# High Resolution Studies of Solar Activity and Space Weather

April 25, 2003

**Proposal Summary**

New Jersey Institute of Technology (NJIT) has been operating Big Bear Solar Observatory (BBSO) since July 1, 1997. Our current three year NSF ATM grant started on March 1, 2001. 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 100 scientific papers under two years of current ATM support. At present, we are building and implementing a high-order adaptive optics system for BBSO, and have began to build our 1.6 m clear aperture, off-axis telescope at BBSO. Further, the NJIT solar physics group continues to grow under strong institutional support. We have hired a new, tenure track assistant professor, Carsten Denker, who became a regular faculty member in the Fall of 2001. Based on our solid record, we propose a three-year program of solar physics research at BBSO covering the decaying phase of solar cycle 23. 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. Our research also requires instrument development so that we can better carry out our proposed high resolution and/or high cadence observations.

Proposed Scientific Programs:

1) Sustained sub-arc second resolution studies of active regions and the quiet sun.

2) High-cadence and high-resolution studies of solar flare emissions.

3) Comprehensive studies of vector magnetic fields associated with flares, filament eruptions and CMEs.

4) Predictions of solar activity and geomagnetic activity.

On-going Instrumentation Projects:

1) Complete our high-order adaptive optics system.

2) Complete 1.6-m New Solar Telescope. We will minimize downtime during the replacement of the 65-cm by the 1.6-m telescope.

3) Implement a parallel computing system for real-time speckle phase diversity reconstruction to obtain real-time diffraction limited images over the entire field of view.

4) Complete and operate our two Fabry-Pérot filter systems (one in the visible and the other in the near IR) for more advanced polarimetry and spectroscopic studies of dynamic phenomena, such as active region development, flaring, filament activation and filament eruption.

Now, let us address two criteria required for an NSF proposal:

(1) Intellectual merit: We are obtaining and using high quality datasets and analysis tools to study a number of critical, leading-edge problems in the solar research. We also build the instrumentation needed to obtain these data.

(2) Broad Impact: Solar magnetic storms can impact human technologies in what is broadly called “space weather”. At BBSO, we make the most precise predictions of space weather. Further, BBSO is taking the lead in developing the next generation of solar instrumentation, while training the next generation of scientists who build instruments. Integrated research and education is emphasized in this proposal.

# A. Results from Prior ATM Support

New Jersey Institute of Technology (NJIT) took over operation of Big Bear Solar Observatory (BBSO) on July 1, 1997. On March 1, 2001, our current three year ATM grant started. This grant is one of two backbone grants supporting BBSO. 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. Our capability of running sustained campaigns is at the core of our ability to provide unique support to community's efforts to study and understand the sun. To ensure a unique and significant scientific role for BBSO, we have made fundamental changes in the observatory's instrumentation since 1997. The advances in instrumentation were critical for improving the quality of our observations, especially for high resolution studies. Meanwhile, better data helped our research group to be even more productive, as evidenced by over 100 publications since March 2001. NJIT continues to strongly support our efforts. NJIT would match this grant with \$300 K for new equipment for the observatory. Furthermore, NJIT has supported the expansion of our group to include a fourth, regular tenure-track faculty member, Carsten Denker. He became an assistant professor starting with the Fall 2001 semester.

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 2001 to 2003. We currently have 11 Ph.D. students (including 3 women), and 3 of the 11 will graduate in 2003. Generally, each student builds the additional instrumentation necessary for his/her Ph.D. work. This broadens the education of the student, while strengthening the observatory. The typical new instrument needed by a solar observatory constitutes a small enough project that one graduate student can handle all aspects of its development. Our typical student will receive a Ph.D. in Applied Physics, Electrical and Computer Engineering or Computer Science. Such training prepares our students for a scientific career, while ensuring broader career opportunities. Our most recent graduate is now leading an IR optics group in a New Jersey company.

Since the beginning of our current ATM support, three of our post-docs have also advanced to higher positions. As mentioned, Carsten Denker is now an assistant professor at NJIT. Jongchul Chae is now an assistant professor at Chungnam National University in Korea. Peter Gallagher has obtained a contract position at NASA/GSFC. In addition, Lou Lanzerotti has joined our center as a distinguished research professor, extending our coverage of space weather.

BBSO has an unpaid, outside Advisory Board, which meets annually to critique our efforts. The board's report is made to BBSO management and passed on to the upper management of NJIT. The current members of the board are Len Fisk (U. of Michigan, Chair), Steve Koonin (Caltech), Jeff Kuhn (UH), and Carl Shrijver (Lockheed/Martin). 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 Steve 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, GSFC; Richard Canfield, Montana State University; 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; Markus Koschinsky, University of Göttingen, Germany; James McAteer, Queens University, Belfast; and Eugenia Christopoulou, University of Patras, Greece. 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.bbso.njit.edu`). We also have implemented an internal fiber optic link and a RAID array for our FTP archive. 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.

The achievements in the instrumentation will be included in the on-going instrumentation section, and in 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 (`www.bbso.njit.edu`), and are numbered starting from 1000.

### A.1 High Cadence Flare Studies

Over the last two years, BBSO scientists have a carried out high cadence (10 ms to 50 ms) flare studies and analyzed the flares (Qiu et al., 2002, Ding et al., 2001, Ji et al., 2003a,b). Ding et al. (2001, BBSO Bluebook #1076) developed a theoretical model to successfully explain the aforementioned observational results. Wang and Qiu (2002, BBSO 1096) have concluded that for impulsive flares, H$\alpha$ far blue wing emissions tend to occur at, or near the magnetic neutral line, indicating reconnection of very low-lying flux ropes.

Qiu et al. (2002, BBSO 1107) combined flare footpoint motion, as derived from high cadence observations, with the measurement of magnetic fields to calculate the DC electric field during a flare. They concluded that this DC electric field varies with the hard X-ray and microwave time profiles. Therefore, for the first time, there is direct evidence of acceleration of electrons by electric fields.

Very recently, Haisheng Ji has performed high cadence flares observations with RHESSI. Two papers have been submitted to Ap.J. (Ji et al., 2003a,b). One studied the temporal structure of the flare on September 9, 2002, and the second one studied the filament eruption on May 27, 2002 with high cadence.

### A.2 Evolution of Magnetic Field During Flares

BBSO's new Digital Vector MagnetoGraph (DVMG) system has shown its power in studies of the evolution of magnetic fields at high resolution and cadence. One significant paper, Spirock et al. (2002, BBSO 1120), demonstrated a rapid/permanent increase of the limbward magnetic flux after a flare. This was explained by the emergence of very inclined magnetic flux.

To follow up this work, Wang et al. (2002a, BBSO 1125) presented results of studies of six X-class flares, all of which show rapid and permanent changes in line-of-sight magnetic fields immediately after flares. All the events showed an increase in the magnetic flux of the leading polarity of a few times $10^{20}$ Mx; three of them showed some degree of decrease in the following polarity flux. The increases are impulsive (while the timescale for the overall change in the flux ranged from 10 to 110 min) and permanent. However, no satisfactory explanation has been found for this curious and provocative phenomenon. Wang et al. (2002b, BBSO 1158) further demonstrated a rapid disappearance of a small sunspot which can be explained fast magnetic reconnection or emerging of a magnetic bubble.

Abramenko et al. (2003, BBSO 1182), studied the evolution of magnetic structure of 4 events observed from BBSO, and convincingly demonstrated the avalanche theory of flares.

### A.3 Study of CMEs

We have contributed to the understanding of the large-scale structure of Coronal Mass Ejections (CMEs). Wang et al. (2001, BBSO 1101) found the first direct evidence of sympathetic flares that directly connect different active regions. More recently, Wang et al. (2002, BBSO 1117) found an important correlation between magnetic "channels" and the onset of CMEs – an erupting magnetic flux rope in the channel. A magnetic channel is defined as alternating, elongated striations of positive and negative magnetic flux on a fairly small scale (a few arcsecs). Flows are observed along the field lines of the channel (Zirin and Wang, 1993). We also found that coronal dimming may be due to chromospheric evaporation (BBSO 1117).

In a series of papers (BBSO 1112, 1127, 1141, 1147 and 1186), we have discovered impulsive injections of magnetic helicity associated with a number of CMEs and associated flares. This project has been lead by Drs. Chae and Moon. Even though Dr. Chae is now based in Korea, he spends a substantial period of time in BBSO each year. The new method of calculating advection term in the helicity was first introduced by Chae et al. (2001, BBSO 1112).

### A.4 Space Weather Forecasting

Our achievements in space weather forecasting are presented in BBSO 1090, 1091, 1104, 1109, 1115, 1121, 1136 and 1168.

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 provide better tools for predicting abrupt changes in solar activity and the often consequent geomagnetic storms. Filament eruptions and flares are compared with magnetic fields observed by ACE.

Every hour, images from our Global H$\alpha$ Network (GHN) are transferred to the web-based BBSO Active Region Monitor (ARM, `www.bbso.njit.edu/arm`), which also includes the most recent full-disk EUV, soft X-ray, continuum and magnetogram data from the Solar and Heliospheric Observatory (SoHO) and YOHKOH (until December 2001). ARM also includes a variety of active region properties from the National Oceanic and Atmospheric Administration's (NOAA) Space Environment Center (SEC), such as up-to-date active region positions and flare identifications. ARM was developed over the last two years (Gallagher et al., 2002, BBSO 1136).

Furthermore, we have developed a Flare Prediction System (FPS) which estimates the probability for each active region to produce C-, M-, or X-class flares based on nearly eight years of NOAA data from cycle 22. This, in addition to BBSO's daily solar activity reports, has been proven to be a useful resource for activity forecasting (BBSO 1104).

Yurchyshyn et al. (2003, BBSO 168) proposed a novel method for predicting geo-effective CMEs and arrivals of geo-magnetic storms. So far, the success rate is 100% based on the study of about 20 events.

### A.5 Publications Supported by the Current ATM Support

The discussion above highlights our scientific accomplishments over the past two years. Because of limited space, we list only selected publications (34 of 101) from the period of our present NSF-ATM support. Please check the home page (`solar.njit.edu`) for a complete list with downloadable copies.

**Selected BBSO Publications (3/2001 to 4/2003)**


**BBSO 1076**: "On the Fast Fluctuations in Solar Flare H$\alpha$ Blue Wing Emission", M.-D. Ding, J. Qiu, H. Wang and P.R. Goode, 2001, Ap.J., 552, 340

**BBSO 1077**: "Small Magnetic Bipoles Emerging in a Filament Channel", J. Chae, S.F. Martin, H.S. Yun, J.-H. Kim, S. Lee, P.R. Goode, T.J. Spirock and H. Wang, 2001, Ap.J., 548, 497

**BBSO 1083**: "A Rapid Change in Magnetic Connectivity Observed Before Filament Eruption and Its Associated Flare", J.-H. Kim, H.S. Yun, S. Lee, J. Chae, P.R. Goode and H. Wang, 2001, Ap.J. Letters, 547, L85

**BBSO 1087**: "Does the Sun Shrink with Increasing Magnetic Activity?", W. A. Dziembowski, P. R. Goode and J. Schou, 2001, Ap.J., 553, 897

**BBSO 1088**: "On the Correlation between the Orientation of Moving Magnetic Features and the Large-scale Twist of Sunspots", V. B. Yurchyshyn, H. Wang and P.R. Goode, 2001, Ap.J., 550, 470

**BBSO 1092**: "Optical Design of a Near-infrared Birefringent Filter System and Measurement of Birefringent Index of Calcite at 1.56 $\mu$m", J. Wang, H. Wang, T.J. Spirock, C.-Y. Lee, N.M. Ravindra, J. Ma, P.R. Goode and C. Denker, 2001, Optical Engineering, 40, 1016

**BBSO 1095**: "Near Real-Time Image Reconstruction" C. Denker, G.Yang and H. Wang, 2001, Solar Physics, 202, 63

**BBSO 1096**: "Relationship Between Flare Cores in H$\alpha$ Far Blue Wing and Magnetic Fields", H. Wang and J. Qiu, 2002, Ap.J., 568, 408

**BBSO 1099**: "Asymmetric Behavior of H$\alpha$ Footpoint Emission During the Early Phase of an Impulsive Flare", J. Qiu, M.-D. Ding, H. Wang, P.T. Gallagher, J. Sato, C. Denker and P.R. Goode, 2001, Ap.J., 554, 445

**BBSO 1101**: "Inter-Active Region Connection of Sympathetic Flaring on 2000 February 17", H. Wang, J. Chae, V. Yurchyshyn, G. Yang, M. Steinnegger and P.R. Goode, 2001, Ap.J., 559, 1171

**BBSO 1102**: "Magnetic Flux Cancellation Observed in the Sunspot Moat" V. B. Yurchyshyn and H. Wang, 2001, Solar Physics, 220, 309

**BBSO 1104**: "Space Weather Research at Big Bear Solar Observatory", P. T. Gallagher, C. Denker, V. Yurchyshyn, T. Spirock, J. Qiu, W. H. Marquette, H. Wang and P. R. Goode, 2002, Ann. Geophysicae, 20, 1105

**BBSO 1107**: "Motion of Flare Foot-Point Emission and Inferred Electric Field in Reconnecting Current Sheets", J. Qiu, J. Lee, D. E. Gary, H. Wang, 2002, Ap.J., 565, 1335

**BBSO 1109**: "Orientation of the Magnetic Field in Interplanetary Flux Ropes and Solar Filaments", V. B. Yurchyshyn, H. Wang and P.R. Goode, 2001, Ap.J., 563, 381

**BBSO 1112**: "Observational Determination of Rate of Magnetic Helicity Transport Through the Solar Surface Via Horizontal Motion of Field Line Footpoints", J. Chae, 2001, Ap.J. Letters, 560, L295

**BBSO 1113**: "The Formation of a Prominence in Active Region NOAA 8668: I. SoHO/MDI Observations of Magnetic Field Evolution", J. Chae, H. Wang, J. Qiu, P.R. Goode, L.H. Strous and H.S. Yun, 2001, Ap.J., 560, 476

**BBSO 1114**: "Development of an Automatic Filament Disappearance Detection System" J. Gao, H. Wang and M. Zhou, 2002, Solar Physics, 205, 93

**BBSO 1117**: "Core and Large Scale Structure of 2000 November 24 X-class Flare and CME" H. Wang, P.T. Gallagher, V. Yurchyshyn, G. Yang and P.R. Goode, 2002, Ap.J., 569, 1026

**BBSO 1120**: "Rapid Changes in the Longitudinal Magnetic Field Related with the 2001 April 2 X20 Flare", T.J. Spirock, V.B. Yurchyshyn and H. Wang, 2002, Ap.J., 572, 1072

**BBSO 1125** "Rapid Changes of Magnetic Fields Associated with Six X-Class Flares". H. Wang, T. J. Spirock, J. Qiu, H. Ji, V. Yurchyshyn, Y. J. Moon, C. Denker and P. R. Goode, 2002, Ap. J., 576, 497

**BBSO 1127** "Flare Activity and Magnetic Helicity Injection by Photospheric Horizontal Motions". Y.-J. Moon, J. Chae, G. S. Choe, H. Wang, Y. D. Park, H. S. Yun, V. Yurchyshyn and P. R. Goode, Ap. J., 2002, 574, 1066

**BBSO 1128** "Statistical Evidence for Sympathetic Flares", Y.-J. Moon, G. S. Choe, Y. D. Park, H. Wang, P. T. Gallagher, J. Chae, H. S. Yun and P. R. Goode, 2002, Ap. J., 581, 694

**BBSO 1136** "Active Region Monitoring and Flare Forecasting", P. T. Gallagher, Y.-J. Moon and H. Wang, 2002, Solar Physics, 209, 171

**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 and P. R. Goode 2003, Submitted to Ap.J. Letters

**BBSO 1145** "Non-LTE Calculation of the Ni I 676.8 Nanometer Line in a Flaring Atmosphere", M.D. Ding, J. Qiu, and H. Wang, 2002, Ap.J. Letters, 576, L83

**BBSO 1146** "A Statistical Study of Two Classes of Coronal Mass Ejections", Y.-J. Moon, G.S. Choe, H. Wang, Y.D. Park, N. Gopalswamy, G. Yang and S. Yashiro 2002, Ap.J., 581, 694

**BBSO 1147** "Impulsive Variations of Magnetic Helicity Change Rate Associated with Eruptive Flares", Y.-J. Moon, J. Chae, H. Wang, G.S. Choe and Y.D. Park, 2002, Ap.J., 580, 528

**BBSO 1157** "Periodic Motion Along a Solar Filament Initiated by a Subflare", J. Jing, J. Lee, T. J. Spirock, Y. Xu and H. Wang, 2003, Ap.J. Letters, 584, L103

**BBSO 1158** "Sudden Disappearance of a Small Sunspot Associated with the February 20, 2002 M2.4 Flare", H. Wang, H. Ji, E. J. Schmahl, J. Qiu, C. Liu and Na Deng 2002, Ap.J. Letters, 580, L177

**BBSO 1168** "Correlation Between Speeds of CMEs and the Intensity of Geomagnetic Storms", V. Yurchyshyn, H. Wang and V. Abra-

menko, 2003, Submitted to Geophysical Research Letters

**BBSO 1179** "1.6M Solar Telescope in Big Bear - The NST", P. R. Goode, C. J. Denker, L. I. Didkovsky, J.R. Kuhn and H. Wang, 2003, Journal of the Korean Astronomical Society, 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 and P.R. Goode, 2003, Submitted to Ap.J.

**BBSO 1183** "Study of Ribbon Separation and Filament Eruption of a Quiet-Sun Flare", H. Wang, J. Qiu, J. Jing and H. Zhang, 2003, Ap.J., in press.

**BBSO 1186** "Magnetic Helicity Changes of Solar Active Regions by Photospheric Horizontal Motions", Y.-J. Moon, J. Chae and Y.D. Park, 2003, Journal of the Korean Astronomical Society, in press.

## 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 achieve 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 geoeffectiveness. The additional instrumentation that we are developing enhances various aspects of the science we propose to do. Because of the wide-ranging and diverse scope of the projects proposed here, and due to the page limit on proposals, we can only briefly describe each scientific program.

### B.1 On Going Instrumentation Projects

There are several on-going instrumentation projects at BBSO. Now, we briefly discuss the ones that will have an impact on the work proposed here.

#### Adaptive Optics

NJIT is midway through a three year grant from NSF-MRI to build two high order adaptive optics (AO) systems (76 element AO systems), one for BBSO's 65 cm telescope and the other for the 76 cm Dunn Solar Telescope at NSO/SP. Dr. Thomas Rimmele of NSO, as a research professor at NJIT, is the PI for the project. The high order AO system is based on the lessons learned from the successful low order one developed and made operational under the leadership of Rimmele. We expect that the BBSO high order AO system will be operational in the middle of 2003, and it will greatly aid our high resolution observations, and our ability to complement/supplement scientific data from NASA missions.

The Coudé-exit of the 65 cm telescope is being modified so that we can utilize the newly remodeled floor beneath the telescopes, with our new optical laboratory there, to host the AO and our next generation magnetograph systems.

#### New Telescope at BBSO

We are designing the new off-axis telescope system at BBSO. BBSO/NJIT, in collaboration with the University of Hawaii (UH), is upgrading BBSO by replacing its principal 65 cm aperture telescope with a modern, off-axis 1.6 m clear aperture instrument. The new telescope offers a significant improvement in ground-based infrared and 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) will use the existing BBSO equatorial mount and observatory building, which will be modified to accept the larger open telescope structure. It will be operated together with our 10 inch (for larger field-of-view vector magnetograms, Ca II K and H$\alpha$ observations) and Singer-Link (full disk H$\alpha$) synoptic telescopes, which have lower resolution and larger fields of view. The NST optical and software control design will be similar to the existing SOLARC (UH) and the planned Advanced Technology Solar Telescope (ATST) facility led by the NSO – all three are off-axis designs.

So far, we have obtained commitment of funding from NASA, Airforce and NJIT totaling \$2M. We have proposed to NSF-MRI for the final \$2M, and that proposal is under review. We have planned our new telescope very carefully, so the down time for the transition is minimized to 3 to 6 months over the winter of 2005-6.

### Visible Light Vector Magnetographs

Our project to make a new Digital Vector MagnetoGraph (DVMG) system is completed. (Spirock et al., 2001, BBSO 1094). The DVMG uses a 1K$\times$1K SMD camera (12 bit, 15-30 frames/s) and has no moving parts. The DVMG has markedly increased the sensitivity and accuracy of our magnetograms – representing a significant improvement over the old, supplanted videomagnetograph. The operational DVMG system serves as the basic model for our new Fabry-Pérot filter-based magnetograph system, which will yield absolutely calibrated vector magnetograms. The approach here reflects our approach to instrumentation in general – each new system builds on its predecessor. The DVMG was built on an earlier version that could not measure vector fields. The Visible light Imaging vector Magnetograph (VIM) – which will use the Fabry-Pérot – will utilize the DVMG experience. The DVMG is part of the Ph.D. thesis work of Tom Spirock. With the 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 DVMG will stay on the 25 cm telescope, while the VIM will reside on the 65 cm telescope (or the 1.6m new telescope when it is completed), with its Fabry-Pérot filter providing 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. The VIM is designed to operate at the diffraction limit of the 65 cm telescope covering a substantial field of view (FOV) of about $140'' \times 140''$. 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 ($\sim$100 mÅ) filtergrams so that we can study, e.g., the H$\alpha$ fine structure with high spectral, temporal and spatial resolution. With the DVMG and VIM, we will be able to measure the magnetic field at two altitudes to determine the field's height variation. We have all the necessary hardware in hand, and expect to complete the VIM by the second year of the work proposed here.

### Infrared Vector Magnetograph

We have installed an infrared (IR), spectrograph-based magnetograph system at BBSO. For this, we purchased an InGaAs camera (320$\times$240 pixels, 12 bit, 60 frames/s) – a camera in which NJIT played an important developmental role. The camera is optimized between 0.9 and 1.6 $\mu$m, and has a quantum efficiency better than 70% over that range. We also developed the necessary optical, electrical and computer software components for the system. The next 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). A recent Ph.D. graduate, Jingshan Wang completed the Lyot filter. We have our operational IR Fabry-Pérot in hand. Our one-of-a-kind Lyot filter has a bandpass of 2.5 Å at 1.56 $\mu$m, giving us a 2.5 Å wide prefilter (narrower than the 5 Å free spectral range of the IR Fabry-Pérot). This will solve the longstanding problem of constructing a filter-based IR magnetograph, while avoiding the complications of using a double etalon. At this time, regularly operating, stable dual etalon IR systems do not exist. The new and unique Lyot prefilter would be used in conjunction with an IR Fabry-Pérot filter.

Then, polarimetry in the near IR will have the same reliability and stability as it now has for visible light. Note that the IR Lyot filter system has 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 quite restricted FOV, our system can utilize almost the entire FOV of the 65 cm telescope ($240'' \times 240''$). In addition, a new detector technology (CMOS devices) offers high quantum efficiency, so that we can take individual exposures well within the correlation time in the near IR ($\sim$100 ms). The strength of the IRIM is its extreme sensitivity and high spatial resolution, which allows us to study weak and small-scale magnetic fields in the quiet sun. We expect the first generation of the IRIM to be on-line shortly after the VIM. As mentioned, we are presently obtaining a large format IR CMOS camera ($\sim$1K$\times$1K from Rockwell Scientific Imaging).

The 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 the subsequent IRIM systems will be located in the Coudé room one floor beneath the observing floor. This optical design for this project is coordinated with that for the adaptive optics project.

## GLOBAL H$\alpha$ NETWORK

We have successfully established a five station H$\alpha$ observing network at BBSO, Kanzelhöhe Solar Observatory in Austria, Catania Astronomical Observatory in Italy and the Yunnan and Huairou Observatories in China. All five stations use the same kind of 2K$\times$2K cameras, each with a pixel resolution of 1 arcsec and temporal resolution of 1 minute. The data are processed with the software that we developed over the last two years. This allows us to monitor solar activity round-the-clock, including real-time reports of all flux emergences, filament disappearances and flares – facilitating our predictions of flaring for each active region. The money for the hardware for this network came from a separate NSF grant (Wang, PI); however, the work to set up this network was supported partially under our current ATM support.

## REAL-TIME SPECKLE IMAGING

One of the difficulties in our 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 ($\sim$2 hour) because the controlling computer's disk is filled by storing all the raw data, so the chances are slim of obtaining a sequence containing the long term evolution of an active region and catching flares during the observations. We have established a 32-node parallel computing cluster, so that we can do real-time speckle reconstructions with a cadence of about 1 minute, and diffraction limited images will be achieved all the time during the entire observing period – we expect this system to be in operation by the summer of 2003. For such observations, we will initially use our 256$\times$256 100 frames/s (fps) Dalsa camera, but will extend to a 1024 by 1024 pixel camera. This work is the thesis project of one of our Ph.D. students. The real-time data will allow us to measure flow fields, which will complement our vector magnetograms. Among other uses, it will improve our efforts to forecast solar storms. We will adopt real-time phase-diversity speckle to further improve the quality of the real-time data. We have hired Dr. Alexandra Tritschler to enhance this project.

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 is for a single isoplanatic patch (of order a few arc seconds in extent). Only multi-conjugate adaptive optics would 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 will be big enough for several days of continuous observation.

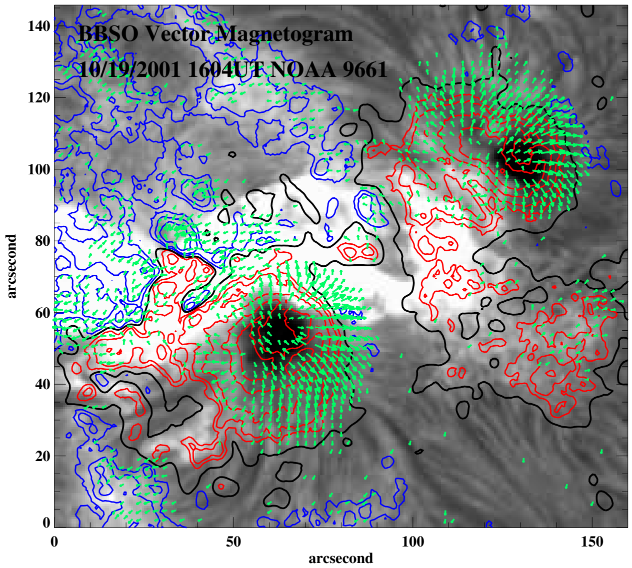


Figure 1: A DVMG vector magnetogram from October 19, 2001. The background is an H$\alpha$ image during an X1.6 flare. Arrows indicate the transverse fields, and the thick, solid black lines are the neutral lines of the line-of-sight magnetic field.

### B.2 Scientific Programs

EVOLUTION OF VECTOR MAGNETIC FIELDS ASSOCIATED WITH SOLAR FLARES

After upgrading/improving several instruments (e.g., the new DVMG, the IRIM and real-time speckle reconstruction, see §B), and with data from SoHO and TRACE, we are 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. Our studies will be aided by our recent upgrade to our DVMG to employ a 1K×1K camera. Figure 1 shows an example of vector magnetogram.

One of the important results from BBSO obtained during the previous solar maximum 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. It appears that a photospheric increase does not always occur. However, it may actually be that sometimes it is simply too small for us to have detected with BBSO's old videomagnetograph system. With the new magnetograph system, we have found some other strange results: rapid and permanent flux changes after all eight X-class flares studied by us (Spirock et al., 2002, Wang et al., 2002).

Figures 2 and 3 demonstrate the results of July 26, 2002 M8.7 flare. Figure 2 shows the trailing and leading magnetic fluxes as a function of time and compared with GOES X-ray light curve. Similar to several events that what we discussed in previous papers, this event shows a sudden and permanent increases of one polarity, and the sudden increase of magnetic shears. Figure 3 shows line-of-sight magnetogram, H$\alpha$ and RHESSI flare emissions, and a comparison between mean transverse fields before and after the flare. The red circle marks the area of enhanced transverse field and magnetic shear, which is located in the neutral line in the core of the flare, as shown by the RHESSI and H$\alpha$ images. The increase in positive magnetic flux, on the other hand, is apparently associated with the slight expansion of the positive polarity sunspot immediately below the circle. The change of line-of-sight magnetic field is confirmed by MDI data.

The DVMG will enable us to do the proposed work. However, by the middle of 2003, we expect to be able to do it better still with our upgrades to a calibrated digital Fabry-Pérot vector magnetograph, the VIM, and an IR Fabry-Pérot magnetograph system, the IRIM. With the VIM and IRIM, we will be sensitive to significantly smaller changes in magnetic shear, and can definitively characterize its behavior. 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 (like SoHO and TRACE) will be combined with BBSO data to obtain the three-dimensional

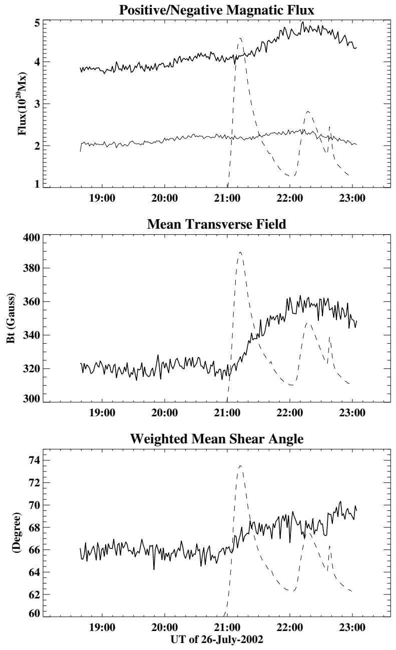


Figure 2: Magnetic flux, mean transverse magnetic field and weighted mean magnetic shear as a function of time for July 26, 2002 event, overplotted by GOES X-ray flux.

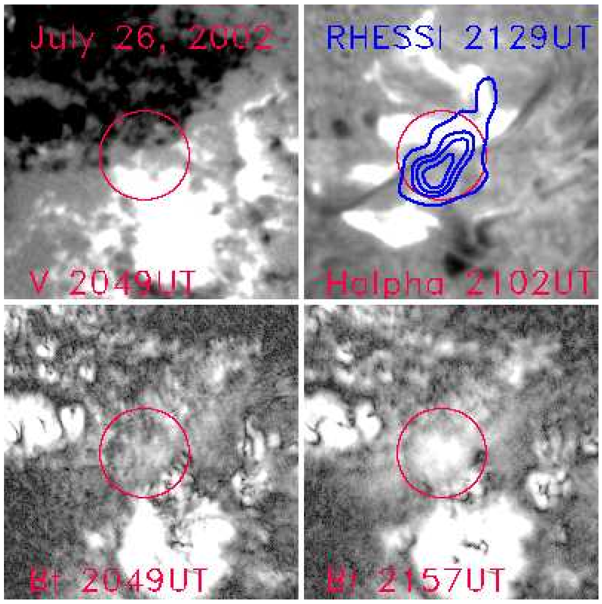


Figure 3: Line-of-sight magnetogram, H$\alpha$ and RHESSI (blue contours) flare emission, and transverse fields before and after the flare. The red circle marks the area where transverse field and magnetic shear had an sudden increase associated with the flare.

structure of magnetic loops.

One of the important tools for studying the evolution of magnetic fields in a flare producing active region 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 do a better job now because the currents will be derived from more accurate vector magnetograms coming from the DVMG. We will 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.

We are aware of that the solar cycle is approaching the solar minimum, and the chance of major solar flares are small. We will overcome this by doing: (1) We will study events that we already got (30 M class or larger flares). (2) Our new instruments will have much improved sensitivity, so we anticipate that the evolution of magnetic fields will be detected for smaller events.

## Synoptic Observations and Space Weather Forecasting

Synoptic observations and research will continue to be one of the primary scientific objectives of BBSO. Accumulated synoptic data sets provide important archives from which one can determine the long-term variation of solar radiation fields and magnetic fields. They 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 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:

**(a) Full-Disk Observations**

These are the backbone of the synoptic program (Denker et al., 1999). The 2K$\times$2K H$\alpha$ images show the full solar disk in high resolution. The five-station 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) which detects filament eruptions in real-time and posts them on the web.

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 can be seen on the BBSO CaK web page, which is updated on a daily basis (`www.bbso.njit.edu/Research`). We will continue to construct a CaK index, and develop an index of the latitudinal distribution of CaK brightness as the solar cycle progresses.

In the near future, the SOLIS system will come on-line. This will not impact our H$\alpha$ network because there is no SOLIS network, and the H$\alpha$ frame rate is several minutes for SOLIS. Of course, we will use SOLIS H$\alpha$ images where appropriate. With SOLIS, the need for our K-line and white light synoptic programs will have to be re-examined. Neither of them takes much time or effort (a few minutes a day), and our view is that we will continue with the ones that provide context for our high resolution observations, and help with our solar activity forecasting into the next activity minimum.

We also plan to include G-Band and CN-band (388 nm) full disk observations, which provide magnetic proxy data for the upper photosphere.

**(b) 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 better than 90% of the time. 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.

As discussed in §A, we have upgraded our space weather program to include the Active Region Monitor (ARM) and Flare Prediction System (FPS). They describe the status of each active region in the real-time. We will continue to improve this system by including more parameters, such as electric current maps and magnetic shear maps.

**(c) 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 specific features – a 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 index (degree of equatorial magnetic field deviation, by ground stations), Ap and Kp indices. While (1) can give a 1-2 hour warning of arrival of geomagnetic storms, (2) is only a 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 and 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. With a much improved data base, we will search for possible relationships between magnetic structures 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 an advanced warning of geomagnetic storms 2 to 3 days before their arrival at the earth.

We have been studying about 20 halo CME events in detail (Yurchyshyn et al., 2001, 2003), and found that the overlying magnetic field structure above erupting filaments may provide a good indicator of the orientation of magnetic clouds. Recently, there have been more comprehensive studies on structure of magnetic clouds from modeling data from multiple spacecraft (Mulligan et al., 2001a, b; Mulligan and Russell, 2001). We believe that their findings will enhance our study and help to determine the orientation of magnetic clouds more accurately, which will improve the comparison with our ground-based measurements and extrapolation.

### Helicity Injection into Erupting Filaments, CMEs and Flares

There have been many reports on the helical structure of solar and heliospheric magnetic fields as observed in photospheric magnetic fields (Pevtsov and Canfield, 2000), coronal X-ray images (Canfield and Pevtsov, 2000), solar filaments (Chae, 2000), coronal mass ejections (Rust, 1999), and interplanetary magnetic clouds (Burlaga, 1988). So far, most observational studies of the helicity of solar active regions have focused on the current helicity, defined as $\int \mathrm{B} \cdot \mathrm{J}\, \mathrm{dV}$, and its sign (or the linear force-free coefficient $\alpha$), mainly because they can be directly inferred from photospheric vector magnetograms (e.g., Hagyard and Pevtsov, 1999). The current helicity is a measure of the topological properties, such as twist and mutual linkages of the lines of electric current (Berger and Field, 1984, Devore, 2000). On the other hand, magnetic helicity, defined as $\int \mathrm{A} \cdot \mathrm{B}\, \mathrm{dV}$, is a measure of twist and linkage of magnetic field lines (Devore, 2000). The magnetic helicity is a physically more useful concept than the current helicity, because magnetic helicity is fairly well-conserved in a closed volume, in the absence of boundary flows. It is considered as a robust invariant in space plasmas, such as the solar corona (Berger, 1999). However, this quantity has rarely been measured because of the difficulty in determining the topological connection of field lines in a 3D space. Instead, there have been efforts to determine its rate of temporal change in an open volume.

Since the solar corona is an open volume with the photosphere as a boundary with normal flux, the magnetic helicity can be transported across the boundary by velocity fields in the photosphere. According to Berger and Field (1984), the Poynting theorem for magnetic helicity in an open volume is given by:

$$\frac{dH}{dt} = 2 \oint (\mathbf{B} \cdot \mathbf{A}_{\mathrm{p}}) v_z \, dS - 2 \oint (\mathbf{v} \cdot \mathbf{A}_{\mathrm{p}}) B_z \, dS \tag{1}$$

where $\mathbf{A}_{\mathrm{p}}$ is the unique vector potential of the potential field determined by the following conditions:

$$\nabla \times \mathbf{A}_{\mathrm{p}} \cdot \mathbf{z} = B_z, \ \nabla \cdot \mathbf{A}_{\mathrm{p}} = 0, \ \mathbf{A}_{\mathrm{p}} \cdot \mathbf{z} = 0 \tag{2}$$

Equation (1) tells that the magnetic helicity in an open volume can change either by the passage of field lines through the surface (first term) or by the horizontal motions of field lines (second term). The second term is particularly dominant if emerging (or submerging) fluxes are insignificant. The second term is called the shuffling term and the first is the advection term.

The BBSO group has recently studied the injection of helicity into active regions and its possible correlation with the onset of flares. Chae (2001) has developed a tool to derive the second term in the equation from the study of line-of-sight magnetograms. These are written in equations (3) and (4):

$$A_{p,x} = FT^{-1}[\frac{jk_y}{(k_x^2 + k_y^2)} FT(B_z)] \tag{3}$$

and

$$A_{p,y} = FT^{-1}[-\frac{jk_x}{(k_x^2 + k_y^2)} FT(B_z)] \tag{4}$$

Chae et al. (2001) studied formation of a filament, and found that the motion of footpoints provide sufficient shuffling helicity into the forming filament. Moon et al. (2002) applied the method to MDI data to study the helicity injection rate associated with several flares,

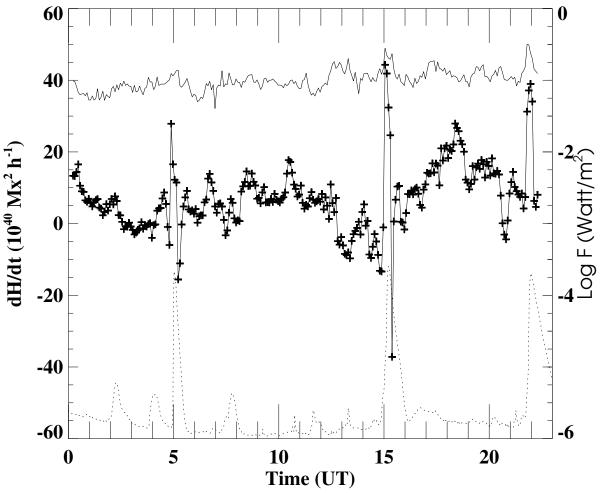


Figure 4: Temporal change of magnetic helicity change rate (thick solid line), GOES X-ray intensity (dotted line), and the sum of the norms of the photospheric velocity vectors (thin solid line) expressed in an arbitrary scale for the November 24, 2000 flares.

and found a correlation between flare energy and amount of helicity injection.

We propose to adopt these techniques to study the evolution of helicity injection rate before, during and after filament eruptions and flares. We will select 10 to 20 events, which will satisfy the following criteria:

(1) Regions are close to disk center to avoid confusion arising from geometric projection.

(2) No major observed flux emergence or cancellations, so the advection term can be ignored.

(3) Filament eruptions and fares are associated with CMEs, so that there is substantial amount of energy and mass release, as well as possible helicity transport into interplanetary space. The knowledge we gain here will also help us to understand the physical picture of helicity injection for CMEs.

Among our selected events, we will include some active region events, and some quiet region events. We understand that there are not many quiet sun events that will satisfy the above selection criteria. However, we have identified three events already and will expect to identify more over the next three years, as the sun goes toward activity minimum. Figure 4 shows results of studies of three flares on November 24, 2002, which occurred in the same active region (Moon et al., 2002). It is demonstrated that the helicity injection is enhanced around the time of the flares. This plot demonstrates the feasibility of the study proposed here.

We will use H$\alpha$ full disk data to identify the time and location of eruptive events and MDI magnetograms to derive the shuffling term of helicity as described above. We will be able to find if an impulsive helicity injection is important in triggering filament eruption, in the similar way as is being found for flares (Moon et al., 2002). For some selected events, we will have vector magnetograph data from BBSO which have better sensitivity, cadence and resolution than the MDI data. We will compare the calculations of helicity injection from two data sources to ensure the accuracy and reliability.

We recognize that we are only considering the shuffling term in the helicity injection. During the process of selecting events for this study, we will evaluate many events to see if the magnetic flux emergence or cancellation is important in the process of filament eruption and flaring. So we will have a by-product of this study, i.e. the percentage of filament eruptions/flares associated with flux emergence or cancellation, and their relative importance in contributing to the advection term in helicity injection. This part is difficult as we need to accurately measure vector magnetic fields as well as velocity fields. Kusano et al. (2002) developed a method of measuring helicity injection rates of both terms associated with flares. It requires the vector magnetograms. Although BBSO's new digital magnetograph system can provide high quality vector magnetograms, an erupting filament is typically not located at the strong magnetic field part of an active region. Therefore, it is very hard to calculate the advection term for the study of filament eruption, even with Kusano et al.'s method.

## HIGH CADENCE FLARE OBSERVATIONS

We propose to make high cadence observations of flares to elucidate the energy release process during flaring. This project is enhanced significantly after the Ramaty High Energy Solar Sprectroscopic Imager (RHESSI) is providing data.

We propose to continue dedicated 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 resolution limit of our facilities.

The key components of the innovative, high cadence BBSO system consist of a $256 \times 256$, 12-bit Dalsa camera (110 fps), and a 1K$\times$1K SMD camera (30 fps with 2:1 binning, otherwise 15 fps). 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 view and cadences.

In our campaigns, we will observe in the far blue/red wing of the H$\alpha$ line, which responds sensitively and promptly to non-thermal electron beams. We also plan to observe the HeI $D_3$ line, which is an ideal line for the diagnosis of electron density in the region of the flare. In particular, the latter line can show emission or absorption depending on the electron column density (Zirin, 1988).

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 heating 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), and to understand the mechanism by which flares accelerate electrons.

## High Resolution Visible and Near IR Observations of Active Regions

(a) Contribution of Footpoint Motion to Coronal Loop Heating

Aschwanden et al. (2000) found that for coronal loops, the heating is concentrated in the footpoints (50 to 300 Mm). Although the heating function was given, the detailed heating mechanism was not described. Contrarily, Priest et al. (2000) found that corona loops have uniform heatings. To understand the problem better, we need to 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 from 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 above events are important. We know that such footpoint motion is hard to observe and characterize in lower resolution magnetograph and filtergraph observations. We plan to detect and characterize such footpoint motions with $0.2''$ spatial resolution, 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 motions and brightness of overlying EUV/X-ray loops. Berger et al. (1998) described the observation and data processing of G-band observation to study motions of magnetic elements. We plan to adopt similar observing techniques, but using our parallel computer clusters to do real time data processing in active regions.

(b) Flux Emergence and Magnetic Channel Structure in Flare Producing Active Regions

There are two very important aspects of evolution of active regions which may be closely associated with solar flares: (1) new flux emergence and (2) unusual flow motions. These two kinds of phenomenon may also be associated with each another (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 and Wang, 1993) ARs. To observe these flows and field structure in detail, we need high resolution and cadence observations, as we are currently performing.

It was found that by Zirin and Wang (1993) that the magnetic channel structure is created by the new flux emergence inside a sunspot and appears as complicated flows along the channels. The area with strong flows, new flux emergence, and complicated channel structure was also obviously associated with several major flares in several active regions. The flux emergence destablizes the existing magnetic configuration and causes magnetic reconnection. Flow motions may contribute to the twist of fluxropes by moving footpoints around. Such flow and channel structures are not well understood–it requires long sequences of high resolution observations that our new DVMG system can provide. In Figure 5, we demonstrated the "channel" in AR 9236 which produced 4 X-class flares from November 24 to 26, 2000. The channel is marked by a white box, which is also at the center of all eruptive flares in this region. H$\alpha$ image of X2 flare on November 24, 2000 is shown in the right panel.

Denker and Wang (1998) demonstrated the power of diffraction limited observations on August 31, 1997, in the flaring active region NOAA 8076. Almost diffraction-limited speckle reconstructions revealed the complex and highly dynamical behavior of a small emerging configuration in the central part of NOAA 8076. We found strong shear flows and indications of strong transverse fields in the small spot. The flare-producing mechanism for this small activity complex was very similar to that of the outstanding flare-producing region NOAA 5395 of March 1989, however, on a much smaller spatial scale.

As we know, if the speckle observing sequences are processed off-line (as in Denker and Wang, 1998), the chance of studying the long term evolution of an active region and catching flares during the observations is slim. Our new system will only save constructed image data– therefore, the disk will be big enough for several day's continuous observation. The real time data product of diffraction-limited quality is essential in this study. We will follow all flare productive regions, with an image scale of $0.1''$. The active regions flows will be derived by local correlation tracking and feature tracking. We expect to answer the following questions:

(1) Do flaring active regions always have the complicated flows as discussed above, if we have sufficient resolution?

(2) Are these flows always associated with flux emergence, and in particular, magnetic channel structure?

(3) Are flows unusually strong before major flares? Monitoring of flows may provide a prediction tool for solar flares and space weather.

(4) what are the electric currents and magnetic shear in the magnetic channel structures?

(c) Near IR Observations

IR solar astronomy is a science whose time has come because of new camera and filter (see §B.1) technologies. The BBSO CMOS camera from Rockwell and IR filter system will be the

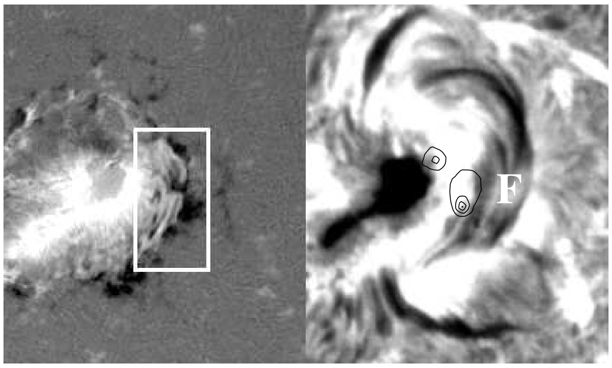


Figure 5: Left panel: a line-of-sight DVMG image of November 24, 2000. The white rectangle marks a magnetic channel structure. The field-of-view is 150×180 arcsec. Right panel: H$\alpha$ image of the X2 flare at 21:53UT, in the same field of view as the magnetogram. An erupting flux rope is denoted by "F", and the black contours show Yohkoh hard X-ray kernels.

unique instrument for this part of research.

For several scientific reasons, studying the sun 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 $\mu$m), so that one can see deeper into the sun at that wavelength. 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 and Rimmele (1999) made near IR observations of granular magnetic fields. Their flux density sensitivity is 1 G, and they identified both strong ($\geq$ 1000 G) and weak ($\leq$ 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.

(c.1) 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 and Morran, 1994). Such a result would sharply constrain models of flux tubes (Spruit, 1976). Whether correct or not, this motivates a detailed study of sunspot and facular contrast and their relative areas in the visible and IR, which would also facilitate microscopic analysis of the energy budget in solar active regions.

(c.2) 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 Å were made by Ewell (1992). New observations were obtained at 1.6 $\mu$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.

(c.3) IR Spectroscopic and Polarimetry Observations:

Lin's (1995) experiment has already demonstrated that the BBSO spectrograph system 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 big active regions, and to derive the temperature, velocity, true magnetic field strength and filling factors of these features.

Stokes Q and U profiles present a more difficult problem than does the V profile due to the severe instrumental polarization of the 65 cm reflector. 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 inversion codes which will help us in the data reduction. Beyond the study of Stokes profiles, the IR spectroscopic study of faculae and pores will be particularly interesting. If these regions are truly cooler, then we should find a different spectral shape among the Fraunhofer lines, and gain a clearer understanding of their temperature profile.

The scientific objectives of IR polarimetry are straightforward: in the active regions, it allows us to measure the magnetic fields accurately, so that the 3-D structure can be extrapolated based on these measurements. Processes, such as magnetic reconnection, can be studied in detail by following the evolution of the 3-D magnetic structure.

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