

High Resolution Studies of Solar Magnetic Activity

Philip R. Goode (PI), Haimin Wang and Carsten Denker

New Jersey Institute of Technology
Center for Solar-Terrestrial Research

Proposal Summary

Our current three year SRT grant started on Feb. 1, 2003. This grant provides primary, backbone support for BBSO. In the past two years since this grant started, the observatory has remained highly productive – both scientifically and in the development of requisite instrumentation. We have produced over 80 scientific papers under the first two years of this SRT support. The most notable achievements are the discoveries of rapid and permanent magnetic structure changes associated with most large flares, and understanding the properties of electric currents in areas of magnetic reconnection that are responsible for the onset of flares and the acceleration of CMEs. These provide a solid starting point for a system view of solar activity and its disturbances through heliosphere to Earth. At present, we are fine-tuning a high-order adaptive optics (AO) system for BBSO, and are building a 1.6-m clear aperture, off-axis telescope, including crucial focal plane instruments, which will provide unique and essential support for current (RHESSI, SoHO, TRACE) and upcoming (SDO, STEREO and Solar-B) NASA satellites to study the Sun.

The next three years will be a critical time for BBSO, as the new 1.6 m telescope is expected to start routine operation in 2006. Therefore, we are expecting breakthroughs in several areas of solar physics. Our program will emphasize sustained campaigns of high resolution and high cadence studies of magnetic fields and the solar atmosphere – efforts for which we are ideally suited. The latest ATST site survey results demonstrated that BBSO is an unique site with sustained (7 to 8 hours daily) very good seeing (good enough to be corrected by AO), which is most suitable for the study of the ever-changing solar activity and space weather, important components in the theme of NASA's Sun-Earth Connection. In fact, nearly all of BBSO's observing campaigns combine BBSO data with that from RHESSI, TRACE, SoHO, etc. to maximize the scientific output from NASA satellites. BBSO data are publicly available in near real-time.

We are now well-along in developing two Fabry-Perot filter systems for the AO equipped 1.6 m telescope. One in the visible and the other in the near infrared for more advanced polarimetric and spectroscopic studies of dynamic phenomena, such as active region development, flaring, filament activation and eruptions. Both of these have already produced useful scientific data, although more development is on-going.

A parallel computing system for real-time speckle phase diversity reconstruction to obtain real-time diffraction limited images over the entire field of view is now on-line for speckle reconstruction.

Proposed Scientific Programs:

1. *Comprehensive studies of vector magnetic fields associated with flares, filament eruptions and CMEs, to understand the triggering of the events and the evolution of the magnetic topology.* These are the central components of NASA's Sun-Earth Connection theme, and to accomplish these we will combine BBSO data with that from TRACE and SoHO, and subsequently SDO, Solar-B and STEREO.
2. *High-cadence (100ms) and high resolution (0.2 arcsec) studies of solar flare emissions, in particular, in combination with NASA's RHESSI hard X-ray observation, to understand the nature of the elementary bursts in the flares, therefore, the acceleration mechanisms of flares.*
3. *Sustained sub-arc second resolution studies of active regions and the quiet Sun in visible and near infrared.* We expect to understand the mass flows of flare producing active regions; the atmospheric structure of faculae, umbral dots and light bridges; the emission mechanisms of flares at 1.6 microns; and more accurate measurement of magnetic fields in the photosphere. This task is complementary to the Solar-B mission: we have a much larger aperture telescope, and have infrared capability, while Solar-B provides continuous seeing-free observations.
4. *Space weather.* Synoptic observations and their application in automated and real-time predictions, via e-mail, of solar activity and geomagnetic activity. This includes target selection for NASA satellites.

A. Results from Prior S&RT Support

On February 1, 2003, our current three year SR&T grant started. This grant is one of two backbone grants supporting BBSO.

The work we propose in the renew this grant is fundamentally connected to the basic goal of the Sun-Earth Connection theme to “understand the origins and societal impacts of variability in the Sun-Earth Connection” by developing “the capability to predict solar activity and the evolution of solar disturbances” and to “understand the role of solar variability in driving space climate”. BBSO is one of two solar observatories in the US with a telescope, instrumentation and a site that enables high resolution studies of the Sun. The other is the National Solar Observatory (NSO) with the Dunn Solar Telescope. Due to the broad and important community service mission of NSO, BBSO is the only one that can work in sustained campaigns – essential for the broadly-based, high resolution observations needed to gather unique data to understand the fundamental nature of solar magnetism and its evolution. At the present moment, “high resolution” means observations with telescopes ≤ 1 m aperture. Our capability of running sustained campaigns is at the core of our ability to provide unique, complementary supporting data in the community’s efforts to study and understand our dynamic star, including complementary data from BBSO for RHESSI, SoHO and TRACE to maximize their scientific output. As well, observing campaigns are essential to determine the origin of “space weather”, which arises from solar magnetic storms and can impact Earth. To ensure a unique and significant scientific role for BBSO, we have made fundamental changes in the observatory’s instrumentation since 1997 with the most fundamental about to come.

The advances to-date in instrumentation were critical for improving the quality of our observations, especially for high resolution studies, as well as giving us experience and confidence for the next steps that are now well-underway leading up to our 1.6 m off-axis solar telescope, which will provide essential, next-generation support for on-going and upcoming NASA missions to study the Sun. To date improvements have yielded better data helping our research group to be even more productive, as evidenced by over 80 publications in the two years since February 2003, including seven in ApJ Letters. NJIT continues to strongly support our efforts. NJIT would match this grant with \$300 K for new equipment for the observatory.

BBSO highly prizes its special role in the education of the next generation of scientists who build instruments. We graduated 4 Ph. D. students from 2002 to 2004. We currently have 15 Ph. D. students (including 3 women), and 3 of the 15 will graduate in 2005.

BBSO has an unpaid, outside Advisory Board, which meets bi-annually to critique our efforts. The Board’s report is made to the Provost of NJIT and the management of BBSO. The current members of the board are Len Fisk (University of Michigan, Chair), Steven Koonin (Caltech), Jeff Kuhn (University of Hawaii), and Spiro Antiochos (NRL). We respect their advice and use it to improve the observatory.

Since NJIT began operating BBSO, its telescope time and data have been open to the community. Many scientists have had observing time.

A partial list includes Steven Koonin, Ken Libbrecht and Hal Zirin, and others from Caltech; Sara Martin, Helio-Research; George Fisher, UC Berkeley; Chris Johns-Krull, Rice University; Terry Kucera, N. Gopalswamy and Peter Gallagher, GSFC; Ronald Moore, MSFC; Richard Canfield, Montana State University; Thomas Rimmele, NSO/SPO; Steven White, University of Maryland; Timothy Bastian, VLA/NRAO; several from China under our NSF-INT US-China Exchange Program; several from Korea under our NSF-INT US-Korea Exchange Program; Oddbjorn Engvold, University of Oslo, Norway; Hardi Peter, Keipenheuer Instiute, Germany; James McAteer, J.G. Doyle, David Garcia and Thanassis Katsiyannis, Queens University/Armagh Observatory, Belfast; and Eugenia Christopoulou, University of Patras, Greece; and Lidia Conatarino, INAF/Catania Astrophysical Observatory.

Further, several Ph. D. students from around the world are using BBSO data as a central part of the work on their theses. Data requests come to BBSO on a daily basis from around the world. Since the summer of 2002,

a substantial part of our data has been available in near real-time on the web (www.bbsso.njit.edu). We are an active participant in the Virtual Solar Observatory (VSO). For users of our telescopes and data, we only ask that they acknowledge BBSO in their resulting publications. Many observers use our data to help plan their observing campaigns. Very soon, all the BBSO data from the previous twelve months, on a rolling basis, will be online, supported by a search engine to aid users.

BBSO achievements in instrumentation will be included in the on-going instrumentation section, while for the remainder of this section, we focus on the results of our scientific programs. Our publications, in the form of BBSO Bluebooks, are also available on our website (solar.njit.edu/preprints), and are numbered starting from 1000.

A.1 High Cadence Flare Studies

Over the last several years, BBSO scientists have carried out high cadence (10 ms to 100 ms) flare studies, in conjunction with RHESSI. Ji et al. (2004, BBSO #1202) used Hard X-Ray (HXR) images and spectra and the time delay between BBSO H α blue-wing emissions and HXRs to distinguish between the thermal and non-thermal emissions. Ji et al. (2003, BBSO #1189) observed the fine temporal and spatial structure of a filament eruption on 2002 May 27 following an M2-class flare. The event appears to be a “failed eruption,” as the filament material, seen in absorption by TRACE, first accelerated then decelerated as it approached its peak height from where the filament threads drained back to the Sun.

A.2 Study of Microflares

Qiu et al. (2004, BBSO 1254) studied solar microflares using coordinated RHESSI hard X-ray and Owens Valley Radio Observatory (OVRO) microwave observations. Using hundreds of events as samples, we studied event distribution with respect to flux, solar activity, and proximity to active regions, in comparison to those of larger scale flares. Non-thermal properties of microflares were investigated through spectral analysis of X-rays and microwaves. We found evidence hinting at the existence of high-energy, microwave-emitting electrons that have a much harder spectrum than electrons detected by RHESSI in hard X-ray emission.

For a different perspective, Liu et al. (2004 BBSO 1208) presented a study of the morphology of many microflares jointly observed by RHESSI and BBSO. In almost all of the events, the hard X-ray sources were elongated structures connecting two H α bright kernels in magnetic fields of opposing polarities. These results suggest that, similar to large flares, the X-ray sources of the microflares represent emission from small magnetic loops and that the H α bright kernels indicate harder X-ray emission from the flare loop footpoints, which are lower down in the atmosphere. Spectral fitting results indicate a nonthermal origin of the X-ray emission above 10 keV during the impulsive phase of all the events, and the photon spectra of the microflares associated with type III bursts (events in which frequency drops with propagation) are generally harder than those without type III bursts.

A.3 Magnetic Field Evolution and Flares

BBSO’s Digital Vector MagnetoGraph (DVMG) system has shown its power in high resolution and high cadence studies of the evolution of magnetic fields. Wang et al. (2002b, BBSO 1158) demonstrated that the rapid disappearance of a small sunspot, which can be explained by fast magnetic reconnection or an emerging magnetic bubble. Abramenko et al. (2003, BBSO 1182) studied the evolution of the magnetic structure of four events observed from BBSO, and convincingly demonstrated the avalanche theory of flares. More recently, Wang et al. (2004 BBSO 1201) showed strong evidence that penumbral segments decayed rapidly and permanently right after three X-class solar flares. We proposed a possible explanation that magnetic fields permanently change from a highly inclined to a more vertical configuration, apparently over about an hour, or less, after the flares.

Liu et al. (2005, BBSO 1255) furthered this work by studying the relationship between the change in δ spot structures and associated major flares. We presented observations of seven events in which part of the penumbral segments in the outer δ spot structure decay rapidly after major flares; meanwhile, the neighboring umbral cores and/or inner penumbral regions become darker. To explain these observations, we proposed a reconnection picture in which the two components of a δ spot become strongly connected after the flare. The penumbral fields change from a highly inclined to a more vertical configuration, which is seen as penumbral decay. The umbral core and inner penumbral region become darker as a result of increasing longitudinal and transverse magnetic field components (for more detail, see Fig. 3 in **B.2.1**). These studies extensively used data from EIT and MDI on board SOHO and from TRACE.

A.4 Study of Coronal Mass Ejections

Qiu et al. (2004, BBSO 1221) verified that the rate of magnetic reconnection in the low corona is temporally correlated with the evolution of nonthermal flare emissions in hard X-rays and microwaves. In addition, however, our new observations revealed a temporal correlation between the magnetic reconnection rate and the directly observed acceleration of the accompanying coronal mass ejection (CME) and filament in the low corona, thus establishing a correlation with the rising “flux rope”. By measuring the magnetic flux swept through by flare ribbons as they separate in the lower atmosphere, we inferred the magnetic reconnection rate in terms of the reconnection electric field inside the reconnecting current sheet (RCS) and the rate of magnetic flux convected into the diffusion region (where field is undergoing reconnection and is not frozen-in).

Jing et al. (2004 BBSO 1236) presented a statistical study of 106 filament eruptions, which were automatically detected by a pattern recognition program implemented at BBSO using $H\alpha$ full-disk data from 1999 to 2003. After comparing with LASCO and MDI data, we found strong correlation among filament eruptions, CMEs, new flux emergence, flares and magnetic helicity.

A.5 Space Weather Forecasting

We are continuing to carry out a statistical study of filament eruptions and flares, their underlying magnetic structure, the onset of CMEs, interplanetary magnetic clouds and geomagnetic storms. The results from our statistical study have provided better tools for predicting abrupt changes in solar activity, and the often consequent geomagnetic storms. Yurchyshyn et al. (2003, BBSO 1168) proposed a novel method to predict geo-effective CMEs and the arrival of geomagnetic storms. So far, the success rate is 100% based on the study of about 20 events. We have used data from ACE and SOHO for these studies. As well, BBSO has played a critical role for target selections for joint observation using NASA satellites (e.g., TRACE and RHESSI).

A.6 Publications Under Current SR&T Support

The discussion above highlights our scientific accomplishments over the past two years. Because of limited space, we list only selected publications (29 of 85) from the period of our present SR&T support. We emphasize that 7 of our publications were in ApJ Letters and 26 in ApJ and that all relied on NASA data combined with BBSO data. Please check the home page (solar.njit.edu/preprints) for a complete list with downloadable copies.

Selected BBSO Publications from February 2003 to Decemeber 2004:

BBSO 1141: *Transient Shear Flows Observed in Active Regions: Magnetic Helicity Pumping by Twisted Flux Tube Expansion*, J. Chae, Y.-J. Moon, D. M. Rust, H. Wang & P. R. Goode, 2003, JKAS, 36, 33

BBSO 1157: *Periodic Motion Along a Solar Filament Initiated by a Subflare*, J. Jing, J. Lee, T. J. Spirock, Y. Xu & H. Wang, 2003, ApJL, 584, L103

BBSO 1168: *Correlation Between Speeds of CMEs and the Intensity of Geomagnetic Storms*, V. B. Yurchyshyn, H. Wang & V. I. Abramenko, 2003, Space Weather, Vol. 2, No 2.

- BBSO 1179:** *1.6M Solar Telescope in Big Bear - The NST*, P. R. Goode, C. Denker, L. I. Didkovsky, J. R. Kuhn & H. Wang, 2003, *J. Korean Astron. Soc.*, 35, 1
- BBSO 1182:** *Signature of Avalanche in Solar Flares as Measured by Photospheric Magnetic Fields*, V. I. Abramenko, V. B. Yurchyshyn, H. Wang, T. J. Spirock & P. R. Goode, 2003, *ApJ*, 597, 1135
- BBSO 1183:** *Study of Ribbon Separation and Filament Eruption of a Quiet-Sun Flare*, H. Wang, J. Qiu, J. Jing & H. Zhang, 2003, *ApJ*, 605, 931
- BBSO 1186:** *Magnetic Helicity Changes of Solar Active Regions by Photospheric Horizontal Motions*, Y.-J. Moon, J. Chae & Y. D. Park, 2003, *J. Korean Astron. Soc.*, 36, 37
- BBSO 1189:** *Observations of the Failed Eruption of a Filament* H. Ji, H. Wang, E. J. Schmahl, Y.-J. Moon & Y. Jiang, 2003, *Ap.J. Letters*, 595, L135
- BBSO 1191:** *Relationship Between CME Kinematics and Flare Strength*, Y.-J. Moon, G.S. Choe, H. Wang, Y.D. Park, & C.Z. Cheng *JKAS*, 2003, 36, 61
- BBSO 1199:** *Halpna Dimmings Associated with the X1.6 Flare and Halo CME on October 19, 2001* Y. Jiang, H. Ji, H. Wang & H. Cheng, 2003, *Ap.J. Letters*, 597, L161
- BBSO 1201:** *Rapid Penumbra Decay Following Three X-Class Flares*, H. Wang, C. Liu, J. Qiu, N. Deng, P. R. Goode & C. Denker 2003, *Ap.J. Letters*, 601, L195
- BBSO 1202:** *Observations of Non-Thermal and Thermal Hard X-Ray Spikes in an M-Class Flare*, H. Ji, H. Wang, E. J. Schmahl, J. Qiu & Y. Zhang 2004, *Ap.J.*, 607, L55
- BBSO 1208:** *Studies of Microflares in RHESSI Hard X-Ray, BBSO Halpna and MDI Magnetograms* C. Liu, J. Qiu, D. E. Gary, S. Krucker & H. Wang 2003, *Ap.J.*, 604, 442
- BBSO 1209:** *Evidence of Rapid Flux Emergence Associated with the M 8.7 Flare on 2003 July 26*, H. Wang, J. Qiu, J. Jing, T. J. Spirock, V. B. Yurchyshyn, V. I. Abramenko, H. Ji & P. R. Goode 2004, *Ap.J.*, 605, 931
- BBSO 1211:** *Magnetic Field, Halpna and RHESSI Observations of the July 23, 2002 Gamma-ray Flare*, V. B. Yurchyshyn, H. Wang, V. I. Abramenko, T. J. Spirock & S. Krucker 2004, *Ap.J.* 605, 546
- BBSO 1221:** *Magnetic Reconnection and Mass Acceleration in a Flare - Coronal Mass Ejection Events*, J. Qiu, H. Wang, C. Z. Cheng & D. E. Gary, 2004, *Ap.J.*, 604, 900
- BBSO 1223:** *High-Spatial Resolution Combining High-Order Adaptive Optics, Frame Selection, and Speckle Masking Reconstruction*, C. Denker, D. Mascarinas, Y. Xu, W. Cao, G. Yang, H. Wang, P. R. Goode & T. R. Rimmele 2004, *Solar Physics*, in press
- BBSO 1224:** *Near Infrared Observations at 1.56 μ of the 2003 October 29 X10 White-Light Flare*, Y. Xu, W. Cao, C. Liu, G. Yang, J. Qiu, J. Jing, C. Denker & H. Wang 2004, *Ap.J. Letters*, 607, L131
- BBSO 1227:** *Automatic Solar Flares Tracking Using Image Processing Techniques*, M. Qu, F. Y. Shih, J. Jing & H. Wang 2004, *Solar Physics*, in press
- BBSO 1228:** *Magnetic Helicity Change Rate Associated With X-Class and M-Class Flares*, K. Hartkorn & H. Wang 2004, *Solar Physics*, in press
- BBSO 1236:** *On the Relation Between Filament Eruptions, Flares and Coronal Mass Ejections*, J. Jing, V. B. Yurchyshyn, G. Yang, Y. Xu & H. Wang 2004, *Ap.J.*, 614, 1054
- BBSO 1238:** *Distribution of the Magnetic Flux in Elements of the Magnetic Field in Active Regions*, V. I. Abramenko & D. W. Longcope 2004, *Ap.J.*, in press
- BBSO 1239:** *Statistical Distributions of Speeds of Coronal Mass Ejections*, V. B. Yurchyshyn, S. Yashiro, V. I. Abramenko, H. Wang & N. Gopalswamy 2004, *Ap.J.* in press
- BBSO 1242:** *Properties of Remote Flare Ribbons Associated with CMEs*, H. Wang 2004, *Ap.J.* in press
- BBSO 1245:** *Near Infrared (NIR) Achromatic Phase Retarder*, J. Ma, J. Wang, W. Cao, C. Denker & H. Wang Oct. 2004, *Proc. SPIE Vol. 5523*, p. 139-147
- BBSO 1247:** *Magnetic Reconnection Rate and Flux-Rope Acceleration of Two-Ribbon Flares* J. Jing, J. Qiu, J. Lin, M. Qu, Y. Xu & H. Wang, 2004, *Ap.J.*, in press
- BBSO 1254 :** *Hard X-Ray and Microwave Observations of Microflares*, J. Qiu, C. Liu, D. E. Gary, G. M. Nita & H. Wang, 2004, *Ap.J.*, 612, 530

- BBSO 1255** : *Rapid Change of Delta Spot Structure Associated with Seven Major Flares*, C. Liu, N. Deng, Y. Liu, D. Falconer, P. R. Goode, C. Denker & H. Wang, 2005, Ap.J. in press
- BBSO 1257** : *Photospheric Shear Flows Along the Magnetic Neutral Line of Active Region 10486 Prior to an X10 Flare*, G. Yang, X. Yang, W. Cao, H. Wang, C. Denker, & T. R. Rimmele, 2004, Ap.J. Letters, 617, L151

B. Proposed Research

Of the two US observatories capable of making high resolution observations of the Sun, BBSO is the one operating in a campaign mode. We believe that a more fundamental understanding of solar magnetic fields and the solar atmosphere depends on sustained, higher resolution and higher cadence observations. Over the past few years, we have substantial accomplishments that position us to advance to the next level of our scientific objectives, which will center on understanding energy release and transport on different scales in the solar atmosphere, as well as the associated evolution of magnetic fields. Our research requires a continuing effort in instrument development, and a dedicated scientific team to make and analyze new observations. At the same time, we will also continue to emphasize one practical application – the prediction of solar activity and its geo-effectiveness. The additional instrumentation that we are developing enhances various aspects of the proposed science. Because of the wide-ranging and diverse scope of the proposed projects, and due to the page limit on proposals, we can only briefly describe each scientific program.

The Advanced Technology Solar Telescope (ATST) site survey was initiated in 2000 and has identified at the end of a four-year survey three excellent sites for solar observing: Big Bear Solar Observatory, California – Mees Solar Observatory, Haleakala, Maui, Hawaii – Observatorio Roque de los Muchachos, La Palma, Canary Islands, Spain (Hill et al. 2004). All three sites are suitable for high-spatial resolution observations. Haleakala and La Palma have strong advantages for coronal science. However, only BBSO – the mountain-lake site – provides consistent seeing conditions with extended periods of excellent seeing from sunrise to sunset (see Figure 1). Periods of excellent seeing (sufficient to be corrected by AO) are limited to one or two hours in the early morning for the Pacific/Atlantic mountain-island sites Haleakala/La Palma, where the seeing deteriorates once the ground heats up and a turbulent boundary layer has been established. The lake at BBSO effectively suppresses this boundary layer and makes the observatory ideally suited for sustained high-resolution and synoptic observing programs.

B.1 Current Instrumentation Projects

There are several on-going instrumentation projects at BBSO. Now, we briefly discuss the ones that will have an impact on the proposed work. Our instrumentation projects are focused on highest possible resolution observations of solar magnetic activity. These instruments are complementary to on-going (SoHO, RHESSI and TRACE) and up-coming NASA missions (SDO, STEREO and Solar-B). Solar-B will provide high resolution observation of solar magnetic fields, however, BBSO will be unique for its large aperture telescope and infrared capability.

B.1.1 New Solar Telescope (NST) at BBSO

We are building a new, off-axis telescope system at BBSO. BBSO/NJIT, in collaboration with the University of Hawaii (UH) and Korean Astronomical Observatory, have teamed to upgrade BBSO by replacing its principal 65-cm aperture telescope (which will be jointly donated by NJIT and Caltech to Prairie View A&M) with a modern, off-axis 1.6-m clear aperture instrument with a $180'' \times 180''$ field of view (FOV). The new telescope

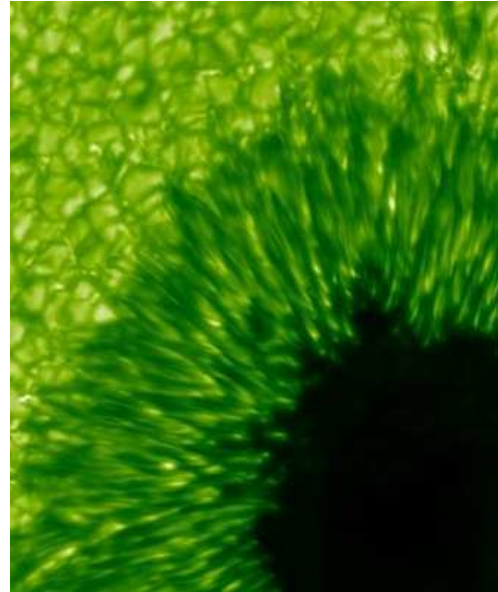
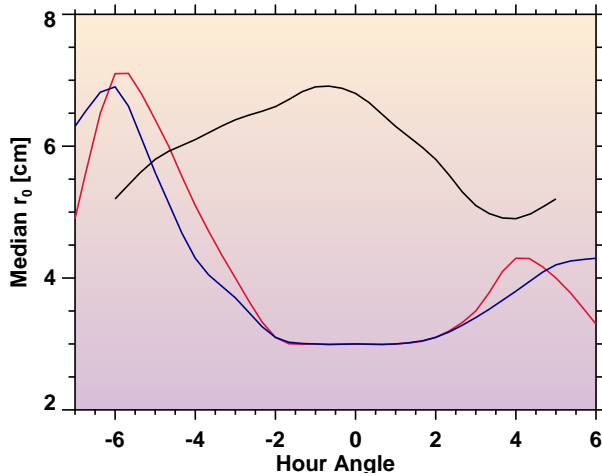


Figure 1: Left panel: The median value of the r_0 (Fried parameter, a rough measure of the diffraction limit, $r_0 \geq 5.5$ cm is required for correction by AO) measurements from the S-DIMM instrument (principal site survey instrument, see www.atst.nso.edu/site/ for details) at the three finalists to be the ATST site (Big Bear, Haleakala, and La Palma) as a function of hour angle (adapted from Figure 10.13 in Hill et al. 2004). Right panel, BBSO often obtains speckle-reconstructed, diffraction limited images, even without the AO system. This is an example of such a high resolution image in green continuum.

offers a significant improvement in ground-based high angular resolution capabilities, and enhances our continuing program to understand photospheric magneto-convection and chromospheric dynamics. These are the drivers for what is broadly called space weather – an important problem, which impacts human technologies and life on Earth. This New Solar Telescope (NST) requires a new, larger dome with louvers to ensure proper airflow inside the dome. The new dome will be installed in Fall of 2005. The primary mirror is being figured at Steward Observatory Mirror Lab, the active mirror cell is presently out for bid, and the optical support structure is in the final stage of design. The secondary mirror will be fixed to a hexapod, which is currently being tested. The NST optical and software control design will be similar to the existing SOLAR-C (UH) and the planned ATST facility led by NSO – all three are off-axis designs. We have full funding for this project. The planned downtime for the transition is minimized to 3 to 6 months over the winter of 2005-6 during solar activity minimum. Full operation is expected by the summer of 2006, which coincides with the first summer covered by this proposal.

The Gregorian focus of the telescope will feed the AO system on the floor beneath the telescope. This, in turn, will feed light to the new, focal plane instrumentation discussed below. The Nasmyth focus on the declination axis will be used for far-IR observations. All focal plane instruments described next are being initially tested with our current 65 cm telescope and be used in the NST.

For at least five years, the NST will be the only very high resolution solar telescope in the U.S. It will uniquely support and maximize the scientific output of on-going and up-coming NASA satellites that observe the Sun.

B.1.2 Adaptive Optics

We are in the final stages of testing two high order AO systems (76 element AO systems), one for BBSO's 65-cm telescope and the other for the 76-cm Dunn Solar Telescope at National Solar Observatory/Sacramento Peak (NSO/SP). Dr. Thomas Rimmele of NSO, as a research professor at NJIT, is the PI for the project. The NSO/SP system is fully operational now. The BBSO system is operational in an engineering mode and will be

used for the NST. The system will be more than adequate for the near-IR. For the visible, we are optimistic, as well because of the superb AO corrected images from the 1 m Swedish telescope in La Palma with its 37 actuator system. However, should 76 actuators prove inadequate for the visible, our system is scalable to higher order.

B.1.3 Visible Light Vector Magnetograph (VIM)

Our Digital Vector MagnetoGraph (DVMG) system has been operational since 2001 (Spirock et al., 2001, see Fig. 2 for a typical vector magnetogram) and is serving as the basic model for our new Fabry-Pérot filter-based magnetograph system, which will yield absolutely calibrated vector magnetograms— the Visible light Imaging vector Magnetograph (VIM). With VIM, we will be able to make much more accurate and higher resolution measurements of the evolving magnetic fields in flare-producing active regions. The Fabry-Pérot system provides the spectral line profile and the full Stokes vector when observing photospheric magnetic fields. This improvement will preclude Zeeman saturation where the fields are strong (in sunspots), and it will also provide filling factors for weaker fields. VIM is designed to operate at the diffraction limit of NST covering the substantial FOV of the NST. In addition, by selecting an appropriate interference filter, any spectral line in the range from 5500 Å to 7000 Å can be studied. The high transmission of the system (no Lyot filter) will also allow real-time image reconstruction of narrow band (~ 100 mÅ) filtergrams so that we can study, e. g., $H\alpha$ fine structure with high spectral, temporal and spatial resolution.

B.1.4 Infrared Imaging Vector Magnetograph (IRIM)

BBSO has built and employed a few generations of near IR imaging systems. The most recent and significant part of our IR instrumentation was the development of a narrow bandpass filter system, which combines a Lyot filter and an IR Fabry-Pérot filter – the IR Imaging vector Magnetograph (IRIM). Our one-of-a-kind Lyot filter, designed by one of our former Ph.D. students, has a bandpass of 2.5 Å at 1.56 μ m, giving us a 2.5 Å wide prefilter (narrower than the 5 Å free spectral range of the IR Fabry-Pérot). This solves the longstanding problem of constructing a filter-based IR magnetograph, while avoiding the complications of using a double etalon. The new and unique Lyot prefilter is being used in conjunction with our IR Fabry-Pérot filter. With this, polarimetry in the near IR will have the same reliability and stability that it now has for visible light. Note that the IR Lyot filter system will have about 20% transmission. IRIM's total transmission is about a factor of two less than that of a dual Fabry-Pérot instrument. However, unlike a dual Fabry-Pérot system, with its instability (requires very accurate tuning that is hard to maintain) and its typically quite restricted FOV for magnetograms, our system is stable and can utilize almost the entire FOV of the 1.6-m telescope. Finally, a new detector technology (CMOS devices) offers high quantum efficiency, so that we can take individual exposures well within the atmosphere's correlation time in the near IR (~ 100 ms). We have obtained and implemented a large format IR CMOS camera (1K \times 1K, 30 frames/s) from Rockwell Scientific Imaging. We enjoyed a quite successful first light of the full IRIM hardware system in November 2004 at Sac Peak. The strength of the IRIM is its extreme sensitivity and high spatial resolution, which allows us to study weak and small-scale magnetic fields in the quiet Sun.

VIM and IRIM will be able to operate simultaneously, so that we can obtain high resolution observations of the Sun's magnetic fields at different altitudes in the solar atmosphere. The VIM and IRIM systems will be located in the Coudé-room, which is one floor beneath the observing floor, along with the AO.

B.1.5 Real-Time Speckle Phase-Diversity Imaging

One of the difficulties in the image processing of high resolution observations is that each set of images takes hours of processing to construct a single diffraction limited image, using speckle imaging techniques (as in Denker and Wang, 1998). This effectively limits us to a short observing day (~ 2 hour) because the control computer's disk is filled by storing all the raw data, so the chances are slim of obtaining a sequence containing the long term evolution of an active region and catching flares during the observations. As well, the off-line

image reconstruction precludes using the images for space weather forecasting. With these in mind, we have purchased and programmed a 32-node parallel computing cluster, so that we now perform real-time speckle reconstruction with a cadence of about 1 minute for a 1K×1K camera, and diffraction limited images will be achieved all the time during the entire observing period. This system is fully operational. The real-time data will allow us to measure horizontal flow fields, which will complement our vector magnetograms. Among other uses, it will directly improve our ability to forecast solar storms. We will adopt real-time phase-diversity speckle to further improve the quality of the real-time data.

We note that when our adaptive optics system is in place, it will aid the reconstruction and provide a powerful test of it, but it will not replace the need for speckle reconstruction, because the adaptive optics system fully corrects only a single isoplanatic patch (of order a few arc seconds in extent), and correction decreases with distance from the fully corrected isoplanatic patch. Only multi-conjugate adaptive optics would fully correct the entire field of view. There is no such system in existence at this time. Our new parallel computing system will only save reconstructed image data, and therefore, the disk of the controlling computer will be big enough for several days of continuous observation.

B.2 Scientific Programs

B.2.1 Evolution of Vector Magnetic Fields Associated with Solar Flares

With the NST and the new focal plane instruments described above, combined with data from NASA missions such as SoHO, RHESSI and TRACE, and future missions such as SDO, STEREO and SOLAR-B, we will be in an excellent position to obtain an unprecedented spectrum of observations elucidating the evolution of magnetic fields during flares, as well as the physics of solar flares.

One of the important results from BBSO obtained during the solar maximum of the early 1990's is the finding that the photospheric magnetic field shear may increase after solar flares (Wang, 1992, Wang et al., 1994). Magnetic shear is defined as the difference between measured fields and potential fields. This finding is not inconsistent with the principle of conservation of energy, because the energy is stored in the full three-dimensional space running from the photosphere to the corona. In the last few years, newly developed BBSO DVMG system allowed us to find some curious results: rapid and permanent flux changes after all eight X-class flares studied by us (Spirock et al., 2002, Wang et al., 2002). Very recently, we made another discovery as we noted earlier: part of penumbral segments in the outer δ spot structure decay rapidly after major flares; meanwhile, the neighboring umbral cores and/or inner penumbral regions become darker (Wang et al., 2004, Liu et al. 2005). Figure 3 demonstrates the results of the October 29, 2003, X10 flare and a proposed, testable cartoon model to explain the observations. The WL images are from TRACE observations, they show the penumbral decay and central umbral enhancement coinciding with the flare. The MDI magnetograms confirmed change of magnetic topology associated with penumbral decay and RHESSI observations demonstrated that these sudden magnetic structure changes were spatially and temporally associated with the flare.

We expect to be able to improve and advance our work with our upgrades to calibrated digital Fabry-Pérot vector magnetographs. With VIM and IRIM using AO corrected light from the NST with its unprecedented spatial resolution, we will be able to detect much more subtle changes than we can at present. In particular, VIM and IRIM will provide spectroscopic diagnoses of the atmospheric structure at different heights, with that we will be able to accurately map the 3-D evolution of the magnetic structure associated the rapid changes discussed above.

In addition, BBSO, with coordinated observations from Huariou Solar Observing Station (HSO), will follow complicated active regions to study magnetic topology, shear and the electric current system. We have been jointly observing magnetic fields with HSO for several years, and obtain 22 hour coverage in the summer. Space data (such as SoHO and TRACE for now, and SDO in the near future) will be combined with BBSO data to obtain the three-dimensional structure of magnetic loops.

One of the important tools for studying the evolution of magnetic fields in a flare producing active region

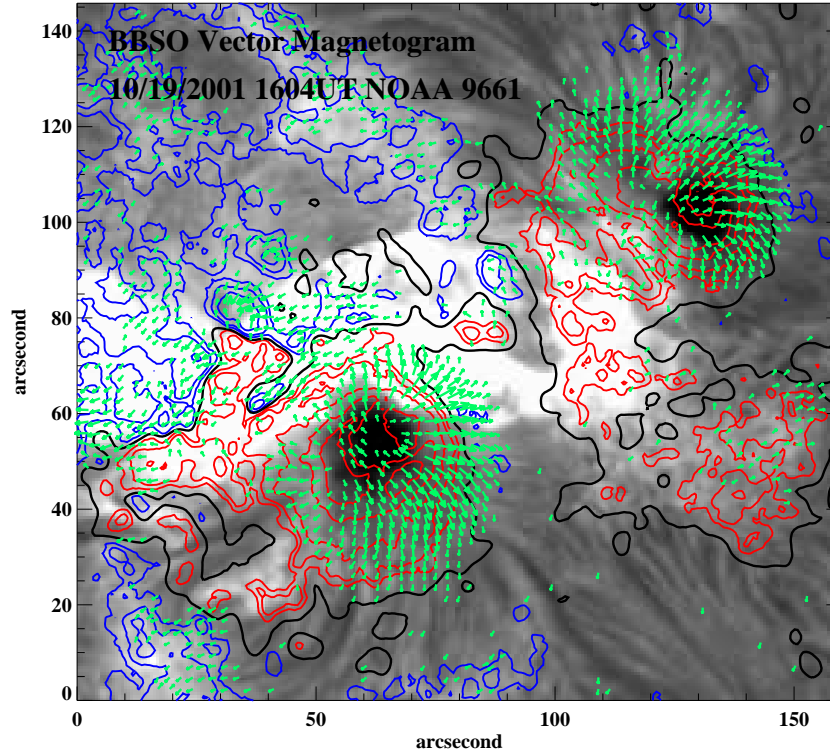


Figure 2: A typical BBSO vector magnetogram obtained from the DVMG. The background is a BBSO $H\alpha$ image during an X1.6 flare. Green arrows indicate the transverse fields, red and blue contours are for negative and positive line-of-sight magnetic field strength, respectively. The thick, solid black lines are the neutral lines of the line-of-sight magnetic field.

is the evolution of electric currents. They contain information on the degree of non-potentiality of the active region. Studies like that done in BBSO by Li et al. (1999) for a single active region will be applied to study the evolution of currents in various kinds of evolving active regions. We can already do a better job than in 1999 because the currents would be derived from the more accurate vector magnetograms coming from the VIM and IRIM. We will also investigate the electric current systems carried to the surface by flux emergence, and the role of the evolution of current systems in triggering solar flares. This latter study requires the VIM under an AO corrected beam, and we expect that the latter study will begin early in the first year of the proposed funding.

The solar cycle is approaching solar minimum, and the chances of major solar flares are small. We will overcome this by: (1) Studying partially analyzed on earlier events (30 M-class or larger flares); (2) Utilizing our new instruments that will have much improved sensitivity, so that we can infer the evolution of magnetic fields by detecting much smaller events; and (3) Developing data analysis tools for the future data of the next solar maximum.

B.2.2 High Cadence Flare Observations

We propose to continue dedicated high-cadence flare observations to study particle precipitation into the chromosphere at the footpoints of flare loops. Our major goal is to search for, and characterize, high frequency variations in the far-wing of chromospheric lines, which are related to high frequency variations in hard X-ray emission, and to examine the spatial scales of these temporal variations by exploiting the NST at its resolution limit (three times the spatial resolution of our largest aperture telescope at present). Of course, we can reduce

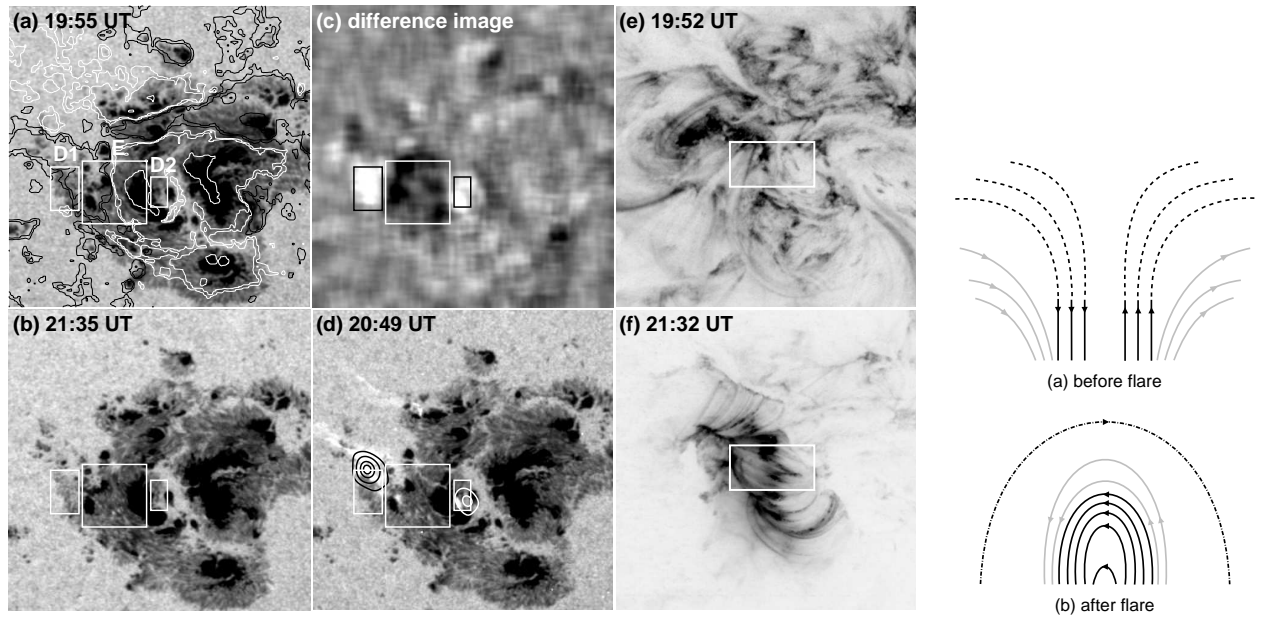


Figure 3: Left six panels show comparison of pre-flare (a, e) and post-flare (b, f) states for the X10 flare on 2003 October 29. (a, b) and (e, f) are TRACE WL and 195 Å images, respectively. (c) is the WL difference image (the post-flare image minus the pre-flare image). (d) is the WL image at flare maximum with superimposed RHESSI 50-100 keV hard X-ray contours. D1 and D2 are two areas of penumbral decay and E is the region of sunspot enhancement along the neutral line (Liu et al., 2005). Right two panels show a schematic interpretation of our observations. (a) Initial magnetic field configuration before the flare. Penumbral fields are in *gray* and umbral fields are in *black*. (b) Magnetic field configuration in the post-flare state. The dash-dot line in (b) represents the connection between the two far-apart footpoints, which may form the large-scale arcade structure of the CME. Note that the footpoint separation should be much larger than scaled in the drawing (Liu et al., 2005).

the resolution, so the NST functions as a light bucket when photons are scarce. The NST's Fabry-Perot systems will provide spectroscopic diagnoses of these flare footpoints.

The other key components of the innovative, high cadence BBSO system consist of a number of cameras with cadences from 10ms to 30ms, and array sizes from 256×256 to $1K \times 1K$. Since the fine temporal structure of flares may range from a few milliseconds to a few seconds, and the spatial scales of these temporal structures are not clear, we need to have the flexibility to cover different image scales, fields-of-views and cadences.

In our campaigns with present instrumentation, we have been making high spatial ($1''$) and high temporal (10 to 30 ms) resolution observations in the far blue/red wing of the $H\alpha$ line, which responds sensitively and promptly to non-thermal electron beams.

Although RHESSI has the potential to obtain a cadence of 10ms for flare observations, its current effective cadence is only 2s, due to instrumentation modulation of the rotating grids. Therefore, without a new data analysis tool, we cannot use RHESSI's full cadence, to combine with BBSO's sub-second cadence data to answer critical scientific questions raised in this section. We have been working with Dr. Gordon Hurford (from the RHESSI team) to demodulate RHESSI time profiles. Together, we have successfully obtained sub-second structure in flare time profiles. We plan to continue to improve the software and compare with our high resolution $H\alpha$ data.

In addition, a similar high cadence (30ms) $H\alpha$ observing system has been established in Ganyu Station of Purple Mountain Observatory in China by our former post-doc Haisheng Ji. So we are forming a high-cadence

observing network to match with the RHESSI's round-the-clock observing mode. This setup has obtained very first data set of a flare in November 2004.

Our scientific objectives are:

1. To spatially resolve individual particle precipitation sites within a footpoint, and the related magnetic field configuration to determine the spatial scale(s) of magnetic reconnection.
2. To analyze the properties of these "elementary bursts", such as their energy and spatial distribution, to set constraints on the models of particle acceleration.
3. To compare high cadence, hard X-ray data from RHESSI and chromospheric emission data from BBSO to understand the detailed process of the heating of the lower atmosphere by non-thermal electrons.
4. To continue to investigate the relationship between the electric field derived from observations and the hard X-ray or microwave time profile (Qiu et al., 2002, BBSO 1107), and to understand the mechanism by which flares accelerate electrons.

B.2.3 High Resolution Visible and Near IR Observations of Active Regions

Contribution of Footpoint Motion to Coronal Loop Heating: Aschwanden et al. (2000) argued that for coronal loops, the heating is concentrated in the footpoints. Although the heating function was given, the detailed heating mechanism was not described. Contrarywise, Priest et al. (2000) hypothesized that corona loops have uniform heating. We propose to address the controversy by focussing on a search for possible heating mechanisms near the footpoints. For the uniform loop heating model, Parker (1988) proposed that the X-ray corona is due to a continuous nanoflaring process. The energy source of these nanoflares is the random motion of footpoints. Furthermore, nanoflares, microflares, and even regular solar flares may be somehow associated (Hudson, 1991), so the observations of footpoint motions associated with all such events are important. We know from experience that this footpoint motion is hard to observe and characterize in lower resolution (1'') magnetograph and filtergraph observations. We plan to detect and characterize such footpoint motions with 0.1'' spatial resolution with the NST by using real-time speckle constructed images. As G-band images show flux tubes very well, we will use our G-band filter to observe for this part of the research. We expect to learn the correlation between footpoint motion and the brightness of overlying EUV/X-ray loops. Berger et al. (1998) described G-band observations and processing of the data to study the motion of magnetic elements. We plan to adopt similar observational techniques, but using our parallel computer clusters to do real-time (with a cadence of 1 minute) data processing in active regions.

Flux Emergence and Magnetic Channel Structure in Flare Producing Active Regions: There are two very important aspects of the evolution of active regions that may be closely associated with solar flares: new flux emergence and unusual flow motions. These two kinds of phenomena may also be associated with each other (Tanaka, 1991, Zirin and Wang 1993). A few well-known active regions showed a close association among flux emergence, flows and major flares. Two of the best past examples are March 1989 NOAA 5395 (Wang et al., 1991) and June 1990 NOAA 6659 (Zirin & Wang, 1993) active regions. To observe these flows and field structure in detail and to understand their basic nature, we need high resolution and high cadence observations. This is another area that the NST will help to achieve breakthroughs by finally advancing us beyond the resolution limit of today's sub-meter class aperture solar telescopes.

Zirin & Wang (1993) found that the magnetic channel structure (elongated structure of mixed polarity and strong transverse fields) is created by new flux emergence inside a sunspot and appears as complicated flows along the channels. The areas with strong flows, new flux emergence, and complicated channel structure were also obviously associated with several major flares in several active regions. The flux emergence destabilizes the existing magnetic configuration and causes magnetic reconnection. Flow motions may contribute to the twist of fluxropes by moving the footpoints around. Such flow and channel structures are not well understood

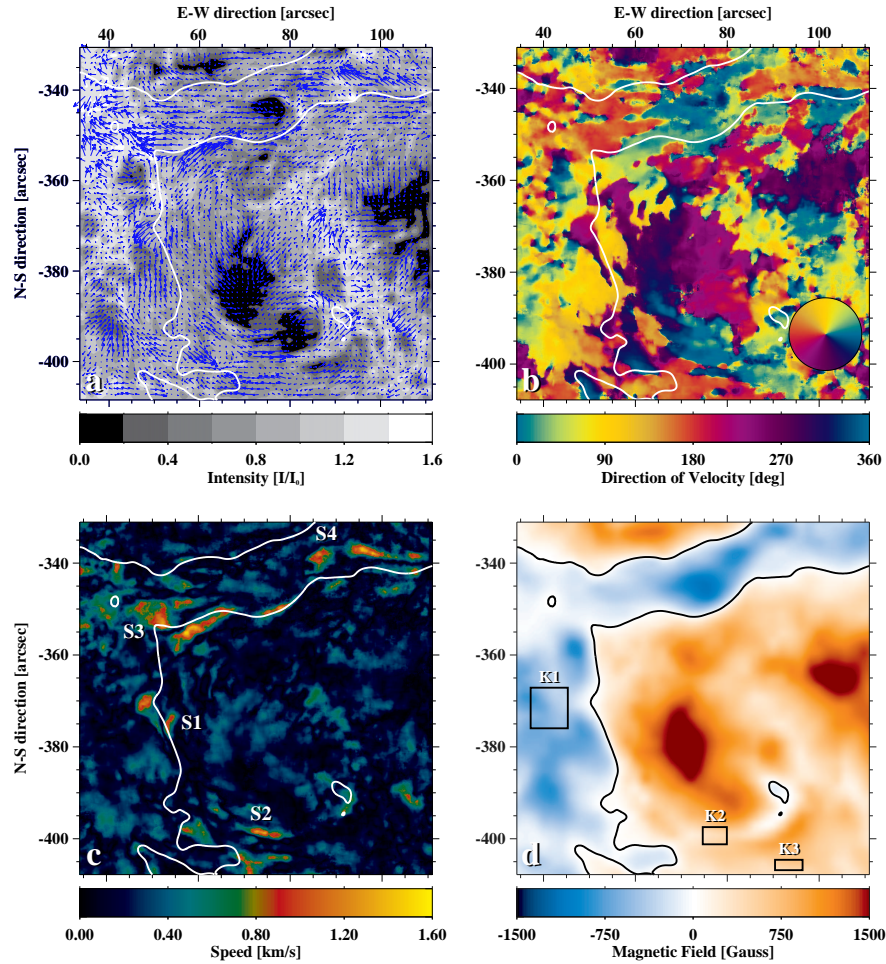


Figure 4: Photospheric flows and magnetic field configuration of NOAA 10486 on 2003 November 29. To illustrate the results of high-spatial resolution local correlation tracking analysis of WL data observed by the BBSO team at NSO/SP, we provide different views of (a) flow vectors, (b) azimuthal angle of the velocity vectors, (c) magnitude of the velocity vectors, and (d) MDI magnetogram with superimposed magnetic neutral lines (Yang et al., 2004). I/I_0 in (a) is the normalized intensity relative to quiet photosphere.

– advancing our understanding requires long sequences of high resolution observations, which the NST can provide.

As we discussed, without real-time speckle reconstruction, the observing sequences are processed off-line (as in Denker and Wang, 1998), and the greatly shortened observing day severely reduces the chance of observing the long term evolution of an active region leading to flaring. Further, you not know for several days if you have caught an interesting event (not useful for space weather forecasting). Our new system will only save constructed image data. Therefore, the disk of the control computer will be big enough for several days of continuous observation. The real-time data product of diffraction-limited quality is essential in this study. We will follow all flare producing regions, with an image scale of $0.05''$. Figure 5 demonstrates the power of such imaging processing, that shows the shear flow of the active region before the X10 flare on October 29, 2003.

In our continued studies, we expect to answer the following questions:

1. Do flaring active regions always show the complicated flows as discussed above, but they are revealed only when we have sufficient resolution ($0.1''$ instead of $0.3''$)?

2. Are these flows always associated with flux emergence?
3. Are flows unusually strong before major flares? Monitoring of flows will strengthen our prediction tools for solar flares and space weather.
4. What are the electric currents and magnetic shear in the magnetic channel structures?

Near IR Observations: IR solar astronomy is a science whose time has come because of new camera and filter technologies. The BBSO CMOS camera from Rockwell and IR filter system will be the unique instrumentation for this part of the proposed research.

For several scientific reasons, observing in the near IR would result in a significant step forward in our understanding of the Sun. First, the Sun has an opacity minimum in the near IR (at about $1.6 \mu\text{m}$), so that one can see deeper into the Sun in that wavelength regime. Second, the Earth's atmosphere is more benign in the near IR, implying more stable images with greatly reduced effects of seeing. Furthermore, one anticipates the greatest benefit of the IR to come in the measurement of magnetic fields because the atomic Zeeman splitting is considerably larger in the near IR (Zeeman splitting increases quadratically with wavelength), so that one can make much more precise measurements of the field and its evolution. Lin & Rimmele (1999) made near IR observations of granular magnetic fields. Their flux density sensitivity is 1 G, and they identified both strong (≥ 1000 G) and weak (≤ 500 G) magnetic field elements in the quiet Sun. Our goal is to achieve observations of that quality, with a device for *daily* use, in both the quiet Sun and active regions. We will concentrate on the following topics:

1. *NIR Flare Observations:* We obtained very first IR flare image at 1.6μ (Xu et al., 2004). With our new setup at BBSO, we anticipate that we will be able to observe these events routinely and to distinguish two competing flare emission models: direct precipitation and backwarming models (see Xu et al. 2004 for a summary of models and our observations).
2. *Broad-Band IR Photometry Near the Sun's Opacity Minimum:* Foukal and his colleagues reported that many faculae are dark in the near IR, while they are bright in visible light (see review by Foukal & Morran, 1994). Such a result would sharply constrain models of flux tubes (Spruit, 1976). Whether correct or not, this motivates our proposed detailed study of sunspot and facular contrast and their relative areas in the visible and IR, which would also facilitate a microscopic analysis of the energy budget in solar active regions.
3. *Umbral Dots and Light Bridges:* Reduced scattered light and the lower contrast of umbrae in the IR make it much easier to study the morphology and evolution of umbral dots and light bridges. Successful measurements at 7700 \AA were made by Ewell (1992). New observations were obtained at $1.6 \mu\text{m}$ (J. Wang, 2001). Over the next three years, we propose to concentrate on determining the magnetic structure of umbral dots and light bridges. Detailed study will provide a basic understanding of the interaction between convection and magnetic fields.
4. *IR Spectroscopic and Polarimetry Observations:* Lin's (1995) experiment has already demonstrated that the BBSO spectrograph system (~ 1 hr scan time) is particularly useful in measuring IR Stokes V profiles. The most important objective of BBSO IR observations here is to carry out superior observations of various solar features from intranetwork fields to large active regions, and to derive the temperature, velocity, true magnetic field strength and filling factors of these features. The IRIM system with the NST will have a much improved capability over the previous BBSO spectrograph system, as it can obtain 2-D spectral scan with high temporal cadence (less than 10 seconds).

Stokes- Q and $-U$ profiles will present a more difficult problem than does the Stokes- V profile due to the instrumental linear polarization of the NST with its three (primary, secondary and one flat) mirrors preceding the

polarization optics. After we are making regular V profile observations, we will start working on the Q and U problem, because accurate vector magnetic field measurements are key to understanding the three-dimensional structure of magnetic fields. Fortunately, we do not need to start this process from scratch. Both sites of the National Solar Observatory (Kuhn et al., 1994) have accumulated experience in correcting for instrumental polarization in IR observations. Their experience will be adapted for the BBSO system. In addition, the High Altitude Observatory (HAO) and Mees Solar Observatory (MSO) groups have developed spectral Stokes inversion codes, which are already helping us in the reduction of our data.

B.2.4 Space Weather and Synoptic Observations

Synoptic observations and research will continue to be one of the primary scientific objectives of BBSO. This observing program, in addition to its own scientific merit, has been supporting NASA missions such as TRACE, SOHO and RHESSI. Later, it will continue in support of SDO, STEREO and Solar-B. At the same time, BBSO's research has benefitted significantly by using the data from these NASA missions. Accumulated synoptic data sets provide important archives from which one can determine the long-term variation of the solar radiation field and magnetic field. The data sets also provide important information elucidating the physics of the solar cycle. For our purposes, we need synoptic observations that are contemporaneous with our high resolution observations. We require both because the solar phenomena that we propose to study may well have a small-scale origin, but also have a large-scale manifestation. We propose to continue to obtain and use the following data:

Full-Disk Observations: These are the backbone of the synoptic program (Denker et al., 1999). The $2K \times 2K$ pixel $H\alpha$ images show the full solar disk in high resolution at 1 frame/min (can reach 5 frames/min). These full disk observations will continue after the NST is in place, and the present synoptic telescopes are gone. We are evaluating several good alternatives telescopes to continue our present synoptic observations. Our five-station global network ensures continuous monitoring of solar activity. We supplement these with long exposure frames for prominences, as well as with off-band frames. We have written and implemented pattern recognition software (Gao et al., 2002, Qu et al., 2005), which detects filament eruptions in real-time and posts them on the web. These data are also part of the Virtual Solar Observatory.

Ca II K-line and white-light images are taken at least once a day. Raw and corrected images and a plot of the K-line index of solar variability can be seen on the BBSO Ca K web page, which is updated daily. We will continue to construct the Ca K index, and develop an index of the latitudinal distribution of Ca K brightness as the solar cycle progresses.

We understand that the SOLIS system is coming on-line. This will not impact our $H\alpha$ network because there is no SOLIS network, and the time between $H\alpha$ frames is several minutes for SOLIS. Of course, we will use SOLIS $H\alpha$ images where appropriate. With SOLIS and the NST, the need for our K-line and white light synoptic programs will have to be re-examined. At present, neither of them takes much time or effort (a few minutes a day), and our view is that we should continue with the ones that provide context for our high resolution observations, and help with our solar activity forecasting.

BBSO Activity Monitoring and Warnings: Accurate predictions of solar activity are most important for the safety of satellites and the protection of power grids and communications systems.

At least once a day, BBSO now provides Solar Activity Reports, which are a visible light survey of active regions. When warranted, BBSO also issues a BBSO Solar Warning forecasting rapid development and/or energetic solar flares in individual sunspot groups. When we predict a flare, we are right more than 90% of the time, and we rarely miss a flare. We also provide daily activity reports to the operation centers of solar missions to optimize their solar targeting. BBSO is officially responsible for target selection of the Max Millennium observing program. In addition to posting the reports and warnings on our web site, the warnings are sent via electronic mail to about 400 people who have requested them. Over the next three years, we will continue these projects.

We have upgraded our space weather program to include the Active Region Monitor (ARM) and Flare

Prediction System (FPS). They describe the real-time status of each active region. We will continue to improve this system by including more parameters, such as electric current maps and magnetic shear maps.

Magnetic Topology of CME Initiating Active Regions and Interplanetary Magnetic Clouds: Large geomagnetic storms are usually caused by a structure in the solar wind having a specific feature – long duration, strong southward interplanetary magnetic fields (IMF) impinging on the Earth’s magnetosphere. There are two possible stages at which we can monitor geomagnetic storms: (1) observing magnetic field fluctuations from a satellite, such as ACE or Wind and (2) measuring the Dst (degree of equatorial magnetic field deviation from ground stations), Ap and Kp indices. While (1) can give a 1-2 hour warning of the arrival of geomagnetic storms, (2) is simply now-casting.

Our objective is to obtain some statistical results on filament eruptions/CMEs, magnetic clouds and geomagnetic disturbances based on 50 to 100 selected Earth directed CMEs. A correlation between filament eruptions and magnetic clouds has been suggested (e. g., Bothmer & Schwenn, 1994, Burlaga et al., 1998, Wilson and Hildner, 1986, Marubashi, 1997). In particular, Marubashi (1997) found a good correlation between the structure of erupted solar filaments and the structure of interplanetary magnetic clouds. We have been studying about 20 halo CME events in detail (Yurchyshyn et al., 2001, BBSO 1109; 2004, BBSO 1168), and found that the overlying magnetic field structure above erupting filaments may provide a good indicator of the orientation of magnetic clouds. With a much improved database, we will search for possible relationships between the magnetic structure of filament eruptions and that of magnetic clouds observed by ACE and WIND in the form of in-situ magnetic field fluctuations. This relationship can be further linked with geomagnetic storms, which are related to the southward component of magnetic clouds. Using this result, we could issue advanced warnings of geomagnetic storms 2 to 3 days before their arrival at the Earth.

B.3 Personnel

This proposal is for the renewal of one of two backbone grants supporting BBSO. It provides half-time support for three postdocs (Wenda Cao, Alexandra Tritschler and Tom Spirock), each of whom is active in research and instrumentation. In addition, to operate the observatory and collect data, the budget includes halftime support for our observer (Randy Fear), mechanical engineer (Jeff Nenow), and electronics engineer (Vlad Abramenko), as well as one-third support for our system manager (John Varsik). It also supports two months of summer salary for Goode, one month of summer salary for Wang and Denker. NJIT will match with \$300 K for instrumentation and one-quarter release time for Goode.

The requested support is consistent with our current SR&T budget for backbone support. The budget reflects our unique mission and extremely high productivity therein.

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