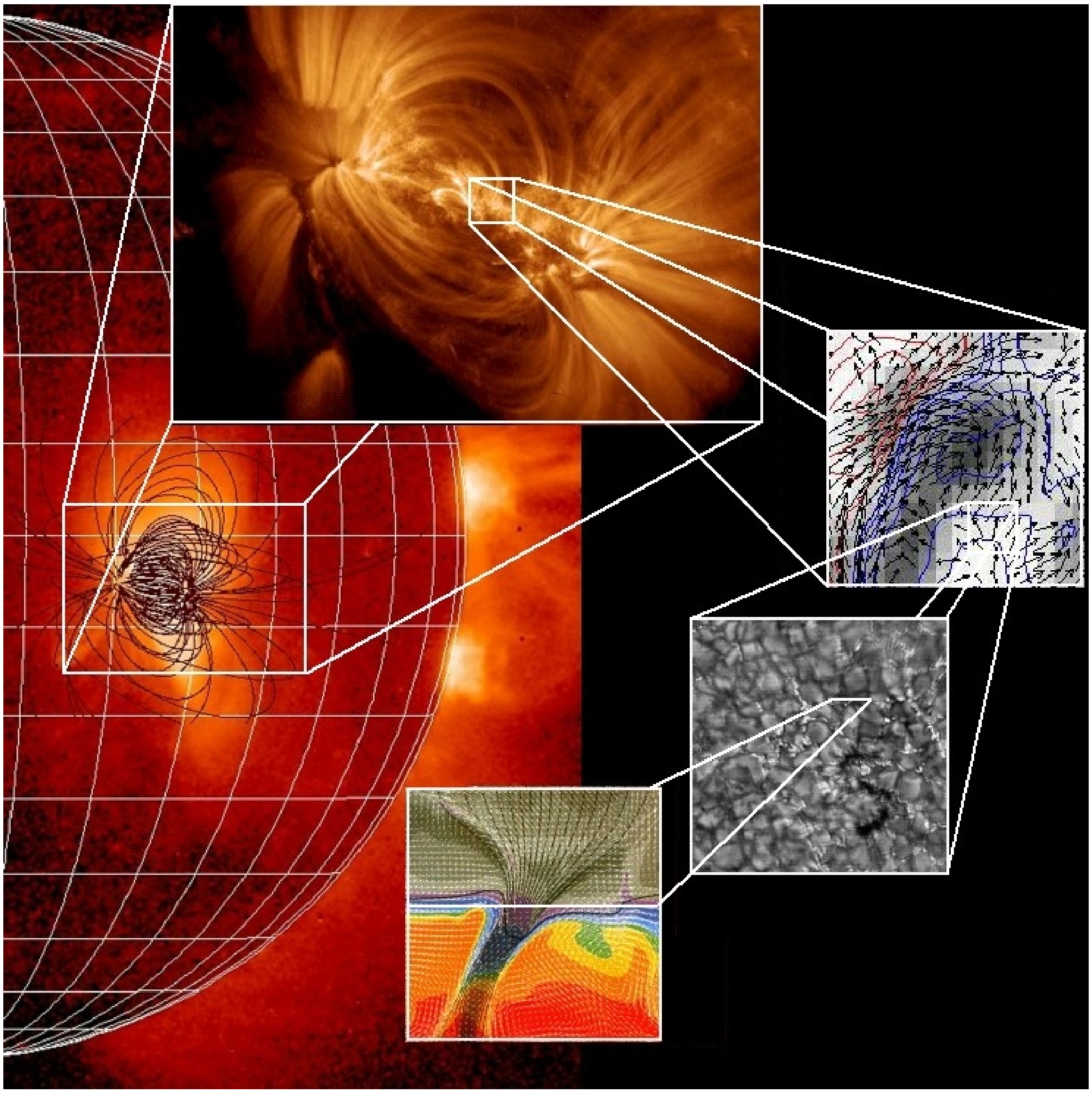
High-Resolution Solar Magnetography from Space Beyond Solar-B



Science Definition Workshop

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Summary of the Science Definition Workshop,
"High-Resolution Solar Magnetography from Space: Beyond Solar-B"

1. Introduction

A Workshop on "High-Resolution Solar Magnetography from Space: Beyond Solar-B", hosted by NASA/Marshall Space Flight Center (MSFC) and the University of Alabama in Huntsville (UAH), was held at the National Space Science and Technology Center (NSSTC) in Huntsville, Alabama from 3-5 April 2001. This report summarizes the purpose, content, and conclusions of the Workshop.

As the Workshop was held the Japan/US/UK Solar-B Mission was on schedule for launch in 2005. The primary goals of the Solar-B Mission are to advance our understanding of the origin of the corona, the outer solar atmosphere, and to study the coupling between the fine-scale magnetic structure at the photosphere and the dynamic processes occurring in the corona. Solar-B will carry the largest (50 cm aperture) visible-light solar telescope flown to date. This telescope, in combination with its focal plane magnetographs and imagers, will provide the first, high spatial resolution (subarcsecond) vector magnetograms uncontaminated by atmospheric seeing. It will make the first continuous sequences of the vector field with spatial resolution down to 0.25 arcsec (180 km) over a field of view covering the area of several supergranules [$(100{,}000\ \mathrm{km})^2$]. Also with this field of view, it is capable of making sequences (frame rate of a few seconds) of images of the photosphere and chromosphere with spatial resolution of 0.2 arcsec (150 km) throughout.

With the development of Solar-B well underway it is appropriate to identify the science objectives for the next high-resolution solar magnetography mission after Solar-B. This process was begun by NASA's Sun-Earth Connection Roadmap exercise of 1999-2000, which identified the need for this mission but did not define the science objectives in detail. Since then, two new initiatives, NASA's Living With a Star (LWS) and NSF's Advanced Technology Solar Telescope (ATST) have increased the need for sharper definition of the science rationale for space-based solar magnetography having resolution and sensitivity beyond that of Solar-B.

As the Huntsville Solar Group has considerable interest in a mission to follow Solar-B they, with the encouragement of NASA Headquarters, took the initiative to organize the Workshop addressed by this report. The Workshop brought together leading solar scientists (see Appendix D: Participants) who are active in solar physics research that is connected with high-resolution magnetography and who could represent the national and international solar physics community. The chief aim of the Workshop was to establish whether a consensus on the need for a high-resolution magnetography mission beyond Solar-B exists, and if so what aspects of the magnetic Sun the mission should address. Not surprisingly, there was unanimous agreement on the need for such a mission. But, at the outset, it was not obvious that a unified set of mission objectives would be agreed upon, and by deliberately including a wide range of topics the outcome was deliberately left open. However the Workshop did yield a consensus on the central objective for the new mission, an answer that was somewhat unexpected. The conclusions of the Workshop contained in this report are intended to provide an input to the next Roadmap exercise, in 2002-03 and as the justification for Science and Technology Definition Studies for the new mission.

2. Content of the Workshop

The science focus of the Workshop was centered on the interplay between convection and magnetic field within a tenth of a solar radius above and below the photosphere (roughly from the depths of supergranules to the heights of active-region coronal loops). Current research across this regime was reviewed in seventeen invited papers. The presenters were asked to identify the critical science questions that will in all likelihood remain unanswered at the end of the decade, and the observational improvements in the measurements of magnetic fields and of magneto-convection that will be needed to answer these questions. The intent of the organizers was to use this process not to define the next high-resolution solar magnetography space mission, but to lay the science foundation for the mission study, which will come later.

Over the two and a half days of the Workshop, a wide range of topics at the cutting edge of solar physics research were reviewed through invited talks from experts followed by extensive discussion within the group. Rather than having a series of review talks on broad solar physics topics such as coronal heating or the solar-cycle dynamo the Science Organizing Committee (SOC) decided to have a core agenda that focussed on current "hot topics" relevant to high-resolution magnetography. The 17 hot topics are listed in the first column of Table 1, in the order in which they were presented (for the list of presenters, see Appendix B: Agenda).

For each topic, the speaker was asked to address four generic questions:

1. What is the science problem and why is it important? (Relation of the specific topic to big questions and broader topics of solar physics, such as the global dynamo, luminosity modulation, coronal heating, flares/CMEs, etc.)
2. What do we know now? (Recent progress; why the topic is hot)
3. What should we expect to learn from Solar-B and ATST?
4. What fundamental problems will remain after Solar-B and ATST that will require high-resolution observations from space?

Following each talk the moderator guided the discussion along the same lines. This format proved to be very effective. The lively and extended discussion periods added considerably to the overall success of the Workshop and enabled the group to reach consensus on the critical science questions and needed observational advances for solar magnetography from space "beyond Solar-B".

Table 1. Workshop Science "Hot Topics" and their Interrelation

<table>
<tr><th>All
Topics</th><th>Regime of
Magnetic Activity</th><th>Directly Involved
Topics</th></tr>
<tr><td rowspan="3">Spectrum of convection
P-mode generation by convective collapse
Intranetwork magnetic fields
Small-scale dynamos
Sunspots
Elementary flux tubes & Sun's luminosity
Emergence & disappearance of magnetic flux
Magnetic carpet
Elementary flux tubes & coronal heating
Transition-region moss
Explosive events in the network
Magnetic nulls
Magnetic helicity
Sheared mag. fields, flares, & CMEs
Magnetography in chormosphere & TR
IR coronal magnetogaphy
Magnetic field extrapolation</td><td>Fine-scale magnetic fields & convection in the photosphere (granular & intergranular scales, ≤ 1000 km)</td><td>Spectrum of convection
P-mode generation by convective collapse
Intranetwork magnetic fields
Small-scale dynamos
Sunspots
Elementary flux tubes & Sun's luminosity
Emergence & disappearance of magnetic flux
Magnetic carpet
Elementary flux tubes & coronal heating</td></tr>
<tr><td>Fine-scale magnetic structure & activity in the chromosphere & transition region (network lane width & smaller scales, ≤ 10,000 km)</td><td>Intranetwork magnetic fields
Sunspots
Emergence & disappearance of magnetic flux
Magnetic carpet
Elementary flux tubes & coronal heating
Transition-region moss
Explosive events in the network
Magnetic nulls
Magnetography in chromosphere & TR
Magnetic field extrapolation</td></tr>
<tr><td>Large-scale magnetic structure & activity (supergranlar & larger scales, ≥ 10,000 km)</td><td>Sunspots
Emergence & disappearance of magnetic flux
Transition-region moss
Magnetic nulls
Magnetic helicity
Sheared mag. fields, flares, & CMEs
IR coronal magnetography
Magnetic field extrapolaion</td></tr>
</table>

Each of the 17 topics is involved with the Sun's magnetic activity. So, the topics are of course interrelated, especially where they concern the same scales and levels of the solar atmosphere. It was recognized from the outset, and underscored as the discussion of the topics progressed, that there is a strong coupling of all scales of the Sun's magnetic activity. Table 1 and the collage on the cover of this report emphasize this overarching aspect of the magneto-active solar atmosphere. The second column of Table 1 breaks the range of scales and heights covered by our 17 topics into three regimes: the fine-scale photosphere, the fine-scale chromosphere and transition region, and all larger-scale aspects regardless of height. For each of these regimes, the third column of Table l lists the subset of our topics that directly involve that regime. The overlap of the three subsets is a direct indication of the strong coupling of the three regimes. This coupling implies that a complete understanding of the many different aspects of our magnetic Sun will require study of the entire magneto-active solar atmosphere as a single complex system.

Besides the 17 invited talks on the specific science topics, there were three invited overview talks and several contributed talks and posters. The first talk of the Workshop was an overview by Ted Tarbell of high-resolution space-based and ground-based solar observatories in the coming decade. This placed all the Workshop participants on an equal footing regarding the observational advances that can be expected and the observational barriers that will remain at the end of the decade. The final two presentations were summaries of the invited talks and discussions. The first talk, by Karel

Schrijver, presented the viewpoint from the theory and modeling side, and the second, by Christoph Keller, presented the viewpoint of the instrument developers and observers. These two talks were followed by the Workshop's final session, which was a consensus-seeking discussion of the main science drivers and the most-needed observational advances for space-based solar magnetography beyond Solar-B.

The invited speakers were requested to produce summaries of their talks in the form of an extended abstract including a figure. The presenters of the contributed talks and posters were encouraged to do the same. The abstracts are collected in Appendix C. For many of the talks, the slides shown with the talk are available on our Workshop Website: http://science.nasa.gov/ssl/pad/solar/Beyond_Solar-B.htm

3. Outcome

There was broad consensus that the overall science goal for the next high-resolution solar magnetography mission is to continue our efforts to fully understand the dynamic coupling of the magnetized solar atmosphere from below the photosphere to the outer corona. This is an extension of the goal of Solar-B, which is expected to lay the foundation upon which this next high-resolution mission will build. Moreover, there was a definite consensus that, as its foremost science objective, the next mission should advance the understanding of the interface between the interior of the Sun and its magnetosphere. In and below the photosphere, the plasma creates and controls the magnetic field, while above the interface, in the magnetosphere, the field controls the plasma. The primary focus of the next mission should be on obtaining a complete three-dimensional description of how the magnetic field and the plasma structure change across the chromosphere/transition region, where neither the plasma nor the magnetic field strongly dominates the other.

Another point of broad agreement was that much of the fine-scale structure and dynamics of the chromosphere/transition region is dictated by photospheric magnetoconvection on granular and intergranular scales. Therefore in terms of the topics listed in Table 1, "Fine-scale magnetic structure & activity in the chromosphere & transition region" was considered to have the highest science priority, followed by "Fine-scale magnetic fields & convection in the photosphere". The remaining regime, "Large-scale magnetic structure & activity" was rated third in scientific priority for the next high-resolution mission. Corresponding to the three regimes of magnetic activity of Table 1, the three main science objectives for the next mission may be stated as follows, in priority order:

1. Discover, measure, and understand the 3D magnetic structure and activity in the chromosphere and transition region on subarcsecond scales.

2. Discover, measure, and understand the 3D structure, motion, generation, and destruction of photospheric magnetic fields on granular and intergranular scales in regions of all field strengths (from the intranetwork to sunspots).

3. Discover, measure and understand the evolving/dynamic magnetic boundary conditions in the photosphere, chromosphere, and transition region that determine the free energy content and 3D form of large coronal magnetic structures and cause these fields to explode in flares and coronal mass ejections.

Based on the three main science objectives and their priority order, it was agreed that the top three observational advances beyond Solar-B needed for high-resolution solar magnetography from space are:

1. Improved/new magnetography and other spectral diagnostics of the structure and dynamics of the visible and UV chromosphere and transition region.

2. Greater photon flux (larger telescope aperture) to achieve higher spectral resolution at high spatial resolution, and hence obtain more sensitive and more accurate measurements of the magnetic field. Note this does not require the optics to be diffraction limited at the full aperture.

3. Spatial resolution of 0.1 arcsec (70 km) or better over a field of view the size of large active regions [300 arcsec (200,000 km) or larger].

In other words, the next mission should provide high-resolution magnetograms and imaged spectral diagnostics of the magnetoactive chromosphere and lower transition region. The photospheric vector magnetograms should have much better sensitivity and accuracy than Solar-B, with the spatial resolution of the ATST or better over a field of view larger than that of Solar-B.

The capability of the next high-resolution magnetography mission needs to advance beyond both Solar-B and the ATST in four major ways:

1. Measure the vector magnetic field in the chromosphere and transition region using spectral lines in the vacuum UV.

2. Greatly surpass Solar-B in spatial resolution (factor of 5).

3. Far exceed Solar-B in sensitivity and accuracy of vector magnetography (factor of 4) and in magnetography of the visible chromosphere.

4. Advance beyond ATST by achieving the 0.1 arcsec resolution of ATST or better over a much larger field of view.

Magnetography in the UV can only be done from above the atmosphere. This capability is not included within Solar-B's instrument complement. The Solar-B magnetographs will observe fields in the photosphere, will have only limited access to the low chromosphere, and will in practice have no access to the higher chromosphere or transition region. The sensitivity of Solar-B to the transverse component of the field will be no better that about 100 Gauss at 0.25 arcsec resolution, due to the photon flux limit of the 50 cm aperture telescope. The ATST is planned to have about 60 times the photon collecting area of Solar-B, and should be capable of detecting transverse fields down to a few tens of Gauss at 0.1 arcsec resolution (70 km). However the ATST will achieve 0.1 arcsec resolution through the use of adaptive optics. Consequently the field of view having this resolution will be limited to roughly the span of a supergranule or less (≤ 30,000 km). Nor is it known to what extent residual scattered light, due to lack of perfect correction of the seeing, will limit the ability of the ATST to detect small intrusions of weak field in strong fields of opposite polarity. Only a space mission can provide high-resolution (≤ 0.1 arcsec), high-sensitivity (≤ 30 Gauss, transverse) magnetograms that have perfect seeing and cover entire large active regions for days on end.

Table 2. Main Science Objectives and their Needed Observational Capabilities for High-Resolution Magnetography from Space "Beyond Solar-B"

Objective (in order of priority)	Needed Capabilities
3D structure and dynamics of the "plasmasphere-magnetosphere" interface between the photosphere and corona	• Resolve, measure, and track I, **B**, v, T, p on scales of ≤ 100 km through the high-β/low-β transition from photosphere to upper chromosphere in quiet regions (B < 100 G) and in active regions (B ≥ 100 G). • Measure line-of-sight component of **B** in the UV upper chromosphere/lower transition region.
Creation, convection, and destruction of magnetic field at ultra-fine scales in the photosphere	• Resolve,measure, and track I, **B**, v, T, p on scales of 30 km. • Detect and measure **B** in small (< 1000 km), weak (< 100 G) magnetic intrusions in domains of strong opposite-polarity flux. • "Space truth" test ground-based adaptive-optics vector magnetography at scales ≤ 100 km.
Magnetic boundary conditions in the photosphere, chromosphere, and transition region and their changes that dictate the configuration and free energy of large-scale coronal magnetic fields and cause them to explode	• Produce vector magnetograms in low-β chromosphere/ transition region and in photosphere, with large FOV (>100,000 km), high resolution (≤ 100 km), and high sensitivity (< 30G, transverse). • Operate in continuous sunlight and perfect seeing for weeks or longer.

Table 2 recaps our prioritized three-regime science objectives and lists their needed observational capabilities in a little more detail. It was well recognized that the observations of the transition region, chromosphere, and photosphere from the next high-resolution magnetography mission need to be made in concert with complementary observations of the Sun's interior and corona. Many of the needed complementary observations could be provided by concurrent solar missions such as Solar Dynamics Observatory and STEREO. Figure 1 depicts the spatial resolution and spectral range needed for the next high-resolution magnetography mission and how these complement and exceed the capabilities of the forthcoming magnetography observatories, SOLIS, Solar-B, SDO, and ATST.

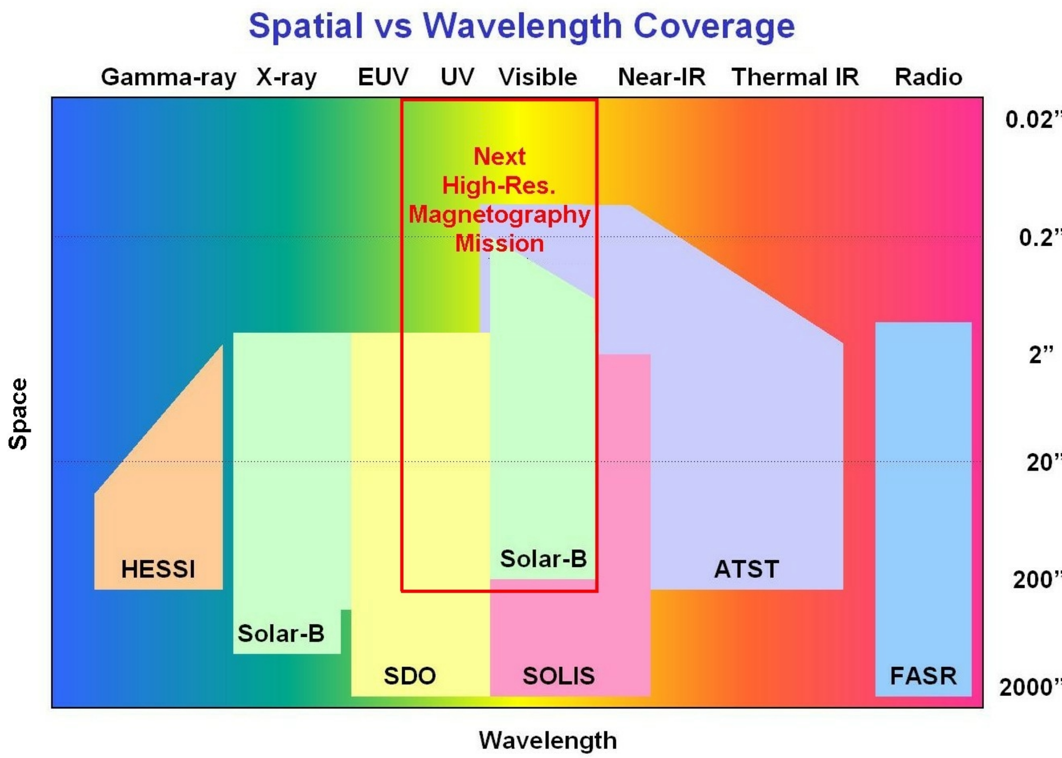


Figure 1. Depiction of two of the four major ways in which the next high-resolution solar magnetography mission beyond Solar-B needs to advance beyond Solar-B and ATST: It should (1) observe the UV chromosphere and transition region and (2) greatly surpass Solar-B in spatial resolution. In addition this mission should (3) far exceed Solar-B in the sensitivity and accuracy of its magnetography, and should (4) advance beyond ATST by achieving the 0.1 arcsec spatial resolution of ATST or better over a much larger field of view.

4. Recommendation

In view of the Workshop consensus and conclusion that (1) there is compelling scientific need for a high-resolution solar magnetography mission beyond Solar-B, and (2) this mission should focus on the 3D structure and dynamics of the magnetic field and plasma in the chromosphere and transition region, the Workshop SOC recommends the following.

1. The next high-resolution magnetography mission beyond Solar-B should be more prominently featured and more clearly defined in the next SEC Roadmap than in the last Roadmap.

2. A Science & Technology Definition Team should be assembled to establish the scientific requirements and to define the advances in technology required to make the observational goals of the mission practical.

3. The necessary technology development funding should be included in Code S budgets for FY04 and beyond at a sufficient level to prepare this mission for a new start no later than the end of the Solar-B mission, around 2010.

Appendix A: Science Organizing Committee

Tom Berger (Lockheed Martin)

Tom Bogdan (HAO)

John Davis (MSFC/NSSTC) (Co-Chair)

David Hathaway (MSFC/NSSTC)

Christoph Keller (NSO)

Jim Klimchuk (NRL)

Barry LaBonte (U. Hawaii)

Dana Longcope (Montana State U.)

Ron Moore (MSFC/NSSTC) (Co-Chair)

Doug Rabin (GSFC)

Ted Tarbell (Lockheed Martin)

Aad Van Ballegooijen (CfA)

Haimin Wang (NJIT/BBSO)

Appendix B: Agenda

Abstracts of the invited talks are in Appendix C, in the order in which the talks were presented. Abstracts of contributed talks and poser presentations are in Appendix D. In the workshop agenda below there are page numbers for the relevant abstracts in parentheses following the title.

Tuesday April 3

8:15 – 8:40 Introduction (John Davis/Ron Moore)

1st Session 8:40 – 10:00 Chair: David Hathaway

8:40 – 9:20 Topic: **High resolution observatories in the coming decade** (14)
- 8:40 – 9:05 Talk by **Ted Tarbell** (Lockheed Martin)
- 9:05 – 9:20 Discussion

9:20 – 10:00 Topic: **Spectrum of convection** (16)
- 9:20 – 9:45 Talk by **Bob Stein** (Michigan State U.)
- 9:45 – 10:00 Discussion

2nd Session 10:20 – 12:20 Chair: Christoph Keller

10:20 – 11:00 Topic: **P-mode generation by convective collapse** (17)
- 10:20 – 10:45 Talk by **Phil Goode** (NJIT/BBSO)
- 10:45 – 11:00 Discussion

11:00 – 11:40 Topic: **Intranetwork magnetic fields** (18,50)
- 11:00 – 11:25 Talk by **Rob Rutten** (U. Utrecht)
- 11:25 – 11:40 Discussion

11:40 – 12:20 Topic: **Small-scale dynamos** (19)
- 11:40 – 12:05 Talk by **Thierry Emonet** (U. Chicago)
- 12:05 – 12:20 Discussion

3rd Session 1:40 – 3:00 Chair: Tom Bogdan

1:40 – 2:20 Topic: **Sunspots** (21)
- 1:40 – 2:05 Talk by **Bala Balasubramaniam** (NSO)
- 2:05 – 2:20 Discussion

2:20 – 3:00 Topic: **Elementary flux tubes and the Sun's luminosity** (23)
- 2:20 – 2:45 Talk by **Jo Bruls** (KIS-Freiburg)
- 2:45 – 3:00 Discussion

4th Session 3:20 – 4:40 Chair: Ted Tarbell

3:20 – 4:00 Topic: **Emergence and disappearance of magnetic flux** (25)
- 3:20 – 3:45 Talk by **KD Leka** (Colorado Research Assoc./NWRA)
- 3:45 – 4:00 Discussion

4:00 – 4:40 Topic: **Magnetic carpet**

4:00 – 4:25 Talk prepared by **Alan Title** (Lockheed Martin),
presented by **Tom Berger** (Lockheed Martin)

4:25 – 4:40 Discussion

5th Session 5:00 – 6:00 Chair: Ron Moore

Contributed presentations: Brief ("one viewgraph") talks/poster plugs; movies; poster viewing

Wednesday April 4

6th Session 8:30 – 9:50 Chair: Aad Van Ballegooijen

8:30 – 9:10 Topic: **Elementary flux tubes and coronal heating** (27, 50)

8:30 – 8:55 Talk by **Han Uitenbroek** (NS0)

8:55 – 9:10 Discussion

9:10 – 9:50 Topic: **Transition-region moss** (29)

9:10 – 9:35 Talk by **Tom Berger** (Lockheed Martin)

9:35 – 9:50 Discussion

7th Session 10:10 – 12:10 Chair: Rob Rutten and Haimin Wang

10:10 – 10:50 Topic: **Explosive events in the magnetic network** (31, 44)

10:10 – 10:35 Talk prepared by **Jongchul Chae** (NJIT/BBSO),
presented by **Haimin Wang** (NJIT/BBSO)

10:35 – 10:50 Discussion

10:50 – 11:30 Topic: **Magnetic nulls** (32)

10:50 – 11:15 Talk by **Dana Longcope** (Montana State U.)

11:15 – 11:30 Discussion

11:30 – 12:10 Topic: **Magnetic helicity** (33, 46)

11:30 – 11:55 Talk by **Alexei Pevtsov** (NSO)

11:55 – 12:10 Discussion

8th Session 1:40 – 3:00 Chair: Alphonse Sterling

1:40 – 2:20 Topic: **Sheared magnetic fields, filaments, flares, and coronal mass ejections** (34, 46, 48, 50)

1:40 – 2:05 Talk by **Terry Forbes** (U. New Hampshire)

2:05 – 2:20 Discussion

2:20 – 3:00 Topic: **Magnetography in the chromosphere and transition region** (35, 54)

2:20 – 2:45 Talk by **Doug Rabin** (GSFC)

2:45 – 3:00 Discussion

9th Session 3:20 – 4:40 Chair: Jim Klimchuk

3:20 – 4:00 Topic: **IR coronal magnetography** (36)

- 3:20 – 3:45 Talk by **Haosheng Lin** (U. Hawaii)
- 3:45 – 4:00 Discussion

4:00 – 4:40 Topic: **Magnetic field extrapolation** (38, 47)

- 4:00 – 4:25 Talk by **Peter Sturrock** (Stanford U.)
- 4:25 – 4:40 Discussion

10th Session 5:00 – 6:00 Chair: Ron Moore

Contributed presentations: Brief ("one viewgraph") talks/poster plugs; movies; poster viewing

Thursday April 5

11th Session 8:30 – 10:00 Chair: Ron Moore

8:30 – 9:15 **Summary of Workshop from viewpoint of theory & modeling** (41)

- 8:30 – 9:00 Talk by **Carl Schrijver** (Lockheed Martin)
- 9:00 – 9:15 Discussion

9:15 – 10:00 **Summary of Workshop from viewpoint of instruments & observations** (42)

- 9:15 – 9:45 Talk by **Christoph Keller** (NSO)
- 9:45 – 10:00 Discussion

12th Session 10:15 – 12:00 Chair: Ron Moore

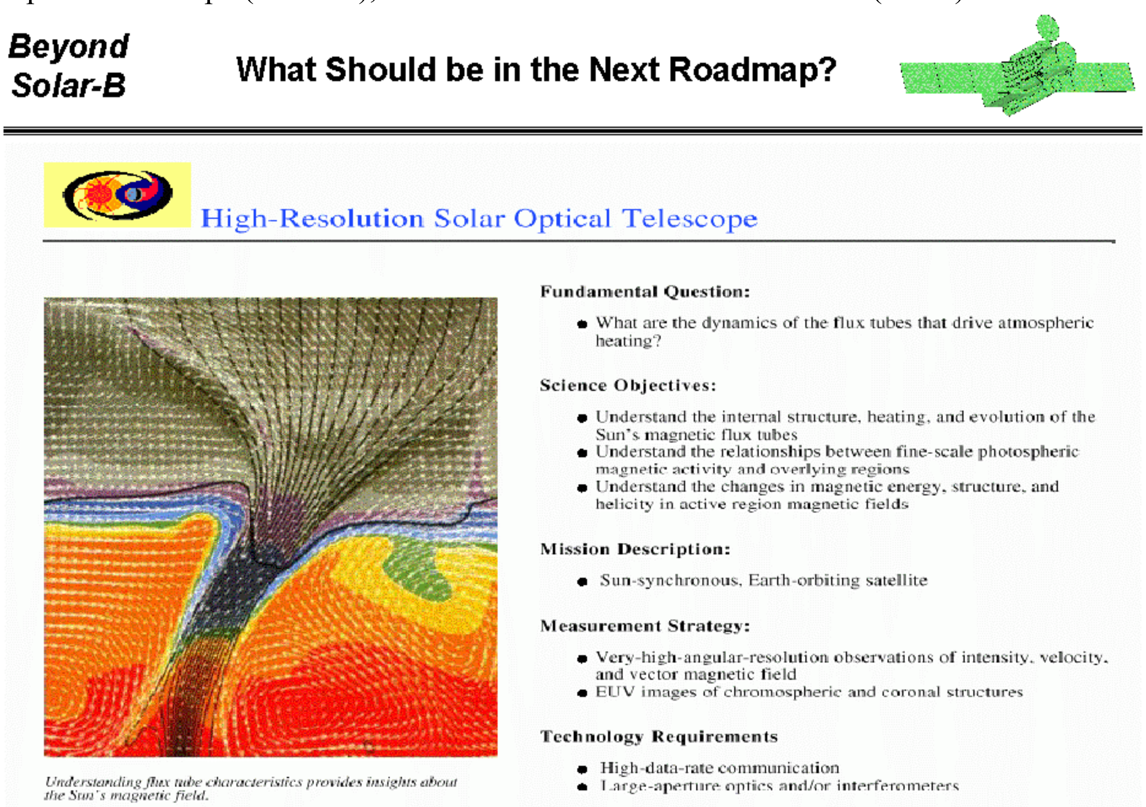
First cut at reaching consensus: discussion of answers to generic questions of Workshop.

Appendix C: Abstracts of Invited Talks (in order of presentation)

High Resolution Observatories in the Coming Decade

Ted Tarbell (Lockheed Martin)

The purpose of my talk was to acquaint the participants with some future ground-, balloon-, and space-based instruments that are being developed or have been proposed to study solar magnetic fields at very high spatial resolution. First, a summary of the Solar-B mission and its Solar Optical Telescope and Focal Plane Package was given. Then the following cast of new characters was described. Ground-based Observatories: Dutch Open Telescope (DOT), New Swedish Solar Telescope (NSST), GREGOR, Advanced Technology Solar Telescope (ATST); plus our old friends at Sacramento Peak, Big Bear, and Tenerife with new technologies such as adaptive optics and new detectors. Balloon Missions: Flare Genesis (FGE), SUNRISE. Space Missions: Solar-B, Solar Orbiter, Chinese Space Solar Telescope, Solar Lite, Solar Probe, Super-X, HIREX, DEUCE. Moderate Resolution Full Disk Observatories: Solar Dynamics Observatory (SDO), SOLIS. Sun-Earth Connections Roadmap placeholder missions: High Resolution Solar Optical Telescope (HRSOT), Reconnection and Micro-Scale Probe (RAM).



The primary goal of the workshop, in my opinion, was to produce a compelling scientific case for a future high-resolution space mission. This scientific rationale (and mission concept or at least measurement requirements) should replace the HRSOT placeholder in the next SEC Roadmap.

My list of reasons to go into space included the following: (1) perfect seeing over a large field of view; (2) excellent uniformity of observing conditions; (3) 24 hours of sunshine and good weather every day; (4) visible, UV, EUV, X-Ray, and IR Instruments in the same observatory; (5) funding which is not a zero-sum game.

Solar Surface Convection

Robert Stein, David Bercik, Dali Georgobiani, Aake Nordlund

We have performed realistic simulations of convection near the solar surface. Our domain extends 6 or 12 Mm horizontally and from the temperature minimum to 2.5 Mm below the surface. We include the effects of ionization in the equation of state and non-gray, LTE radiation transfer. The topology of convection is warm, broad, fairly laminar, diverging upflows in which are embedded cool, narrow, turbulent, converging downflows. Upflows must turnover within about a scale height in order to conserve mass and they advect all passive properties into the downflow lanes. Convection is driven by the buoyancy work of low entropy fluid produced by radiative cooling in a thin surface thermal boundary layer. The action is in the intergranular lanes. That is where the low entropy, high vorticity fluid and magnetic fields are concentrated. That is where non-adiabatic pressure fluctuations excite the p-mode oscillations. That is where acoustic events that produce shocks in the middle chromosphere are excited. That is where pores appear, typically where a ring of magnetic flux surrounds a small granule that is squeezed out of existence as the field collects. The action is also close to the surface. The magnitude of the entropy fluctuations, vorticity, turbulent pressure, p-mode driving all peak close to the surface and decrease with increasing depth. The simulations reproduce many of the observed solar features very accurately: the size spectrum of granules, the intensity distribution, the profiles of weak lines, the p-mode frequencies, energy input spectrum, line shapes, asymmetries and phases.

Our magneto-convection simulations show that the magnetic field is swept into the downflow intergranular lanes and gets concentrated to the point of pressure equilibrium with the surrounding gas. Where the field is strong, the density and temperature are reduced, flows are inhibited, the intensity is reduced, and the optical depth unity surface is depressed (a few hundred km.). Where we advect horizontal field into the domain from below, the surface field has an exponential distribution. Where we impose a mean vertical field there is a broad bump in the distribution at high field strengths. Micropores form in the simulation at vertices of the intergranular lanes. The micropores generally exist for a shorter time than the strong magnetic field concentrations. Pore formation starts with a downflow and the fluid drains downward. The Lorentz force is downward at both the beginning and end of a pores life. The net pressure plus buoyancy force is downward at the surface and upward below the surface during pore formation and upward everywhere during pore dissolution. The net force is downward near the surface and upward deep below the surface during pore formation and upward near the surface during pore dissolution.

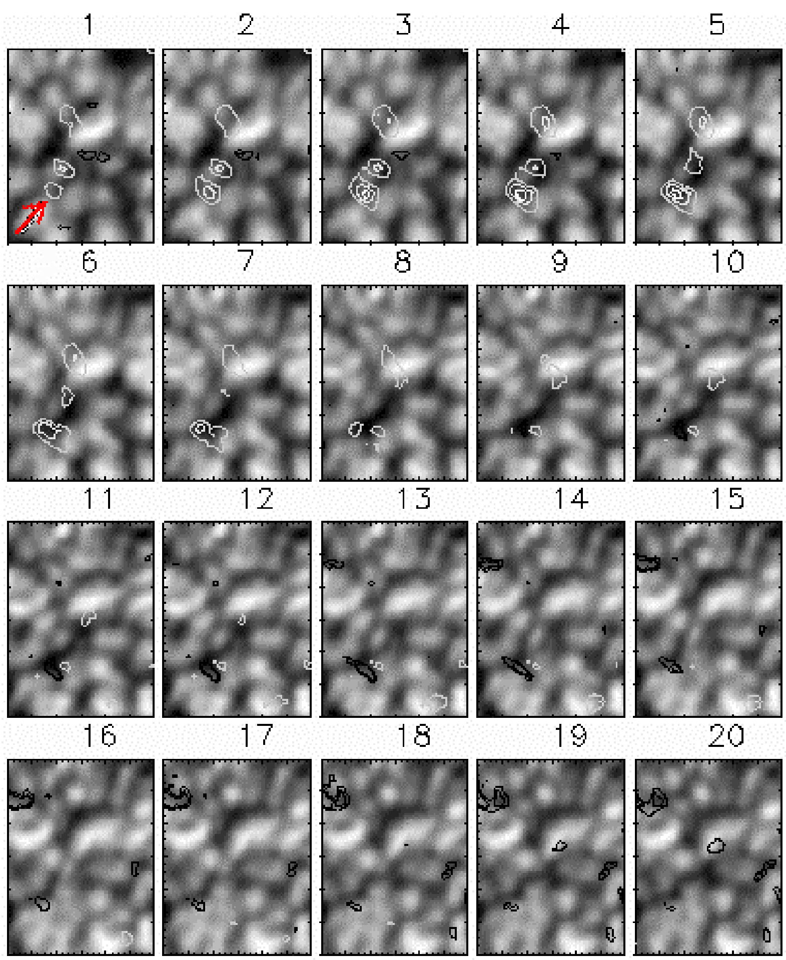
The Excitation of Solar Oscillations

Phil Goode (NJIT/BBSO)

We show that solar oscillations are excited in seismic events that occur very near the solar surface in the dark, inter-granular lanes in a process that is associated with a catastrophic collapse of the lanes in regions of vanishingly weak magnetic field. Our observations measure the velocity field at several altitudes in the photosphere, so that we can distinguish *p*-mode power from seismic event power, since both have their power in the same region of the *k*-ω diagram generally associated with *p*-modes.

This picture of the excitation is not consistent with the standard picture in which the oscillations are excited by the direct action of turbulent convection.

We compare our observational results to simulations of convection by Nordlund and Stein, and find a quite picture of the excitation. There are some differences, however, like the duration of the observed and simulated seismic events. For instance, the real events last about twice as long.

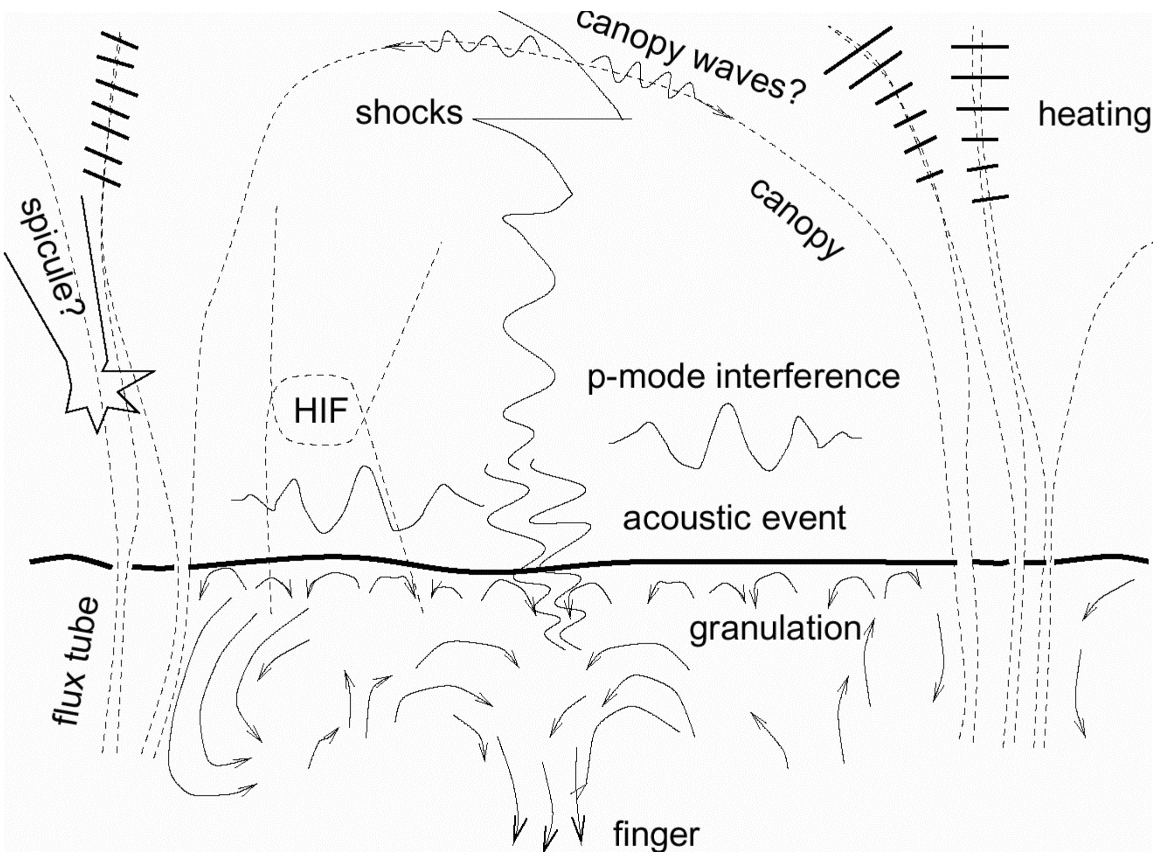


The 20 panels at the left show the time evolution, in 32 *s* steps, of seismic events superposed on the local granulation. Each frame is about 8" by 10". Each seismic event is shown as a contour plot that reveals its intensity and spatial extent. Positive (upward) flux is represented as white contours and negative (downward) flux as black. An arrow in the first panel indicates a seismic event. It begins to appear, grows and fades away after about 10 frames (five minutes), and subsequently a downward flux begins at the same location. It grows and also fades away over a few frames.

Internetwork Magnetism

Robert J. Rutten, Sterrekundig Instituut Utrecht, The Netherlands

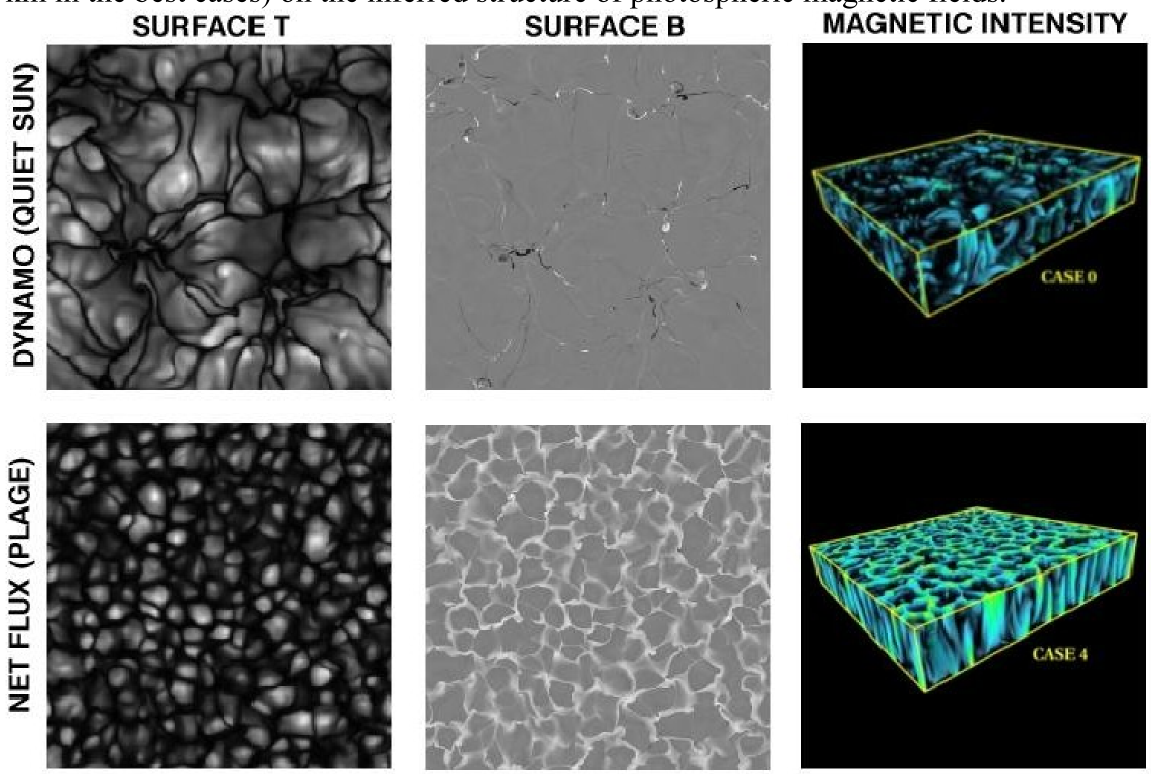
The internetwork scene characterized in the cartoon below contains many unknowns, the major one being the elusive internetwork fields. The term encompasses both magnetic elements with intrinsic field strength below the magnetostatic 1.4 kGauss concentrations ("flux tubes") that constitute the magnetic network, and diffuse fields that are not concentrated in elementary structures. Current upper limit estimates suffer from "bloom" of polarization signatures by imperfect imaging, insufficient angular resolution, insufficient signal to noise, immature diagnostics (incomplete Zeeman inversions and ill-understood Hanle depolarization) and the occasional presence of network-like elements in internetwork areas ("flashers"). It seems likely that there are magnetic fields everywhere in the solar atmosphere, but the verdict on their nature, strength and topological structure is far from in, even at the photospheric level. Higher up, the filamentary canopy structure remains largely uncharted and the connection between photospheric tubes and coronal loops is a major unknown. The latter coupling constitutes a primary research topic for future magnetometry from space.



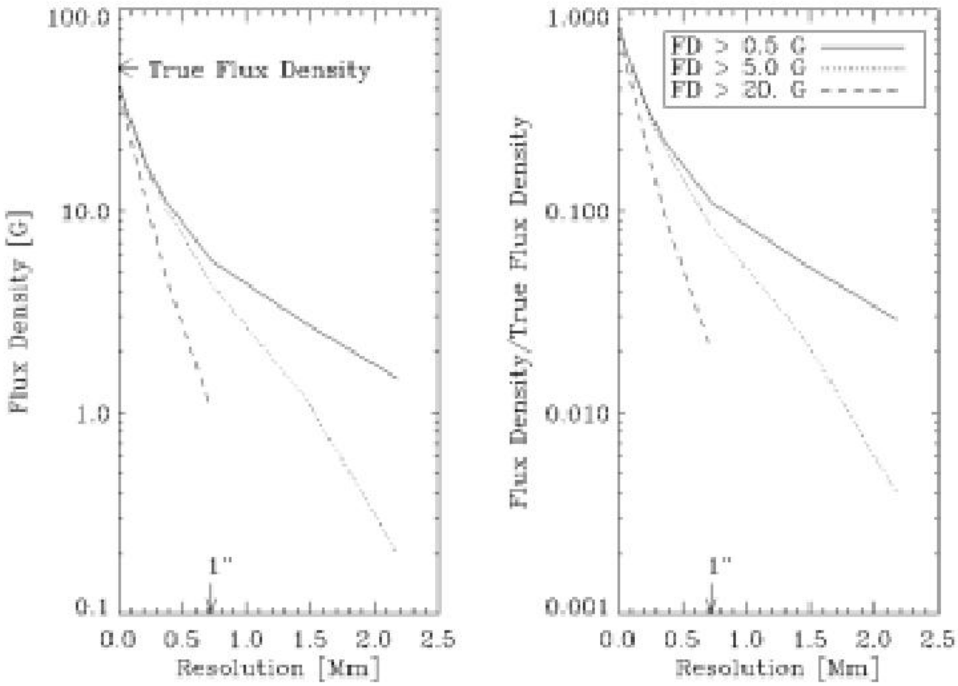
Magnetic fields in the quiet Sun and active region plage: results from Boussinesq simulations

T. Emonet and F. Cattaneo, University of Chicago

Direct numerical simulations of the interaction between magnetic fields and turbulent convection have been conducted in an attempt to obtain some insights about the structure of magnetic fields in the Quiet Sun and plage. Results will be presented for several cases where the vertical magnetic flux through the layer is increased from zero (dynamo case, i.e. quiet Sun) to values high enough to substantially affect the convective flow (plage). We compare the magnetic field in the numerical solutions with typical magnetic structures deduced from recent observations. The high spatial resolution of the numerical solutions (~10 km) is used to study the effects of limited observational resolution (~150 km in the best cases) on the inferred structure of photospheric magnetic fields.



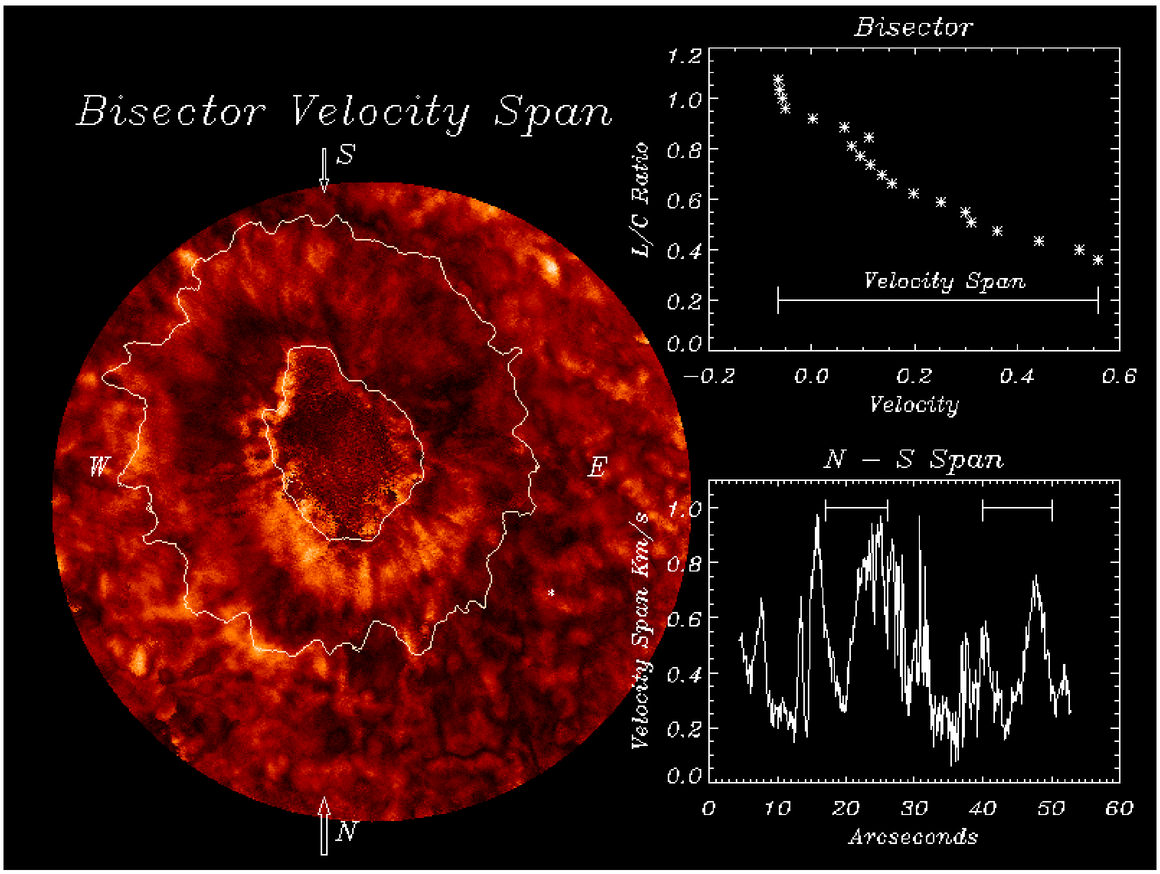
LIMITED RESOLUTION
(with J. Sanchez Almeida, IAC)



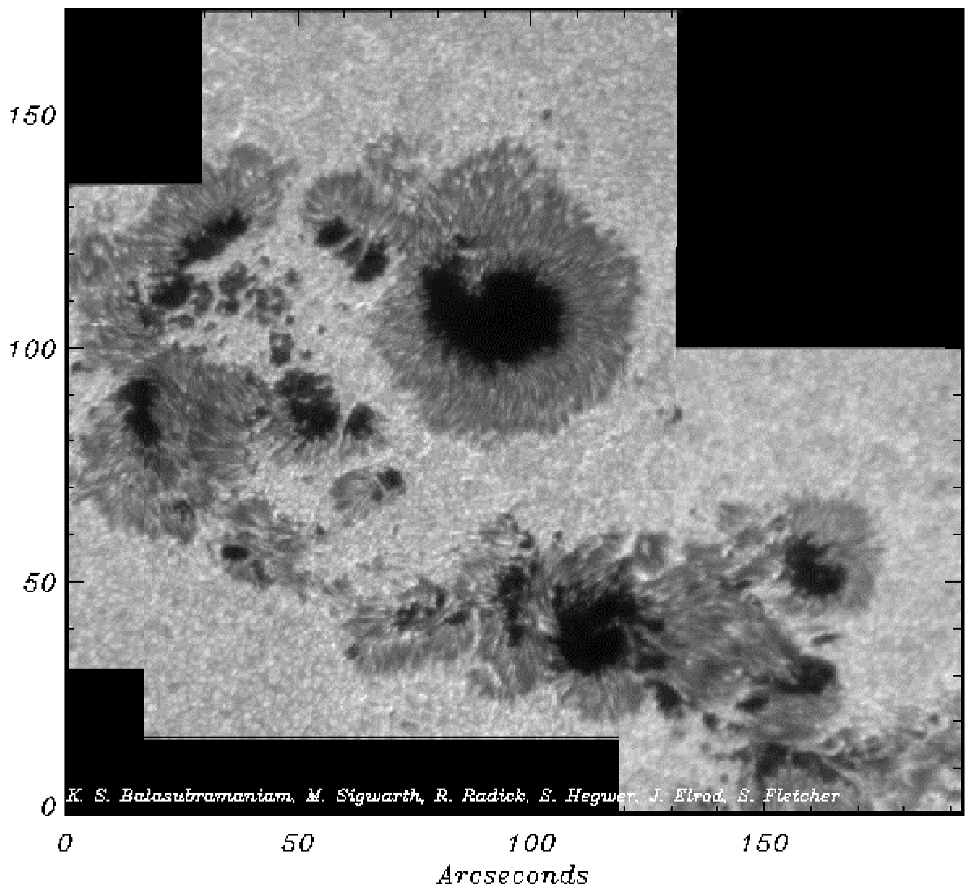
Sunspots

Bala Balasubramaniam (NSO)

Sunspots are significant signatures of the convection-magnetic field interaction in the photospheric layers. In this review I will present a perspective of the current research in on sunspots, our expected understanding of sunspots with the planned Solar-B and ATST telescopes. I will outline the needs of a future space mission beyond the present scientific issues required to understand sunspots.



Balasubramaniam Figure 1. Velocity Span of a Sunspot. A map of the depth-dependent sunspot velocity gradients derived from a non-Zeeman spectral line FeI 5576 Å. The sunspots spans about 50 arcseconds, located at N18E0, on December 19, 2000. This velocity span map was acquired thought a 20 milliangstrom dual-FP tunable filter at the NSO/Dunn Solar Telescope, with Adaptive Optics, to correct for terrestrial image distortion due to poor seeing. The depth-dependent velocities were derived using the spectral line bisectors. Notice the steep gradients in velocity in the bottom right figure at the penumbra, indicated by the horizontal extent lines.

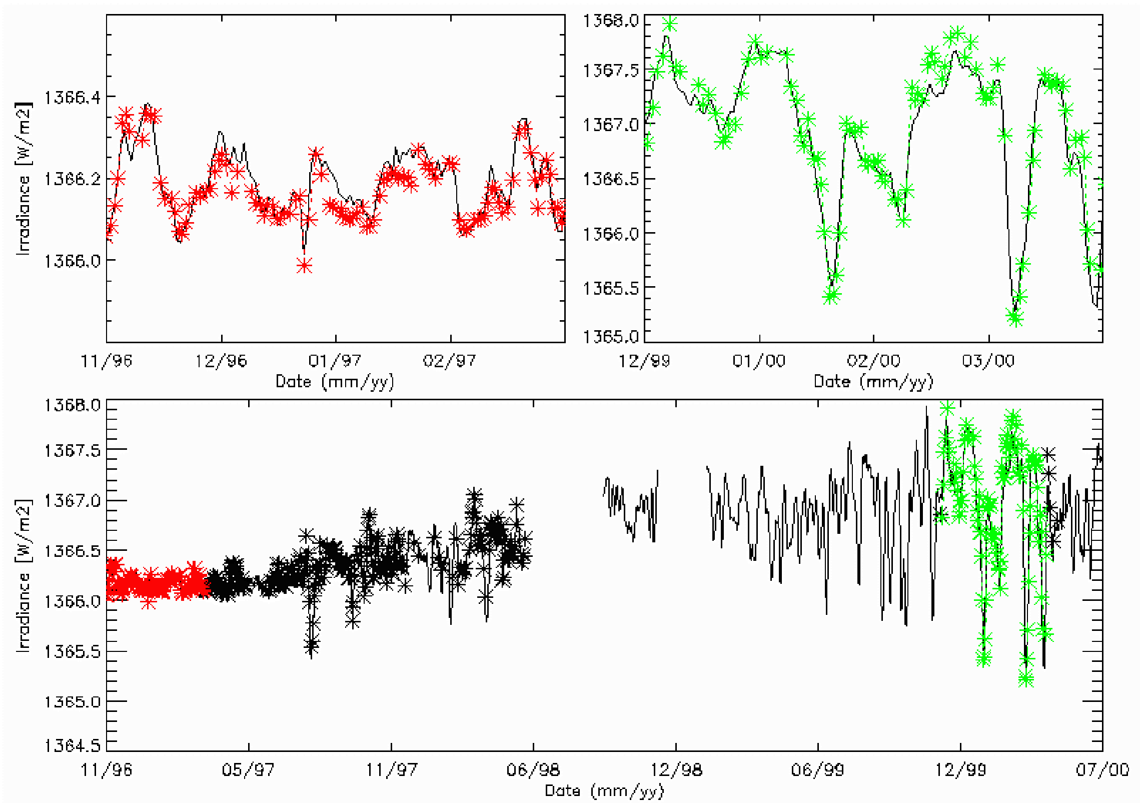


Balasubramaniam Figure 2. A complicated sunspot group illustrating why we need a large FOV space-based telescope to monitor magnetic fields at different heights in the solar atmosphere. This picture is a collage of images taken at the Richard B. Dunn Telescope, National Solar Observatory, Sacramento Peak, Sunspot, New Mexico, on March 27, 2001. This sunspot group extends over more than 140,000 kilometers. The telescope is able to resolve 0.14″ or 100 kilometers on the surface of the Sun. This reconstructed image was acquired though a complicated frame-selection process and took about 100-minutes to acquire. The corresponding Hα super-penumbral structures could extend far beyond the 300″ covered by this sunspot. Beyond the SOLAR-B and ATST Projects we will need a telescope that can measure the magnetic field and thermodynamic characteristics at several heights in the atmosphere, of an evolving sunspot group such as this.

Elementary flux tubes and the Sun's luminosity

Jo Bruls (KIS)

The remarkable success of recent reconstructions of solar irradiance variations from activity minimum to activity maximum on the basis of proxies and semi-empirical models creates the false impression that solar irradiance variations and their relation to small-scale magnetic structures have been fully understood. However, as long as our knowledge of magnetic elements is only sketchy, to a large extent of phenomenological nature and based on spatially unresolved observations, we cannot expect to fully understand solar irradiance variations either.



Bruls Figure 1. Solid curve: observed solar irradiance (VIRGO) from low to high solar activity. Asterisks: reconstruction of the solar irradiance on the basis of full-disk magnetograms and plane-parallel semi-empirical models of sunspots, faculae and the quiet Sun. Left: near activity minimum; right: near activity maximum. (Courtesy M. Fligge.)

Coordinated observations of Solar-B and ATST will contribute significantly to a better understanding of the `birth', evolution and `death' of magnetic elements, and they will vastly improve our quantitative knowledge of magnetic elements, specifically w.r.t. their size, shape, magnetic flux, field strength and geometry, `lifetimes', stabilizing agents, temperature, density, center-to-limb brightness variation across the spectrum.

By providing a more accurate measure of the irradiance variations due to magnetic elements they may confirm or reject the currently most accepted view that on short and medium time-scales magnetic elements are the sole cause of solar irradiance variations. A direct measurement of a possible non-magnetic contribution in the form of temperature or radius variations may still be out of reach, if at all possible.

Direct measurements of waves running along the magnetic elements will provide a better handle on chromospheric and coronal heating mechanisms.

A direct observation of the internal structure of magnetic elements, its variation over a solar cycle, the sub-surface structuring and dynamics of facular and network regions will be beyond the capabilities of Solar-B and ATST.

Emerging and Disappearing Magnetic Flux: Recent Progress and Prospects

K. D. Leka, Colorado Research Associates Div., NorthWest Research Associates

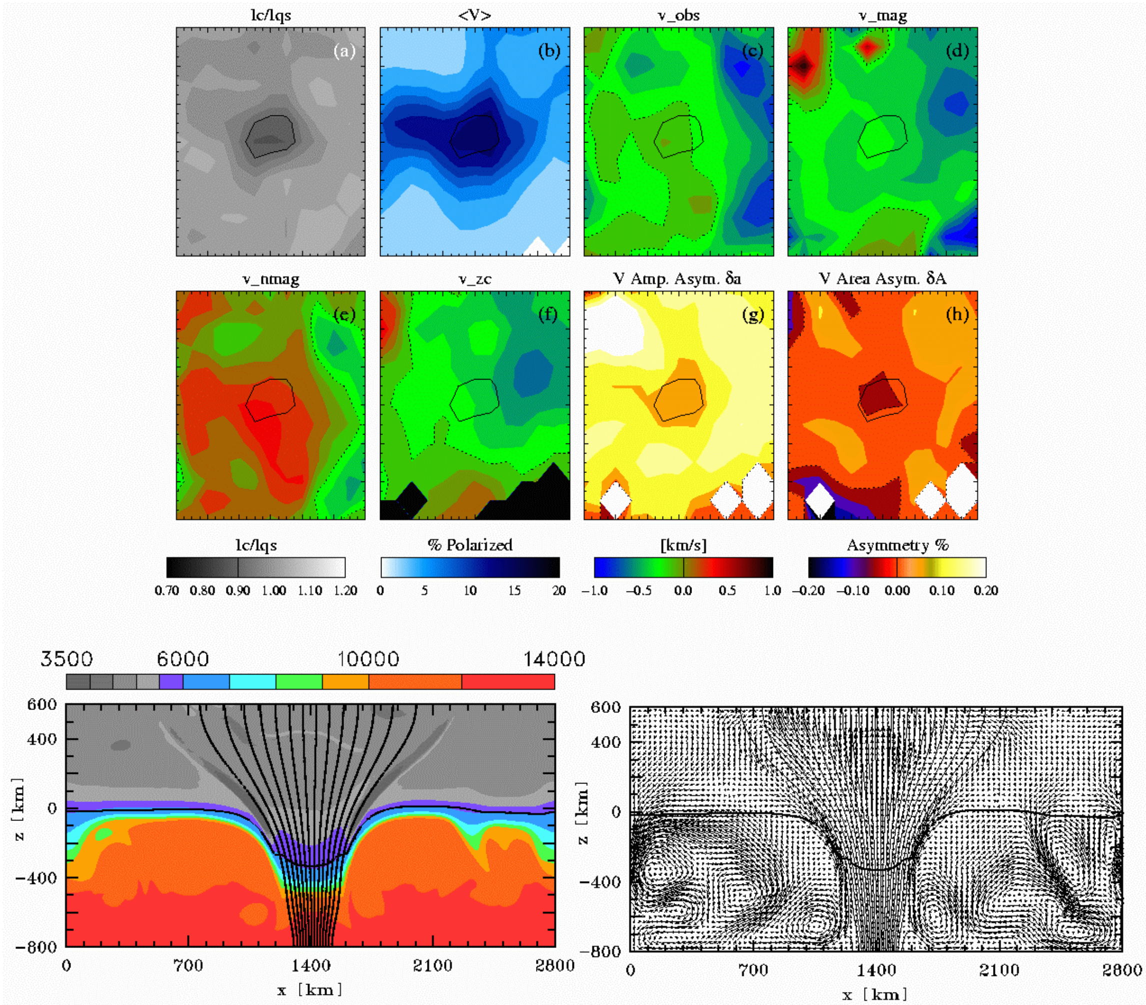
The understanding of the emerging flux phenomenon has increased on both the observational and numerical-modeling fronts over the last decade. The sophistication of the simulations and data (and the interpretation of both) has brought the solar physics community to a better-than-cartoon level of understanding of emerging flux and active-region development, from below the solar surface into the atmosphere, and from small magnetic "knots" or pores to full active-regions and sunspots. Specifically the "gaps" currently being filled (in this sub-topic) include the sub-photospheric dynamics of rising flux tubes, the magnetic morphology, magnetic evolution and dynamics of emerging magnetic flux, the details of magnetic structures over a range of sizes from small pores to sunspots, the formation and structure of sunspot penumbrae and sunspot magnetic canopies.

The gaps which still loom include basic sunspot-structure and active-region questions and span both observations and numerical modeling. They include such queries as "*Why* is there a penumbra at all?", "*What/When/How/Why* are there those ubiquitous moving magnetic features (MMFs) around sunspots?'", and "*When/How/Why* is magnetic flux and magnetic helicity dispersed/removed prior to/prompting/during decay?".

In other words, there are significant nagging details whose omission compromises our physical understanding of active region formation. Even as our observational gaps are filled in, we are looking "for the whole elephant"; a physical picture based upon the full accounting of magnetic/thermodynamic force budget -- not just a snapshot in the photosphere but a well-developed physical scenario complete in z ,t.

Over the next decade during the Solar-B era, observational gaps should be filled to enable comprehensive semi-empirical models of flux emergence and active region formation and decay. High-resolution Stokes spectropolarimetry will require new inversion algorithms (some are developing now) to become routine. Improving the observational capabilities in temporal, height, and spatial resolution will result in more *confusion* than enlightenment without substantial progress in RT/inversion/modeling - as demonstrated during the discussion sessions with recent data from the Advanced Stokes Polarimeter where non-classically-shaped Stokes spectra were the norm and absolutely pathological spectra were common.

The era beyond Solar-B should bring a full exploitation of spectropolarimetry to focus on the determination of the force balance through the atmosphere from flux emergence through sunspot formation to active region decay. Upon such a physical basis one can build the *Why* and *How* questions of emerging flux – *e.g.* a search for pre- or early-emergence signatures that foretell later sunspot or active-region size, complexity, etc. – to complement the answers to *What/When* queries developed through the next decade.



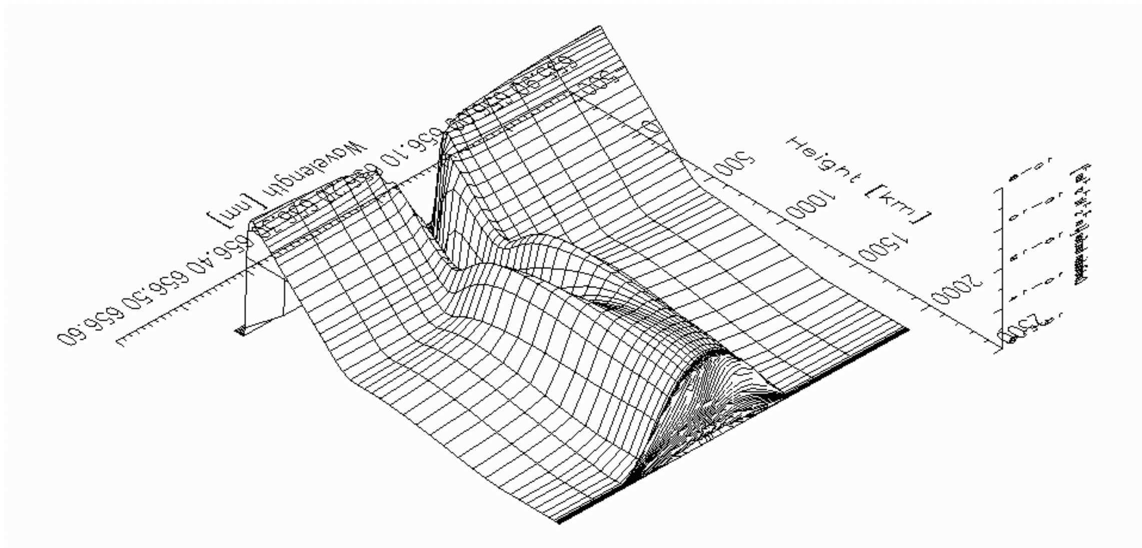
Leka Figure 1. Observations (top) and Numerical Simulation (bottom) of a magnetic pore, from Leka & Steiner 2001, *ApJ* **552**, 354. Direct comparison of the two datasets was performed by exploiting the emergent Stokes spectra from both (*e.g.* the spatial variation of the Stokes *V* asymmetries, see panels (g,h), and *V* zero-crossing, see panel (f)), enabled an investigation of the magnetic canopy effect - the "flaring out" of field lines with height (*cf.* [**B**, T(K)] from simulation, bottom left) coupled with the strong and persistent downdrafts at pore boundaries ([**B**, *v*] from simulation, bottom right).

Elementary Fluxtubes and Coronal Heating

Han Uitenbroek (NSO/Sac Peak)

From space-based images it is clear that magnetic fields play a crucial role in the heating of the solar corona. It is also clear that the motions and deformations the magnetic field undergoes in the kinetically dominated lower atmosphere are the ultimate source of this heating. In what form this energy is transported upward through the chromosphere and transition region, and how it is channeled to the corona where it can be dissipated to give rise to the observed heating, however, is currently very unclear. The required observations pose a difficult task as the relevant region is transparent in most but a handful of spectral diagnostics, most of which are unobservable from the ground. In addition, the chromosphere and transition region are hard to model because of the transitions between different physical regimes that take place. Because of the steep drop in density with radius the magnetic field is able to overcome its domination by kinetic motions (the plasma β goes from larger to less than one at the magnetic "canopy", defined as the $\beta = 1$ surface), and radiation is able to decouple from the thermal properties of the gas so that LTE radiative transfer no longer applies.

To uncover the manner in which energy is transported upwards will require multi-wavelength spectroscopy simultaneously in different diagnostics that range from photosphere through chromosphere and transition region up to the corona, with high spatial, spectral, and temporal resolution. This energy transport may be in the form of high frequency magneto-acoustic waves, or the subtle twisting and braiding of field lines followed by reconnection. One of the more promising observables is the hydrogen Hα line, which is probably one of the most observed solar lines, but is notoriously hard to interpret. It has a double peaked contribution function (see the included figure which shows the contribution function in a standard one-dimensional solar model), and very steep wings that result in high contrast off-center images when velocities are present. However, the line is magnetically sensitive, a property that has been rarely explored so far, and can potentially provide important magnetic field measurements in the elusive intermediate region between photosphere and corona. To interpret the Hα line intensities will require sophisticated radiative transfer, possibly in multi-dimensional geometry, that properly accounts for partial frequency redistribution in Lyman-α, since this line determines to a large extent the amount of the hydrogen ionization, as well as the opacity in the Balmer line.



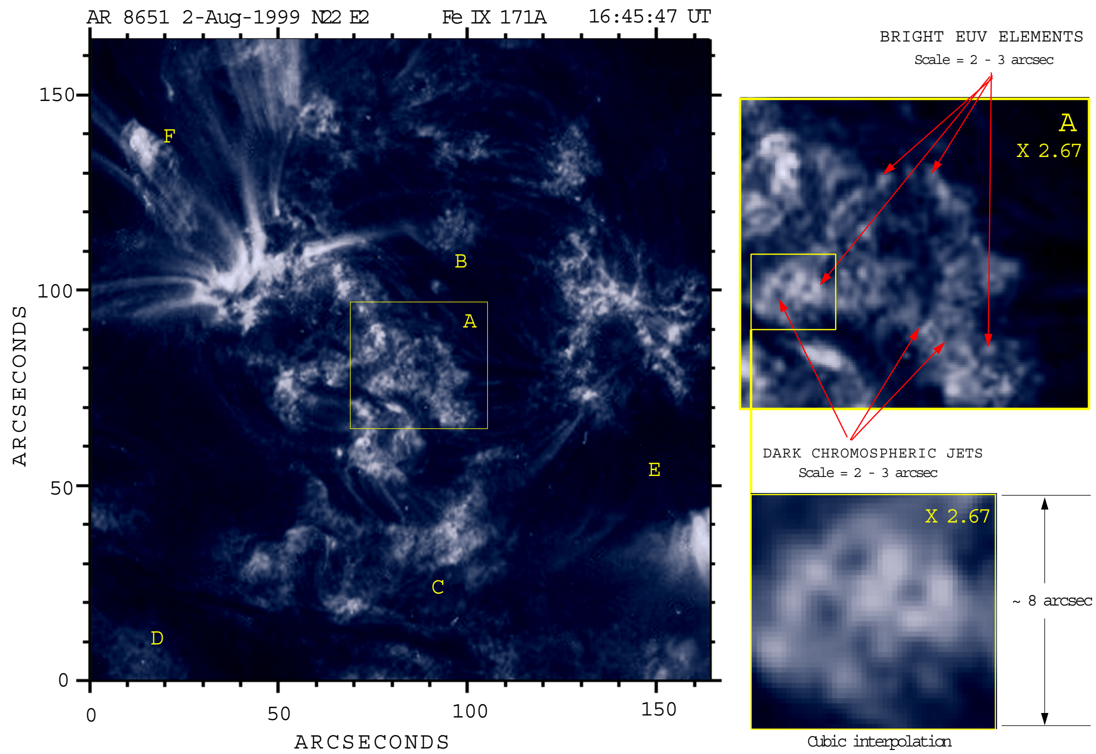
Uitenbroek Figure 1. The Hα contribution function in a standard plane-parallel model.

An Overview of Transition Region Moss

T. E. Berger (LMSAL)

Transition region (TR) "moss" was first identified in 1998 as a novel Extreme Ultraviolet (EUV) emission pattern in TRACE Fe IX/X 171Å images of solar active regions. Although in hindsight it can be seen in SOHO/EIT images and other solar EUV observations, it was not until the TRACE observations that it became clear that this emission pattern clearly differed from the canonical "coronal loop" description of solar EUV structure. The basic properties of moss have been delineated through extensive multi-instrument studies utilizing *Yohkoh*/SXT, SOHO/CDS, SOHO/MDI, and the Swedish Vacuum Solar Telescope (SVST) on La Palma. We now know that the moss pattern is a thin 1 Mm layer, from 1.5 – 2 Mm above the photosphere, consisting of 1 – 3 Mm bright emission elements interspersed with similarly sized dark inclusions. It occurs only over active plage areas that underlie the 3 – 5 MK coronal loops typically seen in *Yohkoh*/SXT images. The bright EUV emission elements are believed to be the transition region (TR) footpoints of hot coronal loop filaments; the dark inclusions are jets of chromospheric material (i.e. 10^4 K plasma), clearly identifiable in simultaneous Hα images taken with the SVST. The jets interact with the EUV elements on 10 – 20 s time scales resulting in a continual dynamic evolution of the fine-scale emission pattern. There is some evidence of weak intrinsic brightness variations on the order of 10% or less possibly indicating localized heating in the moss layer. Significantly, the bright moss elements are *not* found directly above photospheric magnetic elements; the pattern of the bright elements does not correlate with the plage magnetic element pattern on scales of 1 – 5 Mm. Although most patches of moss are stable, evolving on 10 h time scales along with the underlying plage magnetic fields, there are occasionally very rapid post-flare "spreading moss" episodes in which moss patches grow behind the flare ribbons at speeds from 10 – 100 km/s.

This talk reviews the relevant TRACE, SXT, SOHO, and ground-based data as well as some empirical modeling results that underlie our current knowledge of the moss phenomenon. We advance the hypothesis that moss is a classical TR effect, i.e. it is the conductively heated 1 MK TR emission in the compressed footpoint regions of hot, high-pressure, coronal loops in active regions. In this model, coronal loop magnetic field line connections to the photosphere must entail a complex, tangled, topology that is not compatible with the simple idea of field lines rising vertically from the photosphere to create coronal loops. We examine the possible contributions of future instruments such as Solar-B and the Advanced Technology Solar Telescope (ATST) towards a greater understanding of moss and what moss can reveal about the heating processes in the outer atmospheres of cool stars. We conclude with an observational "wish list" for future studies of moss dynamics.

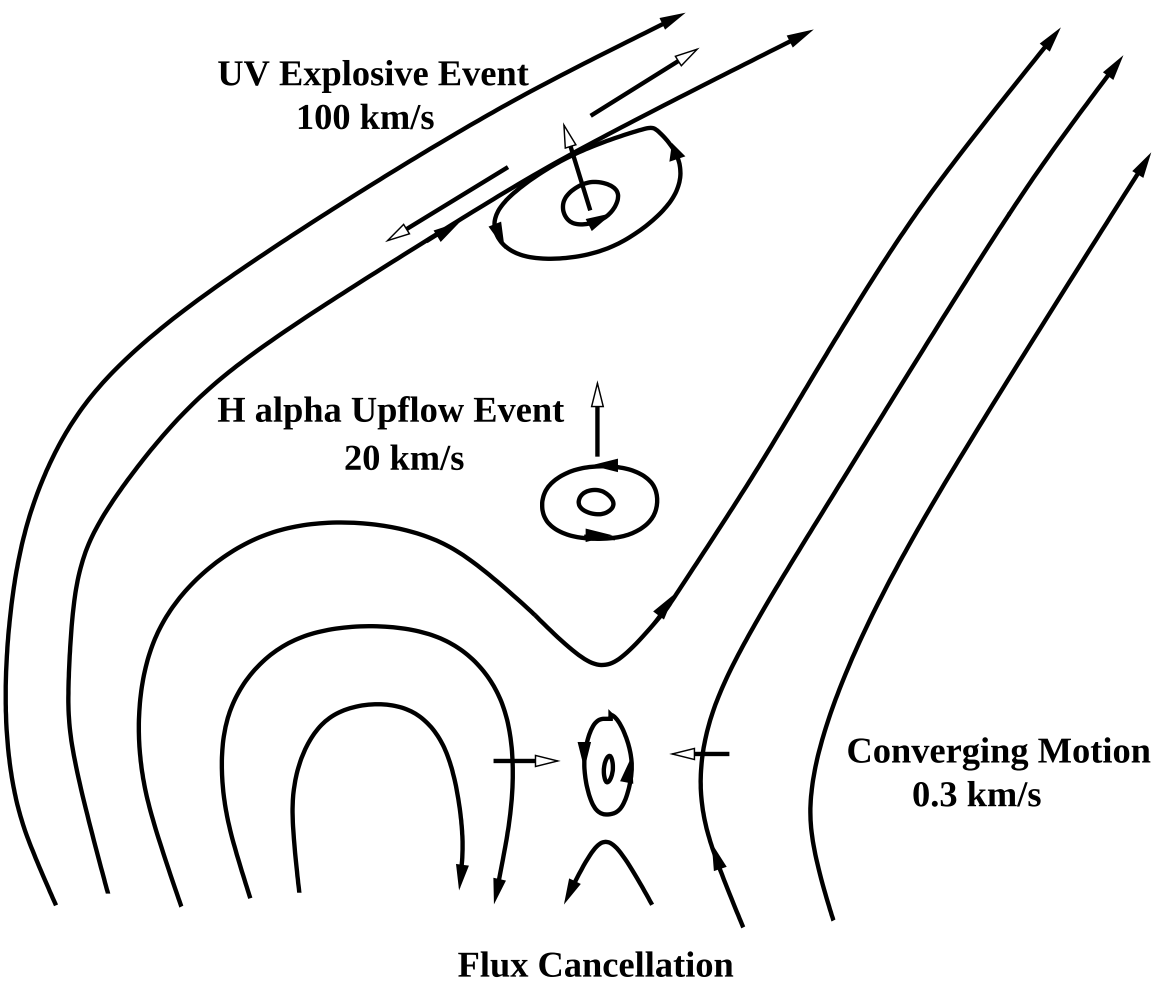


Berger Figure 1. TRACE 171Å image of AR8651 at N22E02, 2-Aug-99. A typical active region exhibiting moss patches throughout the central region.

Explosive Events in Magnetic Network

Jongchul Chae (Big Bear Solar Observatory, NJIT, and Department of Astronomy and Space Science, Chungnam National University, Korea)

Explosive events are small-scale and short-lived high-velocity events that are observed in ultraviolet lines emitted from transition region. They were originally discovered from HRTS experiments. New observations from SOHO have revealed their bi-directional jet nature, bursty and recurrent behavior, strong association with photospheric flux cancellation and Hα upflow events, similarities to blinkers, possible association with density enhancements, energy budget and so on. The strong association with photospheric flux cancellation and chromospheric upflow events suggests that explosive events may be a secondary process that is driven by primary magnetic reconnection occurring in the low atmosphere. Explosive events appear to be important in the coronal heating and solar wind acceleration if they are accompanied by other non-thermal processes like a generation of high-frequency Alfvén waves. The forthcoming mission beyond Solar-B is expected to clarify the physical relationships between flux cancellation and explosive events, and to check the possible existence of non-thermal processes accompanying explosive events.



Nulls in the coronal magnetic field

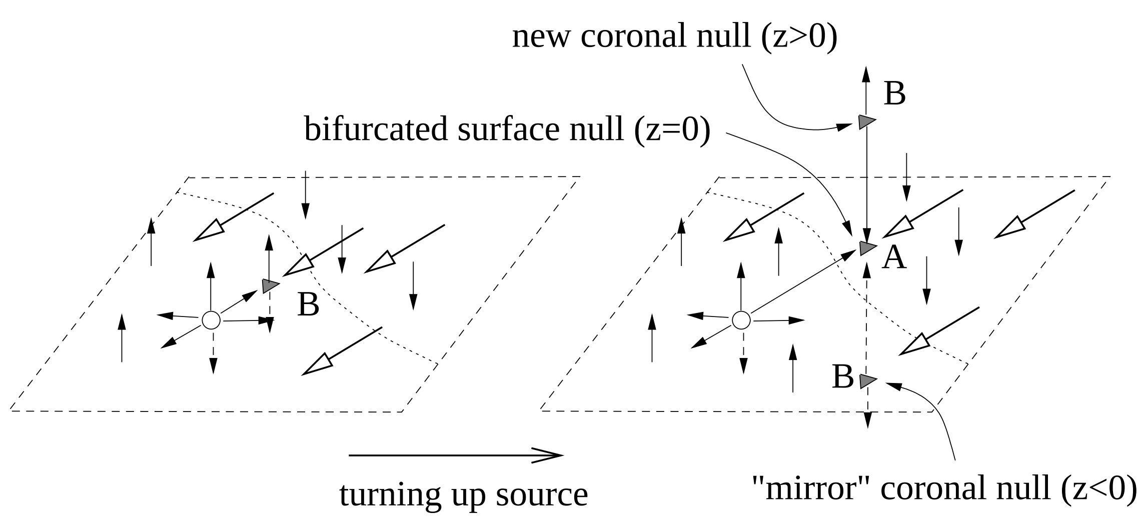
Dana Longcope and Petrus Martens (Montana State University)

Theoretical studies of coronal dynamics have suggested that efficient heating and energy release can occur at magnetic null points, isolated points where $|\mathbf{B}| = 0$. Nulls are significant in magnetohydrodynamics for two distinct reasons. Firstly, because the Alfvén speed vanishes at a null, shear Alfvén waves focus toward it and pile up. This leads to very steep field gradients that can dissipate incident wave energies on fast (Alfvén-transit) time scales. Secondly, the field line mapping is discontinuous at a null point, and boundary motions can lead to equilibrium magnetic fields with current sheets at discontinuities.

Several investigations have found observational evidence for magnetic nulls in the corona. The most direct evidence for coronal null points have come from suggestive shapes in X-ray or EUV images of quiescent or flaring active regions. The relative rarity of this evidence suggests that coronal null points are not a necessary feature in even the most complex magnetic geometries. Two theoretical techniques can be used to estimate the number of coronal null points expected in the corona above an observed photospheric field. Modeling the flux distribution as N point sources on a plane one finds, in general N-1 null points confined to the same plane. Coronal nulls are expected in those cases where a plane-bound null undergoes a topological bifurcation; typically when a sufficiently strong source is surrounded by sources of opposite polarity. Thus one expects far fewer than N coronal null points. Following Albright (Phys. Plasmas v. 6, p. 4222, 1999) a statistical calculation using the average Fourier spectrum $f(\mathbf{k})$ of the photospheric magnetic field predicts a density of nulls at height z

$$n(z) \sim \sum_{\mathbf{k}} |k|^2 f(k) e^{-2z|k|} \Big/ \sum_{k} f(k) e^{-2z|k|}$$

in a potential field. For reasonable spectral forms this density falls off over vertical scales comparable to characteristic horizontal scales.

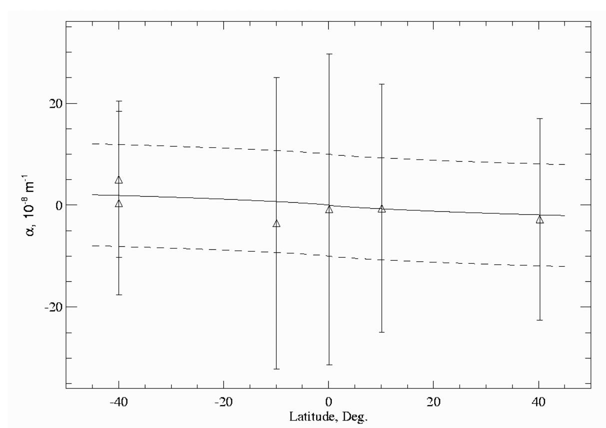


Magnetic Helicity

Alexei A. Pevtsov (National Solar Observatory)

Magnetic helicity – a topological invariant describing handedness of the magnetic fields – contains additional crucial information for understanding the solar dynamo, magnetic reconnection and many other processes on the Sun and interplanetary medium. Helicity is present on all scales in the solar atmosphere. Chromospheric filaments, active regions, coronal sigmoids, large scale magnetic field and interplanetary magnetic clouds, all follow the hemispheric helicity (chirality) rule – a statistical preference for negative helicity in the northern hemisphere and positive helicity in the southern hemisphere. The rule is independent of solar cycle and can be attributed to several different mechanisms, i.e. overshoot region dynamo, differential rotation and field-plasma interaction in the convection zone. The active regions that disobey the hemispheric rule are distributed not randomly over the solar surface, but seem to form in clusters or helicity nests. Some observations suggest that these "abnormal" active regions have enhanced are activity. Similar large-scale organization is also present in the large-scale magnetic field helicity and chirality of coronal flux systems. On a smaller spatial scale, local helicity patches are often present within a single sunspot. There is limited observational evidence that the local helicity structure and its evolution may be associated with solar flares and surges. Thus, for instance, a filament may be destabilized by transport of magnetic helicity from one magnetic system to another. Such helicity loading has been observed in several events and may be important for filament eruptions, Hα surges, X-ray jets and CMEs. It has been suggested that there are two different dynamos operating on the Sun. Subphotospheric (overshoot region) dynamo is responsible for a strong magnetic field of the active regions, but a weak field in the quiet Sun is generated at/near the surface by granular flows. I will demonstrate how the helicity approach can be used to distinguish between these two dynamos.

Mechanism	Helicity
Surface Dynamo	Random sign in both hemispheres
Subphotospheric Processes	Sign changes across equator

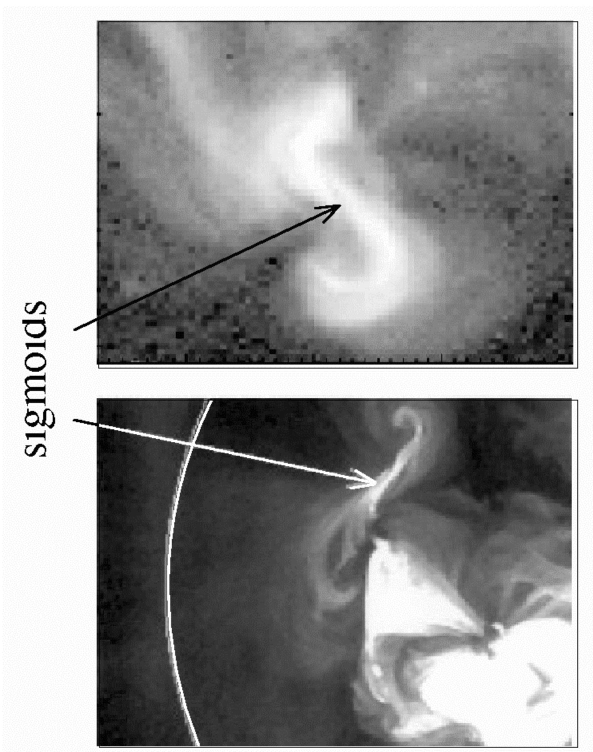


Pevtsov Figure 1. Averaged helicity <α_z> of quiet Sun magnetic field as function of solar latitude. Values from ASP observations are shown as triangles with error bars. Solid (dashed) line shows mean (st. deviation) helicity of a 3×10^{21} Mx flux tube resulting from the Σ-effect (Longcope et al, 1998). Slight hemispheric asymmetry implies subphotospheric origin of quiet Sun magnetic field.

Sheared Magnetic Fields and Solar Eruptions

T.G. Forbes (Institute for the Study of Earth, Oceans, and Space, University of New Hampshire)

Most models for solar eruptions are based on the principle that the energy that drives them comes from the free magnetic energy associated with coronal currents. Because of Ampère's law, such currents necessarily imply that the coronal magnetic field has a curl or, equivalently, a magnetic shear. (Note this definition of shear is not necessarily the same as that used by observers.) There is now ample evidence that sheared fields exist in the corona prior to an eruption, but the overall geometry and topology of the pre-eruptive field remains elusive. However, several recent studies seem to indicate that the pre-eruptive field may be a weakly twisted flux rope with only one to two turns of the field lines along its length. Quantitative models based on such a configuration nicely account for the appearance of large, quiescent prominences prior to their eruption (Aulanier et al., 2000), as well as for the appearance of the X-ray sigmoids (see Figure) that are often observed prior to eruptions (Titov and Démoulin 1999). Although the stability properties of a realistic flux rope configuration have yet to be determined, there are now several analyses (e.g. Lin et al. 1998, Sturrock et al. 2001) that indicate the configuration will lose ideal-MHD equilibrium or become kink unstable if the twist becomes too large.



Forbes Figure 1. Sigmoid X-ray structures (top panel is from Sterling et al. 2000, and bottom panel is from Rust and Kumar 1996)

Aulanier, G., N. Srivastava, and S. F. Martin, *ApJ* **543**, 447-456, 2000.
Lin, J., T. G. Forbes, P. A. Isenberg, and P. Démoulin, *ApJ* **504**, 1006-1019, 1998.
Rust, D. M., and A. Kumar, *ApJ* **464**, L199-L202, 1996.
Sterling, A. C., H. S. Hudson, B. J. Thompson, and D. M. Zarro, *ApJ* **532**, 628-647, 2000.
Sturrock, P. A., M. Weber, M. S. Wheatland, and R. Wolfson, *ApJ* **548**, 492-496, 2001.
Titov, V. S., and P. Démoulin, *Astron. Astrophys.*, **351**, 701-720, 1999.

Magnetography in the Chromosphere and Transition Region

D. Rabin (NASA/GSFC)

Over the last decade, space- and ground-based observations have delineated many aspects of the structure of the magnetic field in the photosphere and corona. Less progress has been made in studying the magnetic field in the chromosphere and transition region. This gap, both physical and conceptual, stands in the way of the unified picture of the solar atmosphere that is a prerequisite for fully understanding energy transport (including coronal heating) and the types of magnetic topology that lead to solar activity (including flares and coronal mass ejections).

The main challenges to magnetography in the chromosphere and in the transition region are different in character. In the chromosphere, difficulties center around the linked theory and modeling required to interpret polarimetry of NLTE absorption lines typically formed over a considerable range of height in the atmosphere. In the transition region, the chief obstacle is the small polarimetric signal expected in even the most favorable lines, such as C IV. Sensitive observations from large ground-based telescopes, such as the proposed Advanced Technology Solar Telescope, together with recent advances in Stokes inversion techniques, should enable progress in measuring the chromospheric field. The transition region field could be measured from space with a targeted instrument in the era beyond Solar-B. A proposed experiment would need to present a clear path from the limited measurements that are feasible to interesting constraints on the character of the magnetic field in the transition region.

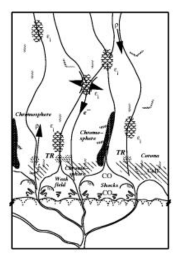
Summary: Magnetography in the Chromosphere and Transition Region

Why?

- Unravel energy transport to and from the upper atmosphere
- Measure *B* where atmosphere is most nearly force-free

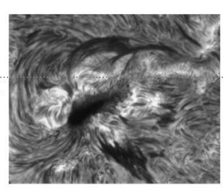
Key Challenge in the Chromosphere

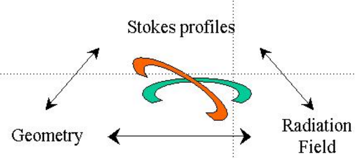
- Interpreting polarimetry of NLTE lines formed in a three-dimensionally inhomogeneous, dynamic atmosphere

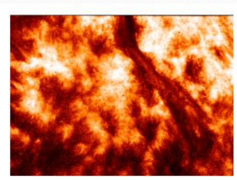


Complex Structure and Energy Transport (Schrijver 2000)

BBSO Hα







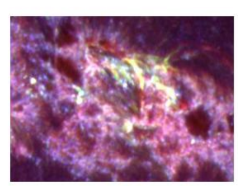
VAULT Lα (1999)

Key Challenges in the Transition Region

- Weak polarimetric signal (full vector field unrealistic)
- Isolating questions that line-of-sight flux measurements can answer

How?

- Chromosphere: large ground-based telescopes, Solar-B
- Transition region: begin with rocket proof of concept



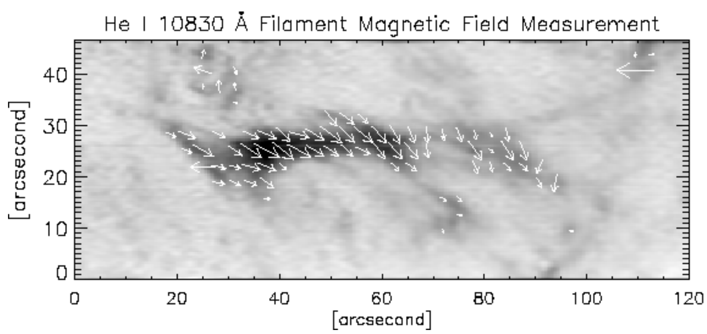
TRACE UV including C IV (1998)

Coronal Magnetometry

Haosheng Lin (Institute for Astronomy, University of Hawaii)

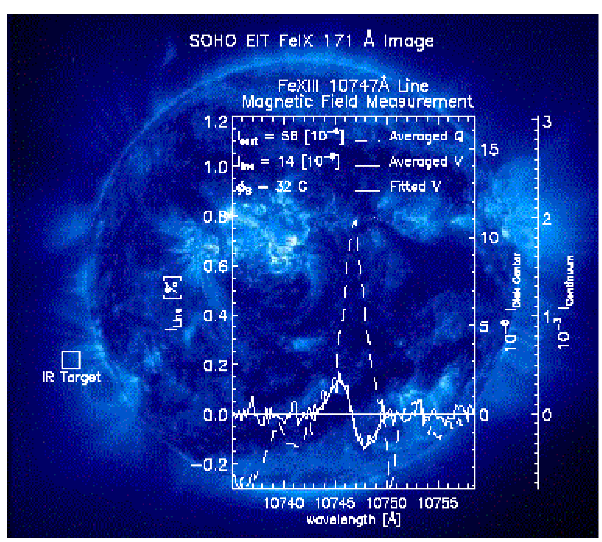
Energetic solar events such as flares and coronal mass ejections (CMEs) in the solar corona inject high-energy charged particles into the interplanetary space and have direct influence over the space environment of the Earth. The magnetic field dominates the structure and dynamics of this region. To understand the physics of the flares and CMEs, direct measurement of the coronal magnetic field is indispensable.

Recent progress in instrumentation and observational techniques for precision IR spectro-polarimetry had made it possible to directly measure the vector magnetic field in the upper atmosphere of the Sun, in both the million-degree *hot* corona observed from the light of the forbidden coronal emission lines, and in the *cool* coronal plasma in prominences and filaments.



Two spectral lines in the near infrared provide powerful diagnostics for the measurement of the coronal magnetic field. The Hanle effect of the He I 10830 Å line can be used to probe the magnetic field configuration of the filaments. The vectors in the figure on the left show the magnetic fields of a quiescent filament measured with the He I 10830 Å line. Since disk observation can resolve the details of the filament structure, and because the Hanle effect of the filament is not subject to the 180-degree ambiguity problem in resolving the direction of the magnetic field, the magnetic field configuration of the filament can be determined completely with certainty.

The Fe XIII 10747 Å forbidden coronal emission line can be used to measure the magnetic field in the hot solar corona. Although determination of the coronal magnetic field direction projected in the plane of the sky by measuring the linear polarization of the coronal emission line is straightforward, the circular polarization measurement of the coronal magnetic field strength has been one of the most challenging experiments in the field of observational solar astronomy for decades. Nonetheless, the figure on the right shows the first resolved Stokes V spectrum obtained recently in the corona



above an active region. The measured magnetic field strength of the IR observation target region approximately 100 Mm above the limb was 32 Gauss.

The He I 10830 Å line and the Fe XIII 10747 Å lines are powerful tools for the diagnostics of the coronal magnetic fields. Future ground-based and space-borne high precision IR polarimeter designed to exploit the capability of these new coronal magnetic field diagnostics undoubtedly will yield rich new information and advance our understanding of the solar corona and the dynamic events therein.

Magnetic Field Extrapolation

P.A. Sturrock (Center for Space Science and Astrophysics, Stanford University)

Since flares, CMEs, etc., are believed to be caused by the sudden restructuring of the coronal magnetic field, there is strong incentive to find a procedure for determining the coronal magnetic field form observational data. One can construct a potential field from line-of-sight magnetograph data, but potential fields contain no free energy to drive activity. It is also possible to construct linear force-free fields, but such fields do not decay with distance from the source. Hence, the simplest class of magnetic fields of real interest is that of nonlinear force-free fields.

We review several methods that have been proposed for reconstructing nonlinear force-free magnetic fields from vector magnetograph data. They all depend on some procedure for resolving the 180-degree ambiguity of the transverse component. Furthermore, all methods are at present limited to reconstruction of fields near disk center.

There have been several attempts to develop an "upward" integration procedure (Wu, Sun, Chang, Hagyard & Gary 1990; Amari et al. 1997). Since the field equations are basically elliptic, this is an ill-posed procedure, and it must be limited in range. Nevertheless, the above authors have been able to carry out this procedure for a useful range of height.

Sakurai (1981, 1989) and Amari, Boulmezaoud, & Mikic (1999) have adopted the "Grad-Rubin" method. The procedure is to begin with the potential field corresponding to the normal field at the lower boundary, then to progressively introduce currents on those field lines, relaxing the configuration to move towards the force-free state. The currents are slowly increased until they match the required boundary conditions. Amari et al. have considered mesh sized up to 120x120x120, and claim that the method converges in only a few iterations.

Mikic & McClymont (1994) use a quasi-MHD model, with resistive and viscous terms, in which the configuration is allowed to evolve in time until it arrives at an equilibrium configuration. The boundary conditions on the lower boundary of the model are the normal components of the field and of the current. In this procedure, "voltages" are applied at the lower boundary, and modified progressively until the normal current in the model matches the values derived from observational data. The model involves "superconducting" boundaries above and on the sides. The solution is actually over-determined if one used boundary conditions on both polarity regions, so it is necessary either to use the current for only one polarity, or to incorporate a procedure to use both polarity regions, subject to some approximation procedure.

Roumeliotis developed two new procedures a few years ago. One is called the "optimization" procedure. Bytaking the divergence equation and the Lorentz-force equation, squaring them, and integrating the sum of the squares over space, one has formed a pseudo-energy such that both equations are satisfied if the energy can be reduced to zero. One can form a pseudo-force at each point by evaluating the variation of the pseudo-energy due to a variation in the magnetic field vector at each point. One can then effectively use the magneto-frictional method by which the magnetic field vector is changed progressively in response to the pseudo-force (Yang, Sturrock & Antiochos 1986). This procedure has been implemented by Wheatland, Sturrock & Roumeliotis (2000) and is currently being further developed, in IDL language, by Jim McTiernan at UC Berkeley. The procedure does work but it is rather slow. If one can find a way to speed up the calculation (such as the non-uniform-step procedure employed by Chodura & Schlueter [1981]), it could be very useful. It is flexible enough that one can in principle develop a procedure that does not require one to specify the field on the upper or side boundaries, but this has not yet been done.

The other procedure proposed by Roumeliotis (1996) is what he calls the "stress and relax" method. The basic idea is to interweave two relaxation procedures. One procedure is to stress the vector potential at the lower surface so that the transverse components closely approximate the observed componenets. The other procedure is to relax the vector potential in the interior, for fixed vector potential on the lower boundary, so as to approximate the force-free state. The equations are set up in such a way that one can take account of the accuracy (or inaccuracy) of measurements. Roumeliotis carried through calculations for a uniform mesh of 145x145x145 on the GSFC Cray X-MP in one hour.

The Grad-Rubin, quasi-MHD and stess-and-relax methods all seem to be promising schemes that deserve further development.

Amari, T., Aly, J.J., Luciani, J.F., Boulmezaoud, T.Z., & Mikic, Z. 1997, *Solar Phys*. **174**, 129

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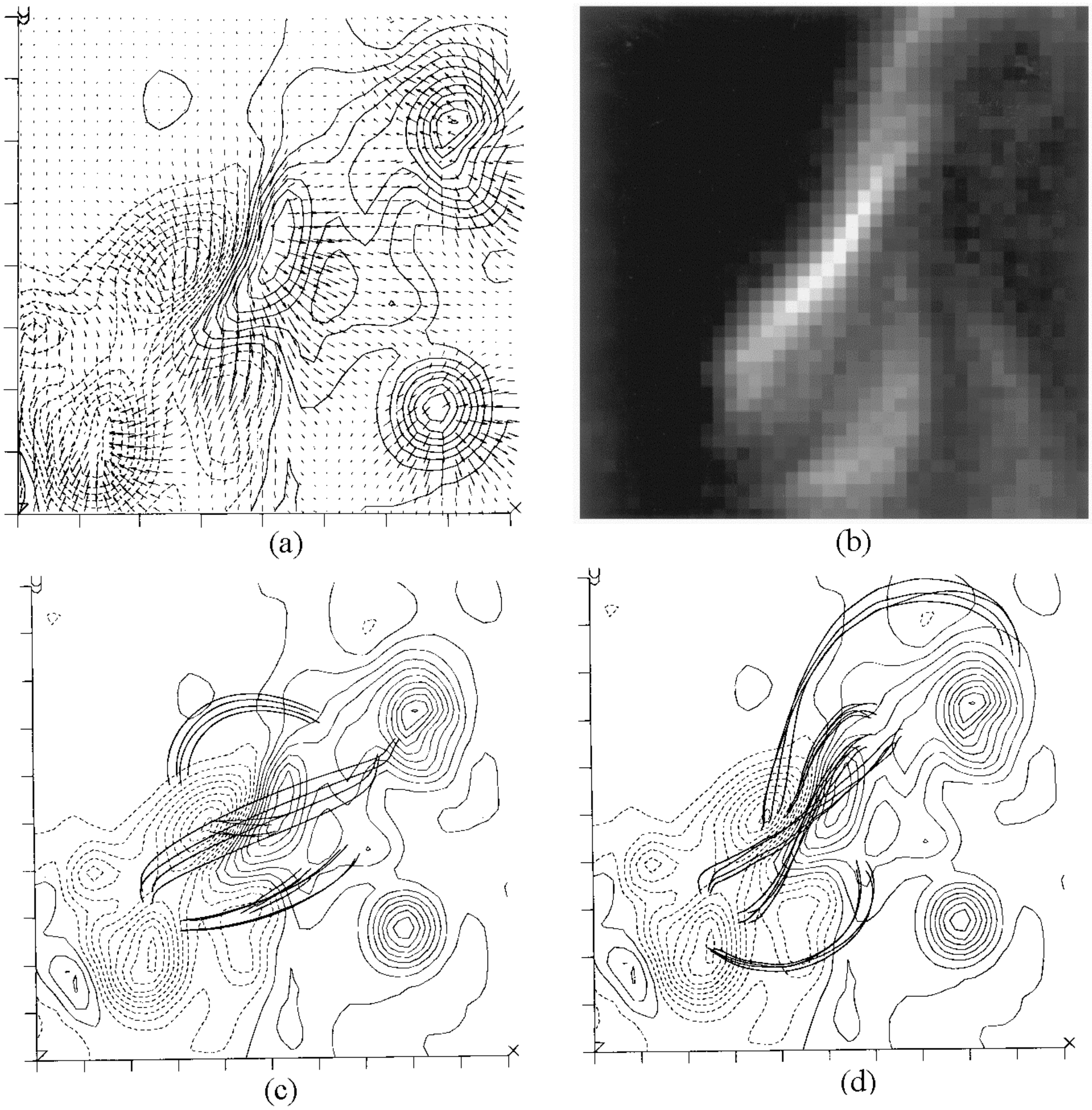
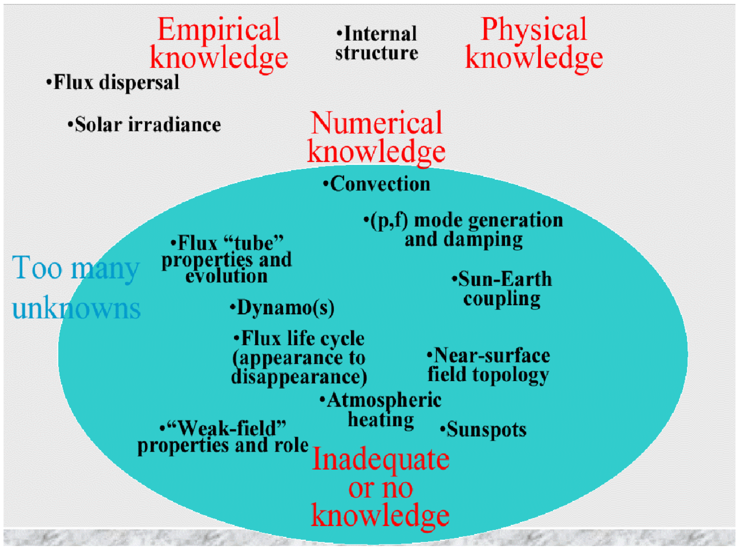


Sturrock Figure 1. Roumeliotis' (1996) reconstruction of the coronal magnetic field for AR 6982 on 1991 December 26. (a) MSFC Solar Magnetograph measurements made at 18:24 UT. (b) SXT image taken at 18:07 UT. (c) Subset of field lines from the potential field, with footpoint locations corresponding to the loops in the SXT image. This magnetic-field pattern is not consistent with the SXT image. (d) Subset of current-carrying field lines from the reconstructed force-free field. This magnetic pattern is consistent with the SXT image.

Workshop Summary: High-resolution solar magnetography beyond Solar-B from the viewpoint of theory and modeling

C. J. Schrijver (Lockheed Martin Advanced Technology Center)

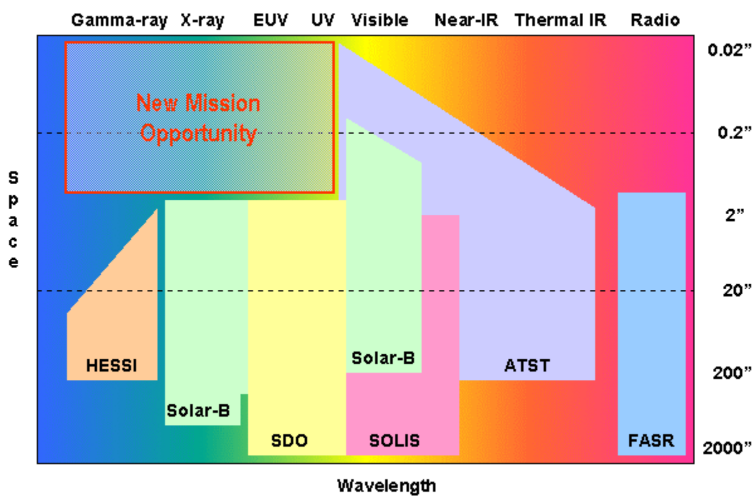


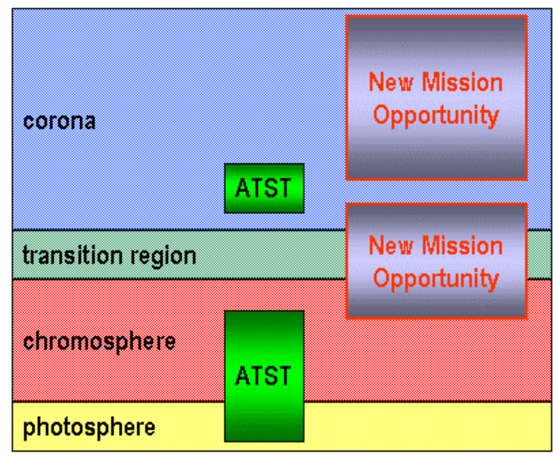
The state of our current knowledge of most of the physical processes that are relevant to solar activity and space weather ranges from primarily empirical or numerical to insufficient, in the sense that the knowledge that we have cannot be fully exploited in, for example, accurate forecasting of solar activity. We expect to make significant advances in our understanding with the help of next-generation spacecrafts and computer models, but a number of topics in the figure above will in all likelihood remain too close to the lower edge of the figure even a decade from now. These problem areas will require a mission that is dedicated specifically to the interface between the interior of the Sun and its magnetosphere. Moreover, the complexity that we are facing requires multi-wavelength, multi-instrument observations that probe the three-dimensional, time-dependent structure of the layers from photosphere to transition region. Only detailed observations, at high spatio-temporal resolution, and with vector-magnetographic coverage at multiple heights in the atmosphere, can provide the empirical knowledge that is required for the validation of theoretical and numerical models. The presentation at the meeting (http://science.nasa.gov/ssl/pad/solar/presentations/SchryverTalk.pdf) summarized the arguments presented by the invited speakers that together resulted in the above conclusions. Moreover, problem areas are identified for six themes: weak-field properties and the dynamo(s), flux-tube and sunspot properties, wave generation and damping, near-surface field topology, atmospheric heating.

Workshop Summary: High-resolution solar magnetography beyond Solar-B from the viewpoint of instruments and observations

Christoph U. Keller (National Solar Observatory)

The requested observing capabilities for a new space-based telescope may be summarized as follows: The ground-based Advanced Technology Solar Telescope in space with some added features. The general capabilities should include: Higher spatial and temporal resolution than presently possible, i.e. 10 km spatial resolution and 1 second temporal resolution; Higher polarimetric accuracy; Field of view up to 8 arcmin; Many spectral lines simultaneously. Transition Region spectrograph with high spatial resolution; and IR imaging spectropolarimetry 1-1.5 µm.





By 2010, we can expect the following observing capabilities: Solar-B will still be operational; ATST will be fully operational delivering 0.05 arcsec resolution over 10 arcsec, covering the 300 nm to 30 µm wavelength range, to be upgraded with MCAO delivering 0.05 arcsec over 100 arcsec; SOLIS Network will provide full-disk vector-magnetograms every few hours 24 hours a day; Solar Dynamics Observatory will provide full-disk synoptic data including vector-magnetograms with 1 arcsec resolution every few minutes; Solar Orbiter will be launched within 2 years. These facilities can address a large part of the science goals that were mentioned during the workshop.

In general, high-resolution spectro-polarimetry is photon-starved. Therefore the required photon flux is a bigger driver for aperture size than the diffraction limit. Therefore, by 2010, it is not easy to gain much in science capabilities from a visible-light telescope in space. The figures above show the areas of opportunity for a new space-based solar telescope.

A potential Advanced Solar Space Telescope might therefore have the overall science goal of *understanding the dynamic coupling of the magnetized solar atmosphere from the photosphere to the corona*. Its primary mission would consist in *providing very high-resolution observations of those parts of the solar atmosphere that cannot be easily observed from the ground* (upper chromosphere, transition region, corona on the disk).

As a secondary mission, it would *provide simultaneous high-resolution observations that can easily be correlated with ground-based data*. A 2-m class space telescope giving access to the visible, UV, EUV, and soft X-ray spectrum with spectrographs and filter-based instruments that can do polarimetry would be a powerful new solar observing tool.

Appendix D: Abstracts of Contributed Presentations

Solar Spicule Observations: What's Needed from Solar-B and Beyond

Alphonse Sterling (NASA/MSFC; NRC/MSFC Research Associate)

Traditionally, the spicules appear as dynamic jets of gas seen at the limb in chromospheric spectral lines. Beckers (1968; 1972) summarizes their observed properties and earlier theoretical ideas for their production, and Sterling (2000) summarizes more recent spicule issues. The chief difficulty in understanding spicules is the inability to observe them well, due to their small widths (< 1") and transient existence (about 10 min). Among the biggest challenges over the next generation of high-resolution instrumentation will be to refine the properties of spicules well enough to narrow down the myriad of suggestions for their origin. With anticipated spatial resolution of < 0".25 and high time cadence, the Solar Optical Telescope (SOT) on Solar-B will hopefully answer many of the outstanding fundamental spicule questions, including, e.g., details of the dynamics of their motions, their identification with structures on the disk, and their relationship to brightenings at their bases (*cf.* Suematsu et al. 1995).

- So what can we hope for beyond Solar-B, with space-based telescopes and adaptive-optics on ground-based telescopes? We list some possible objectives for even higher spatial resolution and better magnetograms than anticipatedfrom Solar-B:

- Will Solar-B really resolve spicules? Beyond-Solar-B instrumentation will be able to refine further information on spicule widths and fine structure.

- We hope to be able to compare disk counterparts of spicules to filigree (elemental flux tubes), which have size ~ 150 km. This will allow us to explore whether spicules are related to merging of flux tubes, or Joule heating at the boundary of flux tubes (Hirayama 1992).

- Search for torsional motions (Alfvén waves) in spicules; spectral capability may be helpful for this.

- If high (spatial) resolution spectra are available, obtaining line-broadening data (e.g., as a function of height, temperature, and time) will be useful forcomparing with predictions from models.

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Beckers, J. M. 1972, *Ann. Rev. Astron. Astrophys.*, **10**, 73
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Nishikawa, T. 1988, *Publ. Astron. Soc. Japan*, **40**, 613
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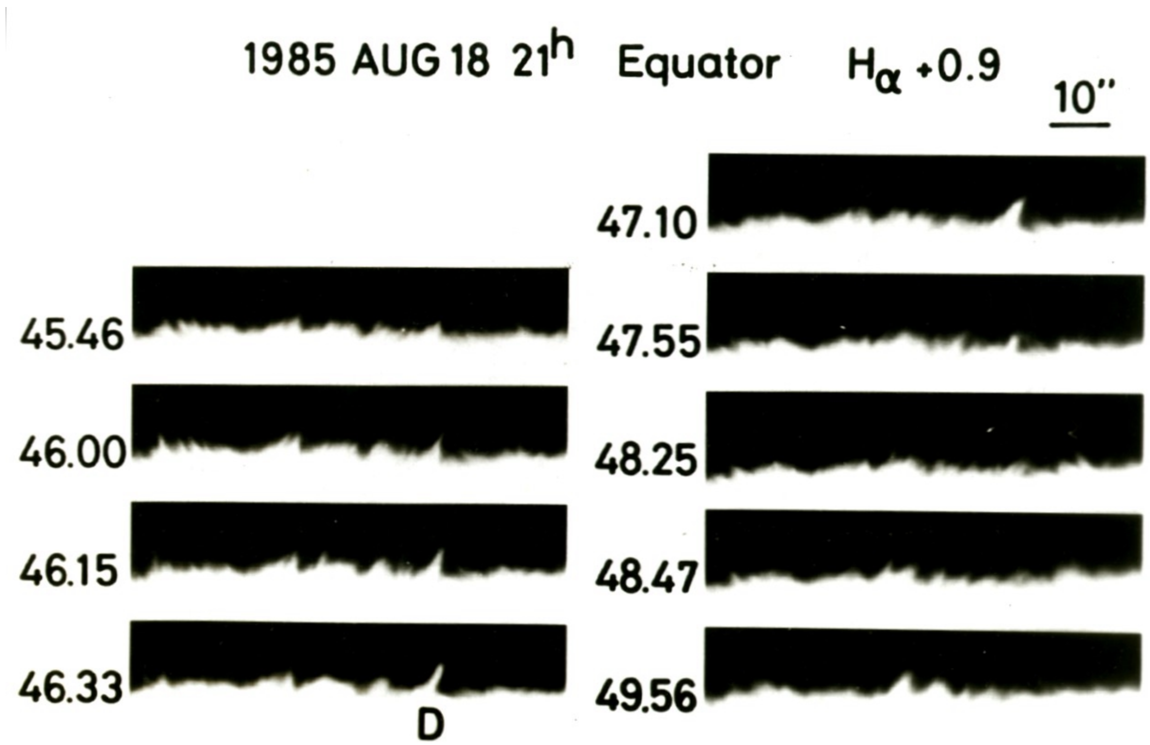
Suematsu, Y., Wang, H., & Zirin, H 1995, *ApJ*, **450**, 411



Sterling Figure 1. Spicules observed from Hida Observatory, Japan (Nishikawa, 1988).

Magnetic evolution of a long-lived active region: the sources of magnetic helicity

.H. Mandrini(1), P. Demoulin(2), L. van Driel-Gesztelyi(2,3,4), B. Thompson(5), S. Plunkett(6), Zs. Kovari(4) and G. Aulanier(2)

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(6) Naval Research Laboratory, Washington, DC 20375, USA

An isolated active region was observed on the Sun during seven rotations, starting in July 1996. We present a study of its magnetic field, concentrating of its helicity evolution. The photospheric field is extrapolated to the corona in a linear force-free approach, allowing us to compute, in a crude way, the coronal helicity of the active region. We also calculate the helicity injected by the differential rotation. Finally, we identify all the CMEs that originated from this active region during its lifetime and using average values of the field and radius of magnetic clouds, we estimate the helicity that should be shed via CMEs. We compare these three values to evaluate the importance of the differential rotation relative to twisted flux emergence as a source of magnetic helicity.

Deriving Coronal Magnetic Fields Using Parametric Transformation Analysis
Allen Gary/ Marshall Space Flight Center/NASA

Improvements to the magnetic field (upward) extrapolations techniques will be needed for the next generation of magnetographs. When plasma beta >1 then the gas pressure dominates over the magnetic pressure. This ratio as a function along a coronal magnetic field line may vary from beta > 1 in the photosphere at the base of the field lines, to beta << 1 in the mid-corona, to beta > 1 in the upper corona. Almost all magnetic field extrapolations do not or cannot take into account the full range of beta. They essentially assume beta << 1 , since the full boundary conditions do not exist in the beta > 1 regions. We use a basic parametric representation of the magnetic field lines such that the field lines can be manipulated to match linear features in the EUV and X-ray coronal images in a least squares sense. This research employs free-form deformation mathematics to generate the associated coronal magnetic field. In our research program, the complex magnetic field topology uses Parametric Transformation Analysis (PTA) which is a new method to describe the coronal fields that we are developing. In this technique the field lines can be viewed as being embedded in a plastic medium, the frozen-in-field-line concept. As the medium is deformed the field lines are similarly deformed. However the advantage of the PTA method is that the field line movement represents a transformation of one magnetic field solution into another magnetic field solution. When fully implemented, this method will allow the resulting magnetic field solution to fully match the magnetic field lines with EUV/X-ray coronal loops by minimizing the differences in direction and dispersion of a collection of PTA magnetic field lines and observed field lines. The derived magnetic field will then allow beta > 1 regions to be included, the electric currents to be calculated, and the Lorentz force to be determined. The advantage of this technique is that the solution is (i) independent of the upper and side boundary conditions, (ii) allows non-vanishing magnetic forces, and (iii) provides a global magnetic field solution, which contains high- and low- beta regimes and maximizes the similarity between the field lines structure and all the coronal images of the region. The coronal image analysis is crucial to the investigation and for the first time these images can be exploited to derive the coronal magnetic field in a well-posed mathematical formulation. This program is an outgrowth of an investigation in which an extrapolated potential field was required to be "inflated" in order to have the field lines match the *Yohkoh*/SXT images (Gary & Alexander 1999, *Solar Phys.*, **186**, 123).

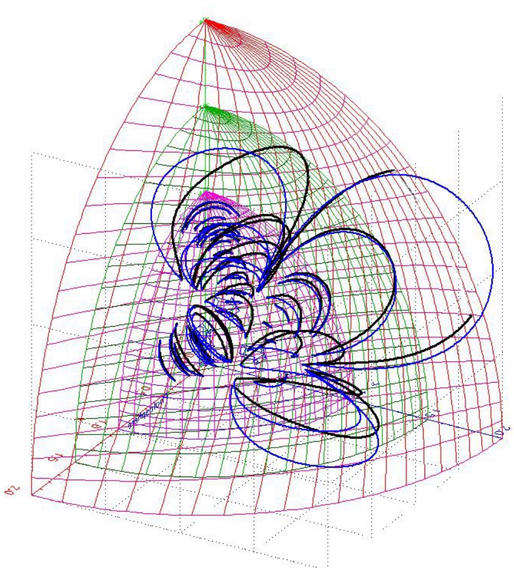


Figure1. Transformation of the magnetic field lines. Color Code: Potential Lines - Distorted Lines (with one line truncated)- Photospheric Shell - Mid-Coronal Shell - Upper Coronal Shell

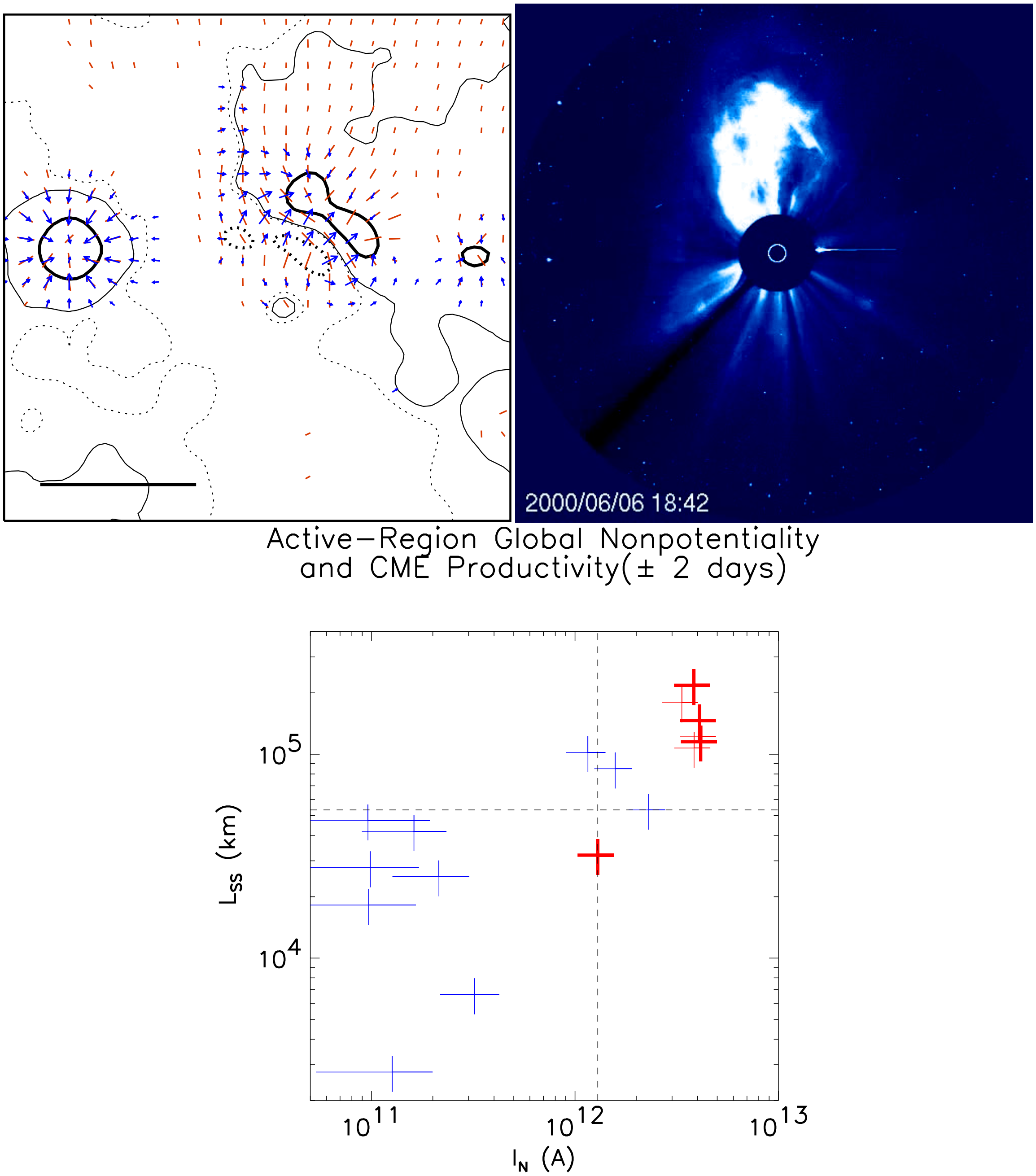
Prediction of Coronal Mass Ejections from Vector Magnetograms: Results from More Active Regions

Falconer, D A, (UAH/MSFC) Moore, R L, & Gary, G A (NASA/MSFC)

In a previous pilot study of four predominantly bipolar active regions observed by both the *Yohkoh* Soft X-ray Telescope (SXT) and the MSFC vector magnetograph in 1991-92, we found that two quantitative measures of the global nonpotentiality of an active region were promising predictors of whether the active region produced coronal mass ejections (CMEs) during its rotation across the Sun (Falconer, D.A. 2001 "A Prospective Method for Predicting Coronal Mass Ejections from Vector Magnetograms," JGR, in press). The two quantitative measures are 1) the total length (L_{SS}) of the segments along the active region's main neutral line on which the vector magnetic field is both strong and strongly sheared, and 2) the global net electric current (I_N) flowing up one side of the bipole and down the other. Two of the active regions had large measured global nonpotentiality (L_{SS} >~10^5 km and I_N >~4×10^{12} Amp) and produced CMEs. The other two active regions had much smaller measured global nonpotentiality and produced no CMEs.

We have now expanded our sample of active regions with 8 more active regions from 1992 to 2000. We have calibrated the line-of-sight magnetic field by comparing it to the line-of-sight field measured by Kitt Peak and/or SOHO/MDI. Using a combination of GOES, *Yohkoh*/SXT and LASCO observations, we determine the number and time of the CMEs produced by each active region during disk passage. We compare our original two measures of global nonpotentiality to each other and to the CME productivity of each active region both during disk passage and within ±2 days of the magnetograms. In addition we compare two additional quantitative global measures to active-region CME productivity. One of these is a measure of an active region's size, the total magnetic flux (Φ), and the other is a normalized measure of global nonpotentiality ($\overline{\alpha}=\mu I_N/\Phi$).

From our larger sample (12 active regions and 17 magnetograms), we find that the trends of Falconer (2001) still hold. Our results show that (1) I_N and $\overline{\alpha}$ are good predictors of which active regions are CME productive during disk passage, (2) I_N and $\overline{\alpha}$ are even better predictors for CME production within ±2 days of the day of the magnetogram, and (3) L_{SS} is almost as accurate a predictor on time scales of ±2 days, and it is more straightforward to measure. In accord with Canfield, Hudson, and McKenzie (1999 GRL V26, #6 627-630), but using Φ instead of sunspot area, our results are consistent with CME productivity increasing with active region size.

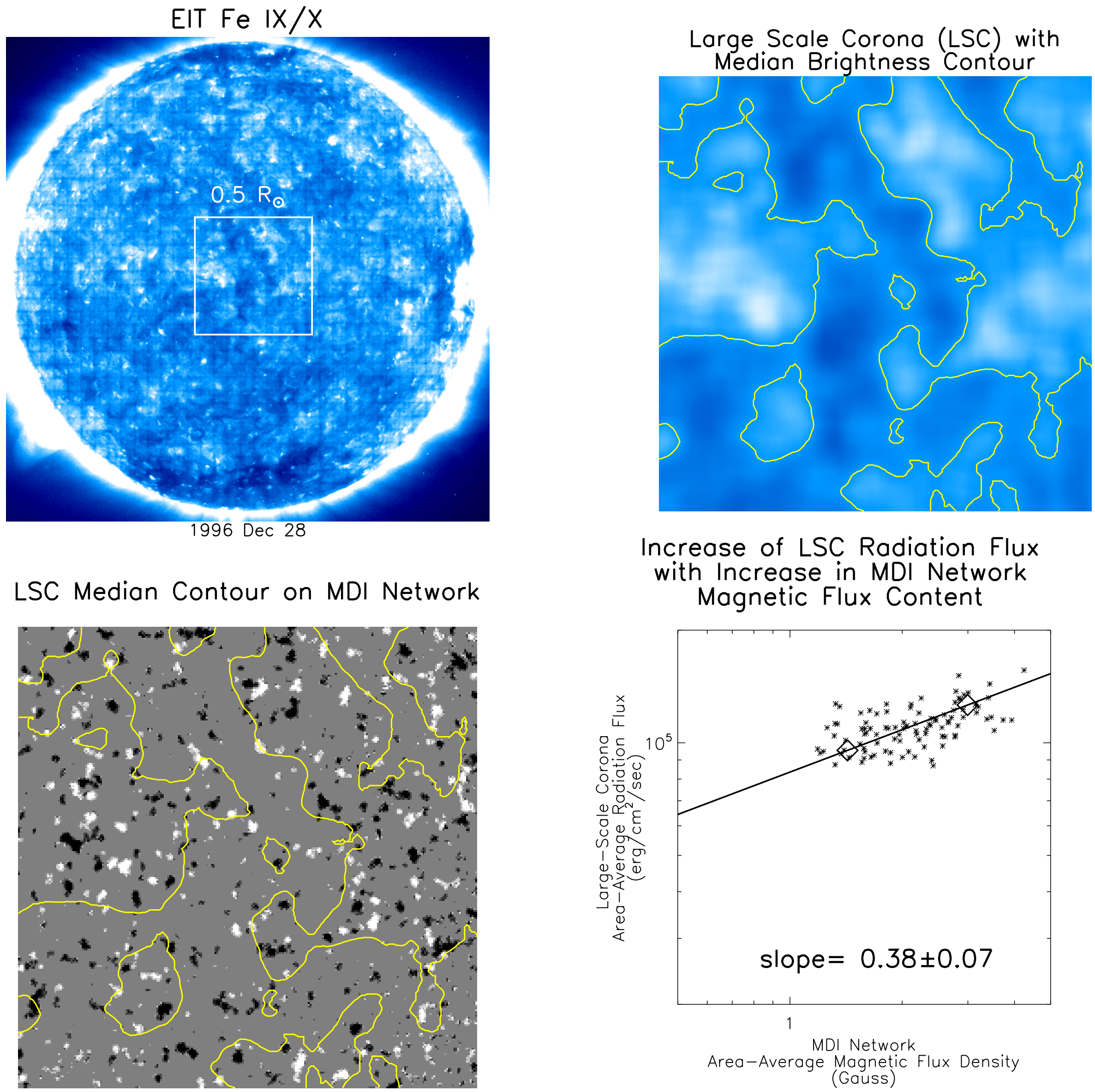


Falconer Figure1. Example observations, global nonpotentiality measurements, and observed CME productivity for 12 active regions. Top left: MSFC vector magnetogram (on 6 June 2000) showing strong global shear and twist in the magnetic bipole rooted in and around a delta sunspot. Top right: LASCO C3 image of the halo CME produced by the active region along with an X flare on the day of the magnetogram. Bottom: Plot of measured length of strong-shear main neutral line (L_{SS}) versus measured global net current (I_N) in our 12 active regions. Blue crosses are for active regions that produced no CMEs within ±2 days of the magnetogram; thin red crosses indicate production of 1 CME; thick red crosses indicate production of 2 CMEs within ±2 days. The arrow points to the (I_N,L_{SS}) point measured from the example magnetogram.

Coronal Heating and the Magnetic Flux Content of the Network

David Falconer, Ron Moore, Jason Porter, & David Hathaway
(NASA/MSFC/NSSTC/Space Science Department)

Previously, from analysis of SOHO/EIT coronal images in combination with Kitt Peak magnetograms (Falconer et al 1998, *ApJ*, **501**, 386-396), we found that the quiet corona is the sum of two components: the large-scale corona and the coronal network. The large-scale corona consists of all coronal-temperature (million-degree) structures larger than the width of the chromospheric network lanes (> 10,000 km). The coronal network (1) consists of all coronal-temperature structures of the scale of the network lanes and smaller (< 10,000 km), (2) is rooted in and loosely traces the photospheric magnetic network, (3) has its brightest features seated on polarity dividing lines (neutral lines) in the network magnetic flux, and (4) produces only about 5% of the total coronal emission in quiet regions. The heating of the coronal network is apparently magnetic in origin. Here, from analysis of EIT coronal images of quiet regions in combination with magnetograms of the same quiet regions from SOHO/MDI and from Kitt Peak, we examine the other 95% of the quiet corona and its relation to the underlying magnetic network. We find: (1) Dividing the large-scale corona into its bright and dim halves divides the area into bright "continents" and dark "oceans" having spans of 2-4 supergranules. (2) These patterns are also present in the photospheric magnetograms: the network is stronger under the bright half and weaker under the dim half. (3) The radiation from the large-scale corona increases roughly as the cube root of the magnetic flux content of the underlying magnetic network. In contrast, Fisher et al (1998, ApJ, 508, 985-998) found that the coronal radiation from active regions increases roughly linearly with the magnetic flux content of the active region. We assume, as is widely held, that nearly all of the large-scale corona is magnetically rooted in the network. Our results, together with the result of Fisher et al (1998), suggest that either the coronal heating in quiet regions has a large non-magnetic component, or, if the heating is predominantly produced via the magnetic field, the mechanism is significantly different than in active regions. This work is funded by NASA's Office of Space Science through the Solar Physics Supporting Research and Technology Program and the Sun-Earth Connection Guest Investigator Program.

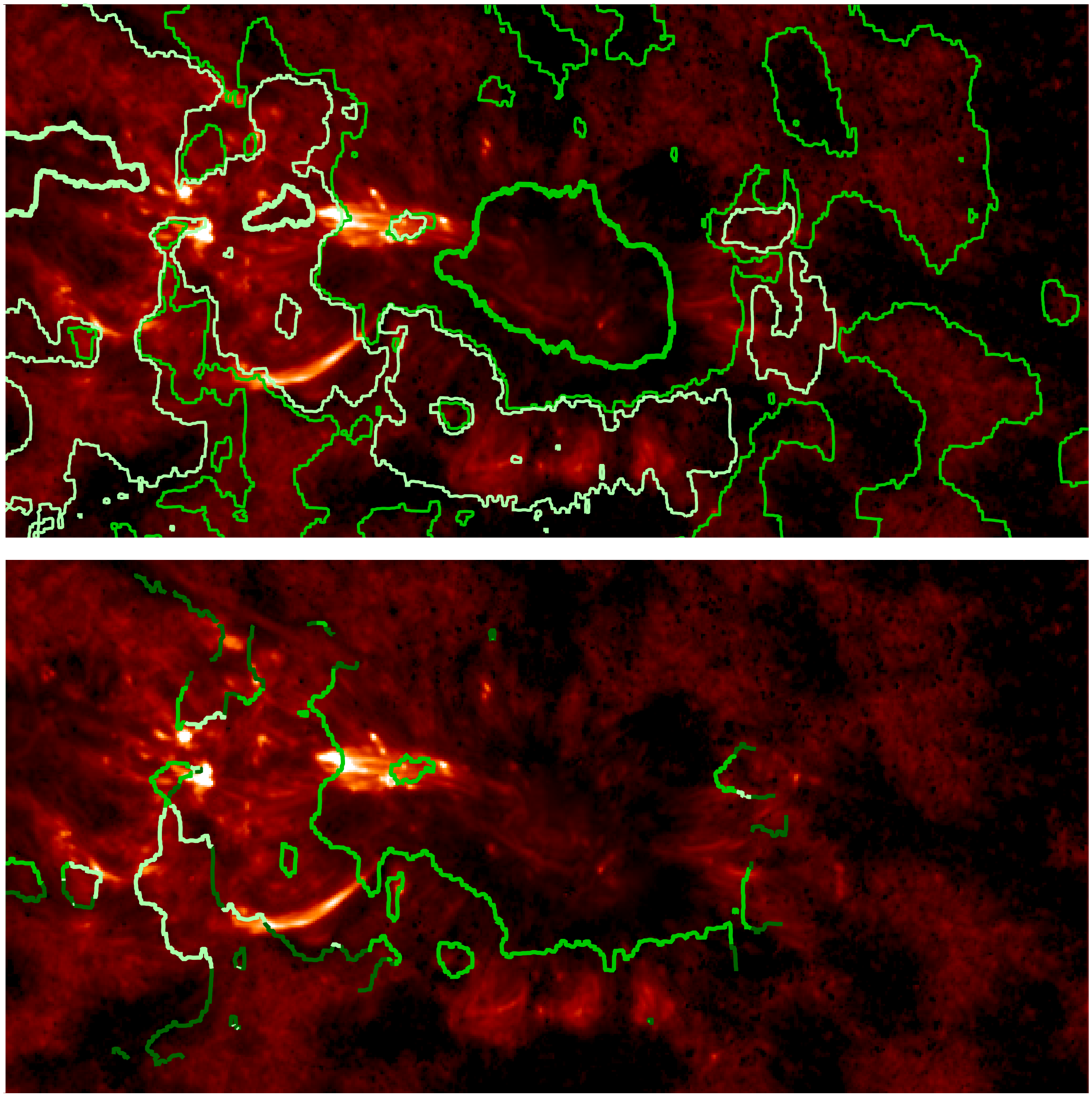


Falconer Figure1. Observed dependence of coronal heating on the magnetic flux content of the underlying network. Upper left: EIT Fe IX/X corona on 28 Dec 1996. The central square region was analyzed on four consecutive days, 27-30 Dec 1996. Upper right: Bright and dim halves of the large-scale corona in the central square on 28 Dec 1996. Lower left: Magnetic network (from an MDI full-disk magnetogram) under the bright and dim halves of the large-scale corona in the central square on 28 Dec 1996. Lower right: Correlation of coronal radiation with the magnetic flux content of the network. The upper diamond is the four-day average for the bright half; the lower diamond is the four-day average for the dim half.

Magnetic Characteristics of Active Region Heating Observed with TRACE, SOHO/EIT, and Yohkoh/SXT

J. G. Porter, D. A. Falconer, and R. L. Moore (NASA/MSFC/NSSTC/Space Science Department)

Over the past several years, we have reported results from studies that have compared the magnetic structure and heating of the transition region and corona (both in active regions and in the quiet Sun) by combining X-ray and EUV images from *Yohkoh* and SOHO with photospheric magnetograms from ground-based observatories. Our findings have led us to the hypothesis that most heating throughout the corona is driven from near and below the base of the corona by eruptive microflares occurring in compact low-lying "core" magnetic fields (i.e., fields rooted along and closely enveloping polarity inversion lines in the photospheric magnetic flux). We now extend these studies to cooler plasmas, incorporating sequences of UV and EUV images from TRACE (in addition to SOHO and Yohkoh data) into a comparison with longitudinal magnetograms from Kitt Peak and vector magnetograms from MSFC. These studies support the previous results regarding the importance of core-field activity to active region heating. Activity in fields associated with satellite polarity inclusions and/or magnetically sheared configurations is especially prominent. This work is funded by NASA's Office of Space Science through the Sun-Earth Connection Guest Investigator Program and the Solar Physics Supporting Research and Technology Program.

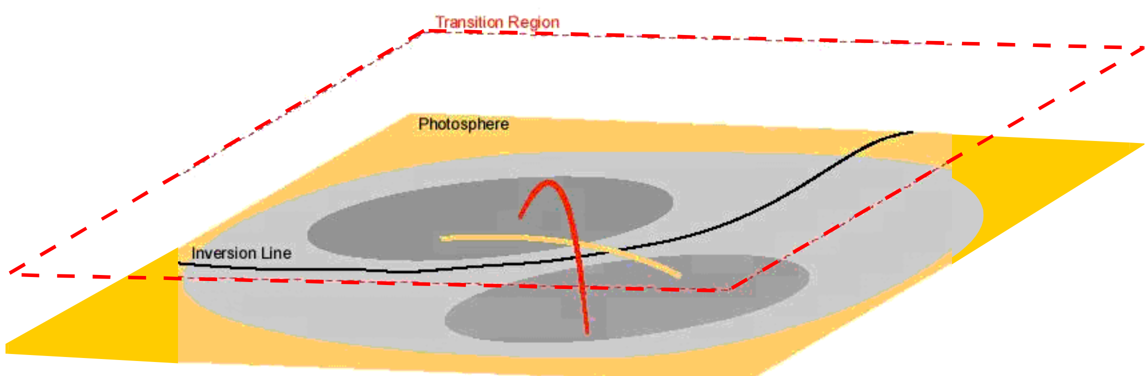


Porter Figure 1. Magnetic locations of C IV microflares in an active region. This single frame from a "C IV" movie derived from TRACE broadband UV data for AR 8323 (September 2, 1998), shows several bright UV microflares in progress. In the top frame contours of longitudinal magnetic field (from Kitt Peak /NSO) are superposed. Thin lines correspond to 25G; thick lines correspond to 500 G. In the bottom frame the superposed lines show locations of neutral lines having transverse field strength >100 G (from NASA/MSFC vector magnetograph observations). The darkest green lines correspond to transverse field strengths between 100G and 150 G. Medium green corresponds to transverse strength > 150 G and low (<45^{o}) shear, bright green corresponds to transverse strength > 150 G and high (>45^{o}) shear.

SUMI: The Solar Ultraviolet Magnetograph Investigation

J. G. Porter, J. M. Davis, G. A. Gary, E. A. West (NASA/MSFC), D.M. Rabin, R. J. Thomas, and J. M. Davila (NASA/GSFC)

A major focus of solar physics is the measurement of the temporal and spatial variability of solar magnetic fields from the photosphere into the lower corona, together with the study of how their behavior produces the dynamic phenomena in this region such as flares and CMEs. Considerable success has been achieved in the characterization of the full vector field in the photosphere, where β, the ratio of the gas pressure to the magnetic pressure, is ≥1. At higher levels in the atmosphere where β <<1, the magnetic field (through the Lorentz force) controls the structure and dynamics of the solar atmosphere, and rapid changes in structure with release of energy become possible. However, observations of the field at these higher levels have proven to be difficult, placing a serious limitation on our understanding of the physical processes occurring there. This poster will discuss the Solar Ultraviolet Magnetograph Investigation (SUMI), a hardware development study for an instrument capable of measuring the polarization in ultraviolet lines of C IV and Mg II formed in the transition region and upper chromosphere. We are currently developing optical technologies necessary to build an instrument that will achieve a major advance in performance over that of earlier attempts (e.g., SMM/UVSP). Initially configured as a sounding rocket payload, such a UV magnetograph would allow us to make exploratory measurements extending the observation of solar magnetic fields into new and dynamic regimes.



Porter Figure 1. Transition Region magnetic field measurements – magnetic shear vs. height. This figure represents an expected configuration of the photospheric and transition region/coronal magnetic fields in a stressed δ-spot active region. A highly sheared low-lying core field is enclosed within a more nearly potential arcade of loops at some higher level. Whether the shear decreases with height between the photosphere and chromosphere in such a region, as we might expect from the overall change, is not known. The shear might even increase over this lower range. On an initial rocket flight, our UV vector magnetograph should have sufficient observing time to measure the vector field in Mg II and the longitudinal field in C IV. (Measuring the full vector field in C IV is likely to require longer observations.) First-look data such as these can show whether the shear increases or decreases with height between the photosphere and chromosphere. In addition, such data could show how much of the core field closes below the height of formation of Mg II. Repeated measurements may find changes in rapidly-evolving active regions as the core fields reconnect to change the shear, even over the short time of a rocket flight. In more complicated regions such as those involving a satellite spot, comparison of the inversion line seen in the longitudinal C IV measurement with the inversion line calculated from photospheric magnetographs may show substantial shifts, for comparison with field extrapolations.

This work is supported by NASA through the SEC Program in Solar Physics and the program for Technology Development for Explorer Missions and Sofia.

Appendix E: Participants

1. Bala Balasubramaniam (NSO)
2. Tom Berger (Lockheed Martin)
3. Tom Bogdan (HAO)
4. Jo Bruls (KIS)
5. John Davis (MSFC/NSSTC)
6. Thierry Emonet (U. Chicago)
7. David Falconer (MSFC/NSSTC/UAH)
8. Andrzej Fludra (Rutherford Appleton Lab.)
9. Terry Forbes (U. New Hampshire)
10. Allen Gary (MSFC/NSSTC)
11. Phil Goode (NJIT/BBSO)
12. Mona Hagyard (MSFC/NSSTC)
13. David Hathaway (MSFC/NSSTC)
14. Christoph Keller (NSO)
15. Jim Klimchuk (NRL)
16. Alexander Kosovichev (Stanford U.)
17. K D Leka (Colorado Res. Assoc./NWRA)
18. Haosheng Lin (U. Hawaii)
19. Yang Liu (Stanford U.)
20. Dana Longcope (Montana State U.)
21. Ron Moore (MSFC/NSSTC)
22. Alexei Pevtsov (NSO)
23. Jason Porter (MSFC/NSSTC)
24. Doug Rabin (GSFC)
25. Ed Reichmann (MSFC/NSSTC)
26. Dave Rust (Johns Hopkins U./APL)
27. Rob Rutten (U. Utrecht)
28. Alexander Ruzmaikin (JPL)
29. Karel Schrijver (Lockheed Martin)
30. Bob Stein (Michigan State U.)
31. Alphonse Sterling (MSFC/NSSTC/NRC)
32. Peter Sturrock (Stanford U.)
33. Steve Suess (MSFC/NSSTC)
34. Ted Tarbell (Lockheed Martin)
35. Han Uitenbroek (NSO)
36. Aad Van Ballegooijen (CfA)
37. Lidia vanDriel-Gesztelyi (MSSL)
38. Haimin Wang (NJIT/BBSO)
39. Ed West (MSFC/NSSTC)
40. Shi Tsan Wu (UAH)
41. Yohei Yamauchi (MSFC/NSSTC/NRC)