensual empirical models produced. Recent numerical simulations of theoretical models on magnetic field structures and their effect on the newest irradiance measurements will be applied to the problem. The experimental work will concentrate on solar cycle 23 data. Our team includes the experimentalists who best understand these instruments and the resulting data sets, and the theoreticians with the most recent developments.

1 Scientific rationale

There is a clear direct correlation between photospheric magnetism and irradiance; among the earliest published work on the subject is Willson et al. (1981), in which the strong correlation between 0.2% decreases in solar irradiance and the passage of a large sunspot group across the disk was noted. There is now a consensus there is a direct correlation between photospheric magnetism and irradiance and it is "almost" proven that photospheric magnetic field is the sole cause of solar irradiance variations on timescales shorter than one solar cycle (on time scales of days to several months). The explanation of longer time scale variations is less clear. We are also still far from having a satisfactory description of the physics that relate magnetism and solar irradiance, either theoretically or experimentally. A goal of the program proposed here is to establish an observational and theoretical framework that will allow extrapolation of the available irradiance measurements to the longer time scales needed for application to paleoclimate records and forecasting.

During the last 20 years there has been significant progress both in the observation of magnetic fields in the photosphere and on the study of total solar irradiance, spectral irradiance, and localised sources of irradiance variation through photometrical imaging. A significant part of solar cycle 23 is being observed by several instruments that provide information with state-of-the-art techniques (by SOHO, ACRIMSAT, and SORCE in space, and by ground based observatories at San Fernando Observatory/CSU Northridge, PSPT / Hawaii and Rome, the Kitt Peak SOLIS project, and others). There are several studies that attempt to evaluate the influence of photospheric magnetic elements on the solar irradiance, yet there are significant apparent discrepancies in the results obtained. Recently several studies on the effect of faculae and network on solar irradiance have published results (Preminger et al., 2002, Krivova et al., 2003, Walton et al., 2003, Ermolli et al., 2003) with significant differences in their conclusions. It is interesting to note that the definition of faculae and network is not quite the same in the quoted papers. A question of fundamental importance is the cause of longer term, secular changes in solar irradiance, which are the most interesting for climate studies.

The new sensitive magnetometers are now able to detect magnetic signals over a large fraction of the solar surface, i.e., outside the active regions and the network appearing in routine magnetograms (e.g., Kitt Peak mag. or MDI). (See, e.g., Dominguez Cerdeña et al., 2003) The existence of this complex but ubiquitous magnetism will become even more evident with the advent of modern space borne magnetographs (Solar-B or Sunrise), thus it will be mandatory that we understand the role of the ubiquitous magnetism for the solar irradiance variations.

A second unanswered observational question is the amount of variability in each wavelength. Unruh, Solanki and Fligge (1999, 2000) and Fontenla et al. 1999 combine model spectra of solar features with information on the area coverage of sunspots and faculae to predict the integrated solar flux spectrum at various stages of the solar cycle. The spectral irradiance variations from space now being made by SORCE/SIM should help clarify these questions, which are important in understanding the effect on Earth. However, computations of radiative transfer through three dimensional magnetic structures is still in an early state, despite of the success of such models in reproducing sensitive observations of bright points in molecular bands (Schüssler et al 2003). It is fair to say that a quantitative understanding of the relation between magnetic field and brightness is still hampered by the fact that it depends critically on the size of the magnetic structures, of which the distribution is poorly known. On the theoretical side, significant advances are being made on several fronts. Three dimensional magnetohydrodynamic simulations (Emonet and Cattaneo 2001) and realistic 3-D compressible radiation-MHD simulations (Vögler and Schüssler 2003; Stein and Nordlund 2002) relevant to magnetic features have recently been carried out.

A new generation of instruments is being assembled to operate during solar cycle 24, such as SDO, Solar-B, Picard, SUNRISE, Solar Orbiter (solar cycle 24 or 25), GREGOR telescope, and these will improve our observational data set, but will not of themselves provide the needed relation between irradiance and magnetic field. We propose to put together a baseline description for this relation now, which will be good preparation for the proper exploitation of the new generation of observations.

2 Aim

The team will meet in an effort to find, from the experimental point of view, a consensus on the present knowledge of irradiance versus photospheric magnetic field properties, taking into account:

a) Photospheric intensity, including effects of spatial or angular resolution of the observations, wavelength, continuum and line contribution, angular distribution of the emission or centre to limb variation, and stray light

b) Magnetic field structures, including type, size, evolutionary information, and vectorial structure.

c) Total solar irradiance (TSI) measurements, including discrepancies in absolute accuracy and relative changes in the space-borne instruments.

d) High resolution spectral radiance and moderate resolution irradiance spectra.

e) An estimation of the influence of the inter-network fields.

The above work can be done both observationally and from a theoretical point of view. Given the intensities and the number densities of various solar features, one can estimate their contributions to the total irradiance. In addition, spectral synthesis in numerical models may provide more information on the influence of solar surface features on the irradiance.

The meeting(s) will be used to compare the different restoration methods of full disk images used by the community. These restorations include elimination of stray-light effects that, if not properly considered, underestimate the effects of local magnetic field concentrations on the irradiance measurements (sunspot look brighter and plages look darker).

We will concentrate on solar cycle 23 data in order to limit the observations to well known instruments. The team will produce an agreed upon set of internally consistent observational results, and with explanations in case of discrepancies. As a result of this research effort we will suggest what and how future measurements should be done, and understand the limitations of the current data.

From the theoretical point of view we will review where we stand on solar atmosphere models, on magnetic field structures and their effect on irradiance, and the progress to be effected. Of fundamental importance is the role played by the new generation of MHD simulations and what they teach us about solar irradiance variations. The following tasks will be part of this effort:

a) Carry out a sequence of local (8 by 8 Mm, say) simulations with varying amount of magnetic flux through the computational box, thus covering the range between "quiet" Sun and strong plage. Prescribe the specific entropy of the fluid entering the box from below, but not the energy flux, so that the latter can develop according to the developing magnetic structure. Analyze the results after a statistically stationary state has developed:

1)outgoing total energy flux (integrated over angle), frequency-integrated and in a number of continuum bands

2)Center-to-limb variation (CLV) specific intensity frequency-integrated and in a number of continuum bands

3)CLV of specific intensity in photospheric spectral lines.

The simulations will be compared with observations with the aim of quantifying the contributions of regions with different amount of magnetic flux to total and spectral irradiance variability.

b) Consider the center-to-limb variation (CLV) of the emission of individual magnetic features in simulations:

1) flux tubes and sheets
2) plage/network elements
3) pores

Again, frequency-integrated quantities and spectral information will be obtained separately.

c) Carry out non magnetic and magnetic simulations with enhanced convective energy flux at the bottom of the box. Consider again CLV of integral and spectral fluxes, compare with observations and with the results under a). The aim is to try to distinguish between radiance variations caused directly by magnetic surface features and by a change of convective transport properties (perhaps localized in regions of enhanced emergence of magnetic flux).

In addition to these studies of the crucial effects taking place at the Sun's radiating surface, possible effects with origin below the surface (e.g. Spruit 1991) should be revisited with an up to date assessment of their importance.

Besides individual articles presented in the sessions we shall produce two or three multi-authored review articles summarizing the results of the team research, at least one that will make the point on the experimental results, and another that will try to harmonize experimental measurements an theoretical models. The format will be agreed at an early phase of the project.

References

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3 Reasons for choosing ISSI as implementation site

One of the major factors blocking progress in this field is that the scientists analysing irradiance data and those studying solar magnetic fields are generally situated in two communities. Bringing these together is one of the main aims of this activity. The team activity will bring together theorists and experimentalists that will exploit the data sets and solar atmosphere models installed at ISSI during their sessions. These people work in separate institutes in Europe and the USA, and ISSI is an excellent common ground to bring them together.

ISSI is, almost by definition, the ideal environment to perform the coordinated data analysis and of the various data sets obtained by space instruments aboard several spacecraft (i.e. SOHO, ACRIMSAT, SORCE, possibly TRACE), and also by ground based observatories (PSPT in Hawaii and Rome, San Fernando, Kitt Peak, Tenerife VTT and perhaps the Swedish telescope of La Palma). The team members will compare their image processing techniques, and will provide the deduced magnetic field and intensity data of various structures (sunspots, faculae, network) as input parameters to the participating theoreticians. The theorists will demonstrate how their models attempt to describe the measurements and show what parameters need to be measured to understand the underlying physics. The results will be a firm basis for the future space missions SDO, Solar-B, PICARD, and SUNRISE on the way to Solar Orbiter.

Few individual groups have sufficient mass for internal cross fertilization such as required for this proposed understanding of the Sun, and this ISSI team will bring together specialists from around the world to enable the desired interdisciplinary sharing of ideas and methods. The ISSI study team will be a unique occasion to achieve cross fertilization on a larger scale.

4 List of participants (Brief CVs appended)

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5 Schedule of the project (number and duration of meetings, anticipated periods, participants if different from full team, etc).

Two initially planned sessions, about one week long: autumn 2004 and autumn 2005, with an intermediate session in spring 2005 if ISSI finance and planning allows. The intermediate session may be replaced by internet conferencing: second and/or third session formats to be decided at the first session.

Possible dates: 23-27 August 2004 or 11-15 October 2004, 6-10 June 2005, 26-30 September 2005, to be fixed once selected by consensus among team members and in agreement with ISSI planning.

Session 1:

1) Overview of TSI, photospheres intensity and magnetic measurements with detail on each instrument. Comparison of results and methods on instrument-by-instrument basis. Indicate solar atmospheric layer sampled. Cross-check definitions of network, faculae, pores, sunspots, magnetic elements, active regions. Choose periods of simultaneous observations with good data from each instrument. Create sub-groups to distil individual TSI, magnetic, and active region composite records for solar cycle 23.

2) Overview of theoretical and phenomenological models and numerical simulation: solar atmosphere, magnetic field in the photosphere: static and dynamic properties. Interpretation of the rich phenomena revealed by realistic 3-D simulations. Presentation of the models and define tasks to perform in data analysis to achieve a good understanding of them, and to provide a guideline for future observations.

Session 2:

Present phenomenology of magnetic causes of irradiance variations. Give limitations of correlations and phenomena unexplained by current comparisons of composites. Give interpretation of comparisons revealed by 3-D simulations. Define specific areas benefiting from observational or modelling improvements.

Consider what models and observations might be appropriate for longer term irradiance versus magnetic comparisons to address secular TSI changes. Start draft of papers giving results of models comparing irradiance and magnetic composites.

6 Facilities required (Computer equipment, access to data basses,)

Computers for data and model handling: programs and compilers: IDL, other TBD
Data and model storage space, TBD.
Access to several solar data databases.

7 Financial situation and requirements from ISSI

We would like to request that ISSI provides accommodation for about 12 team members, two times one week, and a few days of specially invited guests over a period of 12 months. We are 16 members and so far four team members can support themselves, but the other 12 would only be able to pay their travel. We envisage at the moment two sessions, but we may request, after the first session an additional session with partial attendance, if the financial conditions at ISSI allow, or otherwise held some internet conferences between.

Appendix A. Addresses, telephone, fax, e-mail of all participants.

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Appendix B Brief CV's of participants (in independent mail attachments).

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