

A. Proposal Summary

New Jersey Institute of Technology (NJIT) has been operating Big Bear Solar Observatory (BBSO) since July 1, 1997. Our current four year NSF grant started on March 1, 2004. This grant provides primary, backbone support for BBSO. In the past three years since this grant started, the observatory has remained highly productive – both scientifically and in the development of requisite instrumentation. We have graduated 9 Ph.D.s, produced over 100 publications and obtained successful observations with adaptive optics (AO) system and near infrared magnetograph. BBSO is in the final stage to build its 1.6 meter, off-axis new solar telescope (NST). The first-light of this telescope is expected within a year. We anticipate that, in the next 5 to 10 years, the AO equipped NST will be the prime facility to study solar activity with high resolution in US, and will be a test-bed for the 4-meter Advanced Technology Solar Telescope (ATST).

The instrumentation tasks to be finished are:

1. Setup NST and transform it to routine operation.
2. Integrate 96 actuator active optics system to NST.
3. Integrate visible and near infrared vector magnetograph systems to NST.

Using the instruments above and data from BBSO's rich archive, as well as space-based data from a number of new NASA missions, the high-light of proposed scientific programs includes:

1. High-cadence and high-resolution studies of solar flare emissions. These observations will provide details of flare energy precipitation on sub-arcsecond spatial scales and sub-second temporal scale. In particular, we will attempt to understand the physics of our new discovery: flare ribbons initially contract before the well-known separations.
2. Comprehensive studies of vector magnetic fields associated with flares, filament eruptions and CMEs, to understand the triggering mechanism of the eruptions and atmospheric restructuring after the eruptions. In particular, we will attempt to understand the physics of our recent discovery: photospheric magnetic fields changes rapid and irreversibly associated with flares.
3. Study of flow fields in flare productive active regions will be advanced using high resolution, high cadence and continuous observations. In particular, we will investigate the structure and evolution of shear flows along flaring neutral lines and in new flux emergences.
4. Sustained sub-arc second resolution studies of active regions and the quiet sun. In particular, we will address the problems of the energy source of coronal heating, from the high resolution observations of footpoint motion, magnetic reconnection, and chromospheric signatures of energy release.

Finally, we address the two merit criteria required for an NSF proposal:

Intellectual merit: We are obtaining and using high quality data sets, while developing and applying analytical tools to study a number of critical, leading-edge problems in solar research. The NST will play a crucial role in the advances of solar physics in next few years.

Broader Impact: Solar magnetic storms can impact human technologies in what is broadly called “space weather”. At BBSO, high quality data and analysis tools will aid 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. An integrated approach to research and education is at the heart our efforts, which is reflected in this proposal.

B. Project Description

B.1. Results from Prior ATM Support (April 2004 to June 2007)

New Jersey Institute of Technology (NJIT) took over operation of Big Bear Solar Observatory (BBSO) on July 1, 1997. On April 1, 2004, our current three year NSF 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 the community’s efforts to study and understand the sun. Observing campaigns are essential to determine the origin of “space weather”, which arises from solar magnetic storms and can impact earth. Since 1997, we have made fundamental changes in the observatory’s instrumentation to ensure a unique and significant scientific role for BBSO. The advances in instrumentation were critical for improving the quality of our observations, especially for high resolution studies. BBSO is in its critical path, as its 1.6 meter New Solar Telescope is expected to obtain the first light within a year. Meanwhile, even though we devoted a lot of effort in instrument development, better data helped our research group to be even more productive, as evidenced by over 100 publications in the three years since April 2004. 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 9 Ph.D. students from 2004 to 2007. We currently have 10 Ph.D. students (including 8 men and 2 women), 3 of whom will graduate in 2008. Since the beginning of our current NSF support, three of our post-docs have also advanced to tenure-track positions. Wenda Cao is now an assistant professor at NJIT. Jiong Qiu is now an assistant professor at Montana State U. Deqing Ren is an assistant professor in California State U. Northridge.

BBSO has an unpaid, outside Advisory Board, which meets bi-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 (University of Michigan, Chair), Steve Koonin (Caltech), Jeff Kuhn (University of Hawaii), and Spiro Antiochos (Naval Research Lab). 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. 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.bbsol.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.

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. The rest of this section highlights some of our scientific achievements under current NSF support.

B.1.1. High Cadence Flare Observations

Using BBSO’s high cadence, high resolution observations, Ji et al. (2004) studied rapid changes of the relative positions of two conjugate flare footpoints. We probed the fine temporal structures connected to the distance between the centroids of two conjugate kernels of an M2.3 flare on 2002 September 9 in NOAA Active Region

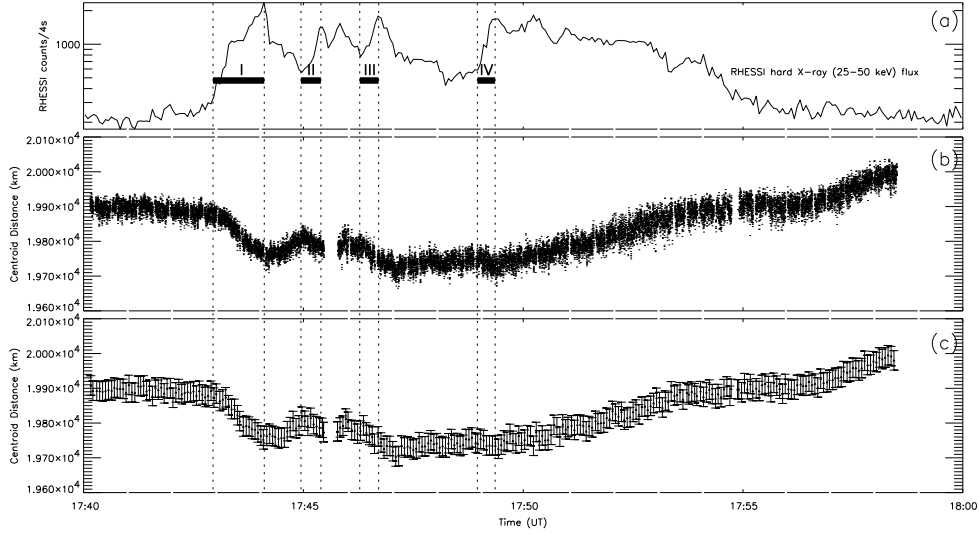


Figure 1: Above: RHESSI HXR light curve of 2002 September 9 flare, in the energy band of 25 to 50 keV for which the time resolution is 4 s. (b) Time profile of centroid distance between the two conjugate kernels, for which the cadence is 40 ms. (c) Time profile of centroid distance with error bars, which is rebinned according to the RHESSI HXR 4 s time resolution. The dotted lines indicate the rising periods of four HXR spikes (Ji et al., 2004b).

10105. It was observed at BBSO at the far off-band center wavelength of $H\alpha$ -1.3A, with a cadence of 40 ms. As shown in Figure 1, the time profile of the separation distance shows an excellent anti-correlation to that of the hard X-ray (HXR) emissions in 25-50 keV, which exhibit a number of separate spikes. The separation between the two centroids **decreases** at the rising periods of four HXR spikes, then it increases after the peak time of the flare to show the expected separation motion. We speculated that this new and perhaps surprising tendency for the energy deposition can be explained as being caused by current-sheet pinch motions, which, at the same time, enhance the magnetic energy reconnection rate to produce the observed HXR spikes. As we will discuss later, this could also be the signature of implosion as proposed by Hudson (2000).

This results is confirmed recently with even clearer evidences. Ji et al. (2006) presented the results from a high-cadence (40 ms) $H\alpha$ blue-wing observation of an M1.1-class solar flare, which occurred in NOAA AR 10687 on 2004 November 1. These studies also agree with recent RHESSI results, e.g., the ones presented by Veronig et al. (2006), Sui and Holman (2003), Sui et al. (2004), all showing some sort of loop contraction before the main phases of the eruptions.

B.1.2. Rapid Evolution of Magnetic Fields Associated with Flares

Very recently, we presented a new observational result of rapid changes of sunspot structure associated with a substantial fraction of flares (Wang et al. 2004a; Deng et al. 2005; Liu et al. 2005; Chen et al., 2007). In particular, Liu et al. (2005) studied the relationship between the change in δ spot structures and associated major flares for seven events. The results are quite consistent for all the events: 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. The rapid changes, which can be identified in the time profiles of white-light (WL) mean intensity, are permanent, not transient, and thus are not due to the flare emission. The co-aligned magnetic field observations show substantial changes in the longitudinal magnetic field associated with the decaying penumbrae and darkened central areas. In two events for which vector magnetograms were available, we find that the transverse field associated with the penumbral decay areas decreased, while it

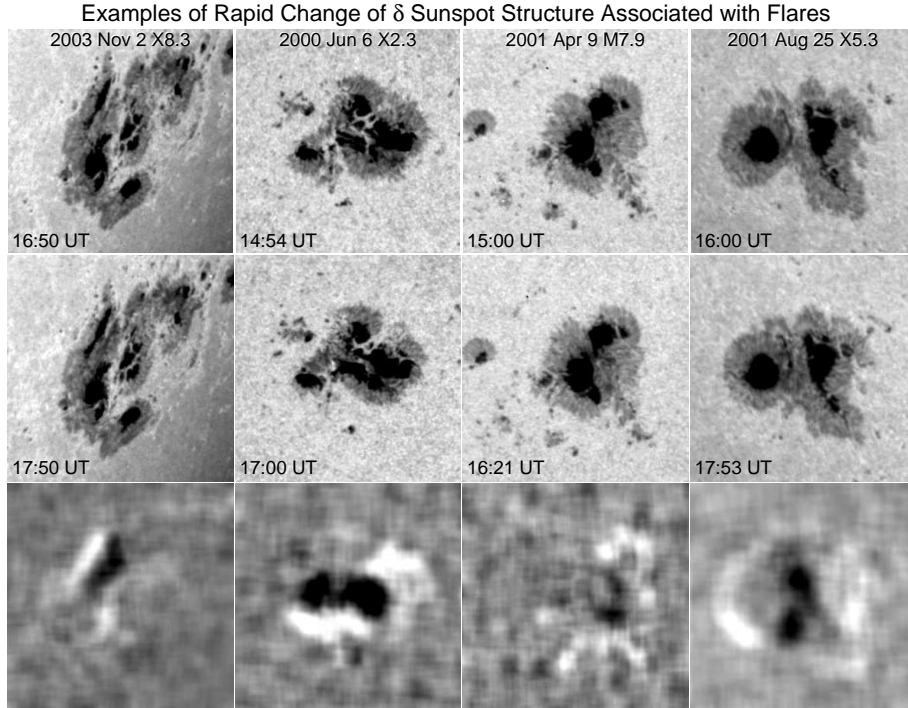


Figure 2: TRACE WL images revealing the rapid change of δ sunspot structure associated with four major flares. The top, middle, and bottom rows show the pre-flare images, post-flare images, and the difference images between them, respectively. The white feature in the difference image indicates the region of penumbral decay, while the dark feature indicates the region of central umbral/penumbral enhancement (Adapted from Liu et al. 2005).

increased in the central darkened regions. Both events also show an increase in the magnetic shear after the flares. To explain these observations, we propose 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 leads to penumbral decay. The umbral core and inner penumbral region become darker as a result of increasing longitudinal and transverse magnetic field components. Figure 2 shows the examples of such rapid changes of sunspot structure as described above: the difference between pre- and post-flare images that the flaring neutral line is darkened while a bright ring appears corresponding to the penumbral decay in the peripheral penumbrae.

Wang (2006) found obvious changes of magnetic gradient occurred immediately and rapidly following the onset of each flare. In addition, we evaluated the mean relative motions between two magnetic polarities in these δ regions, in the direction parallel and perpendicular to the flaring neutral lines, respectively using the method of Center of Mass (CoM) calculation, and found that: (1) Converging motions correspond to the gradient increase; diverging motion, the decrease; (2) For all the events, there appeared a sudden release of magnetic shear associated with each flare, signified by a decrease of CoM separation between 500 and 1,200 km in the direction parallel to the neutral lines. Combining the findings presented in several papers, we propose that these are evidences of magnetic reconnection at or close to the photosphere.

Furthermore, we presented results of a statistical study of rapid penumbral decay associated with flares (Chen et al. 2007). We found that the rapid structure change of sunspots is more likely to be detected when associated with large solar flares. The larger the flare magnitude, the larger the change. For X-class flares, 45% events show distinct change. But for M- and C-class flares, this percentage drops to 16% and 10%, respectively.

B.1.3. Relationship among Filament Eruptions, Flares, CMEs and Magnetic Reconnection

We measured the photospheric magnetic fields and the flare ribbon separation speeds then derived two physical terms for the magnetic reconnection rates: the rate of magnetic flux change involved in magnetic reconnection in the low corona and the electric field inside the reconnecting current sheet (RCS) that is generated during magnetic reconnection. A certain correlation is found between the magnetic reconnection rate and the acceleration of erupting filaments that represents the early stages of flux-rope eruptions in the low corona (Jing et al., 2005). In addition, certain temporal correlation between reconnection rate and flare emissions was found.

Jing et al. (2004) studied over 100 filament eruptions and found that: (1) 56% filament eruptions were associated with CMEs; (2) active region filament eruptions have a considerably higher flare association rate (95%) compared to filament eruptions in quiescent regions (27%), but a comparable CME association rate (43% and 54%, respectively) and (3) 68% of disk events were associated with new flux emergence. In addition, we derived the sign of magnetic helicity and the orientation of the magnetic field associated with seven halo CMEs and demonstrated that the geoeffectiveness of a halo CME may be predicted by these two parameters.

Very recently, we discovered the ribbon-like HXR emission in a sigmoidal active region that was observed for the first time with RHESSI (Liu et al., 2007). Taking advantage of this new observation, Jing et al. (2007) detailed the translation of HXR source morphology with time from the compact sources to the ribbon-like structure concentrating on the spatial distribution of HXR intensity and reconnection rate. These results thus provide 3D observational features that challenge the classical 2D reconnection models that have been discussed by many authors.

B.1.4. Application of Artificial Intelligence in Detection and Characterization of Solar Activity

We have developed a suite of software to automatically detect and characterize solar activities. The current operational codes are for detection of flare (Qu et al., 2003, 2004), filament eruptions (Qu et al., 2005), CMEs (Qu et al., 2006) and prominence eruptions (Fu et al., 2007). This has been a successful multi-discipline programs, that involves faculty and students in solar physics and computer sciences.

B.1.5. Selected BBSO Publications from March 2004 to June 2007

The discussion above highlights our scientific accomplishments over the past three years. Because of limited space, we list only selected publications (30 of 100) from the period of our present NSF support. Please check the home page (solar.njit.edu/preprints) for a complete list with downloadable copies.

- BBSO 1158** : *Sudden Disappearance of a Small Sunspot Associated with the February 20, 2002 M2.4 Flare*, Haimin Wang, Haisheng Ji, Edward J. Schmahl, Jiong Qiu, Chang Liu, Na Deng, 2004, Ap.J. Letters, 580, L177
- BBSO 1236**: *On the Relation Between Filament Eruptions, Flares and Coronal Mass Ejections*, Ju Jing, Vasyl B. Yurchyshyn, Guo Yang, Yan Xu Haimin Wang, 2004, Ap.J, 614, 1054
- BBSO 1239**: *Statistical Distributions of Speeds of Coronal Mass Ejections*, V. Yurchyshyn, S. Yashiro, V. Abramenko, H. Wang N. Gopalswamy, 2005, Ap.J., 619, 599
- BBSO 1240**: *Magnetic Helicity Change Rate Associated With X-Class and M-Class Flares*, Klaus Hartkorn Haimin Wang, 2004, Solar Physics, 225
- BBSO 1242**: *Properties of Remote Flare Ribbons Associated with CMEs*, Haimin Wang, 2005, Ap.J, 618, 1012
- BBSO 1247**: *Magnetic Reconnection Rate and Flux-Rope Acceleration of Two-Ribbon Flares*, Ju Jing, Jiong Qiu, Jun Lin, Ming Qu, Yan Xu Haimin Wang, 2005, Ap.J, 620, 1085
- BBSO 1254**: *Hard X-Ray and Microwave Observations of Microflares*, Jiong Qiu, Chang Liu, Dale E. Gary, Gelu M. Nita Haimin Wang, 2004, Ap.J, 612, 530
- BBSO 1255**: *Rapid Change of δ Spot Structure Associated with Seven Major Flares*, Chang Liu, Na Deng, Yu Liu, David Falconer, Philip R. Goode, Carsten Denker Haimin Wang, 2005, Ap.J, 622, 722
- BBSO 1257**: *Photospheric Shear Flows Along the Magnetic Neutral Line of Active Region 10486 prior to an X10 Flare*, Guo Yang, Yan Xu, Wenda Cao, Haimin Wang, Carsten Denker Thomas R. Rimmele, Ap.J Letters, 2004, 617, L151
- BBSO 1267**: *Rapid Penumbral Decay in Active Region NOAA 9026 Associated with an X.23 Flare*, Na Deng, Chang Liu, Guo Yang, Haimin Wang Carsten Denker, 2005, Ap.J, 623, 1195
- BBSO 1270**: *High Resolution Observations of Multi-Wavelength Emissions during Two X-Class White-Light Flares*, Yan Xu, Wenda Cao, Chang Liu, Guo Yang, Ju Jing, Carsten Denker Haimin Wang, Emslie, A. Gordon, 2006, Ap.J., 641, 1210

- BBSO 1272:** *Re-evaluation of the Magnetic Structure and Evolution Associated with the Bastille Day Flare on 2000 July 14*, Haimin Wang, Chang Liu, Yuanyong Deng Hongqi Zhang, 2005, Ap.J, 627, 1031
- BBSO 1273:** *Relationship Between Magnetic Gradient and Magnetic Shear in Five Super Active Regions Producing Great Flares*, Haimin Wang, Hui Song, Jing, Ju; Yurchyshyn, Vasyl; Deng, Yuan-Yong; Zhang, Hong-Qi; Falconer, David; Li, Jing, 2006, ChJAA 6, 477
- BBSO 1279:** *Properties of Small Dark Features Observed in the Pure Near-Infrared and Visible Continua*, Yan Xu, Wenda Cao, Jun Ma, Klaus Hartkorn, Ju Jing, Carsten Denker Haimin Wang, 2005, Ap.J Letters, 628, L167
- BBSO 1281:** *Large-Scale Activities Associated with the 2003 October 28 X10 Flare*, Chang Liu, Jeongwoo Lee, Na Deng, Dale E. Gary Haimin Wang, 2006, Ap.J. , 642, 1205
- BBSO 1286:** *Multiwavelength Study of Flow Fields in Flaring Super Active Region NOAA 10486*, Na Deng, Yan Xu, Guo Yang, Wenda Cao, Chang Liu, Thomas R. Rimmele, Haimin Wang Carsten Denker, 2006, Ap.J. 644, 1287
- BBSO 1290:** *Evidence for a Quadrupole Magnetic Configuration in the April 9 2001 M7.9 Flare as Inferred from Multi Wavelength Observations*, V. Yurchyshyn, M. Karlicky, Q. Hu H. Wang, 2006, Solar Physics, 235, 147
- BBSO 1294:** *The Statistical Relationship Between the Photospheric Magnetic Parameters and the Flare Productivity of Active Regions*, Ju Jing, Hui Song, Valentyna Abramenko, Changyi Tan Haimin Wang, 2006, Ap.J., 644, 1273
- BBSO 1295:** *The Automatic Predictability of Super Geomagnetic Storm from Halo CMEs Associated with Large Scale Solar Flares*, Hui Song, Vasyl Yurchyshyn, Guo Yang, Changyi Tan, Weizhong Chen Haimin Wang, 2006, Solar Physics, 238, 141
- BBSO 1299:** *The Rate of Emergence of Magnetic Dipoles in Coronal Holes and Adjacent Quiet-Sun Regions*, V.I. Abramenko, L.A. Fisk V.B. Yurchyshyn, 2006, Ap.J. Letters, 641, 65
- BBSO 1309:** *Coronal Heating and Photospheric Turbulence Parameters: Observational Aspects*, V.I. Abramenko, Alexei P. Pevtsov R. Romano, 2006, Ap.J Letters., 646, L81
- BBSO 1310:** *Rapid Changes of Photospheric Magnetic Fields around Flaring Magnetic Neutral Lines*, Haimin Wang, 2006, Ap.J., 649, 490
- BBSO 1311:** *Adaptive Optics at the Big Bear Solar Observatory: Instrument Description and First Observations*, Carsten Denker, Alexandra Tritschler, Thomas R. Rimmele, Kit Richards, Steve L. Hegwer Friedrich Woger, 2006, PASP, 119, 170
- BBSO 1381:** *Automatic Detection of Prominence Eruption Using Consecutive Solar Images*, Gang Fu, Frank Y. Shih Haimin Wang, IEEE
- BBSO 1319:** *Field Dependent Adaptive Optics Correction Derived with the Spectral Ratio Technique*, C. Denker, N. Deng, T.R. Rimmele, A. Tritschler A. Verdoni, 2007, Solar Physics, in press
- BBSO 1321:** *Diffraction-limited Polarimetry from the Infrared Imaging Magnetograph at Big Bear Solar Observatory*, Wenda Cao, Ju Jing, Jun Ma, Yan Xu, Haimin Wang Philip R. Goode, 2006, PASP, 118, 838
- BBSO 1322:** *First Light of the Near-Infrared Narrow-Band Tunable Birefringent Filter at Big Bear Solar Observatory*, Wenda Cao, Klaus Hartkorn, Jun Ma, Yan Xu, Tom Spirock, Haimin Wang Philip R. Goode, Solar Physics, 2006, 238, 207
- BBSO 1325:** *The Ribbon-Like Hard X-Ray Emission in a Sigmoidal Solar Active Region*, Chang Liu, Jeongwoo Lee, Dale E. Gary Haimin Wang, 2007, Ap.J., 658, L127
- BBSO 1331:** *The Relaxation of Sheared Magnetic Fields - A Contracting Process*, Haisheng Ji, Guangli Huang Haimin Wang, 2007, Ap.J., 660, 893
- BBSO 1332:** *Filament Eruption after the Onset of the X1.5 Flare on 2005 September 13*, Haimin Wang, Chang Liu, Ju Jing Vasyl Yurchyshyn, 2007, Submitted to Ap.J.

B.2. Current Instrumentation Projects

B.2.1. New Solar Telescope

The center task of BBSO instrumentation is around the construction of NST, the 1.6m off-axis telescope. This project is near its completion. The new, larger dome, required to house the NST, has been installed. The off-axis, 1.7 m primary mirror (PM) is undergoing final touch-ups at Steward Observatory Mirror Lab, while the secondary mirror (SM) is finished and silvered. The PM is active and its shape is controlled by a wavefront sensing system after the SM. The optical support structure (OSS) is being built by DFM of Longmont. The OSS will be installed in Big Bear during August of 2007 with engineering first light to follow immediately. The first draft of the control system software has been written and is undergoing testing.

The major tasks in the first year covered by the proposal include will be: (1) Integration of NST; (2) Telescope Alignment, (3) First light observations in the Nasmyth station.

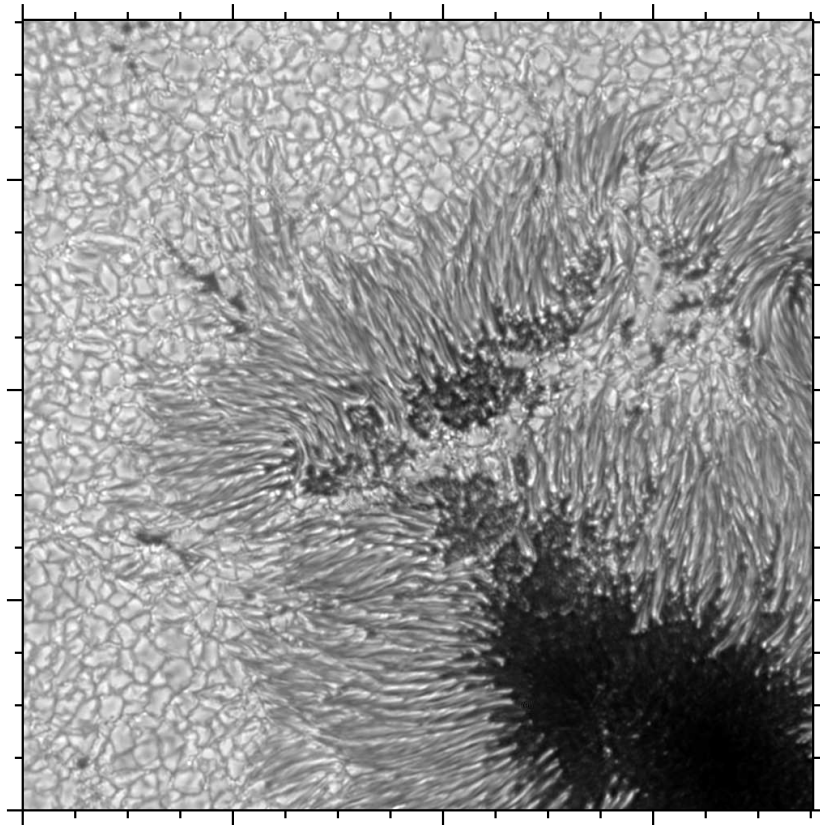


Figure 3: A recent diffraction-limited image obtained at BBSO on April 29, 2005 with the AO-76 system and speckle reconstruction.

B.2.2. Adaptive Optics (AO)

We have successfully built two high-order AO systems (76 element deformable mirror AO systems), one for BBSO's 0.6 m telescope and the other for the 0.7 m Dunn Solar Telescope at National Solar Observatory/Sacramento Peak (NSO/SP). Dr. Thomas Rimmele of NSO, as a Research Professor at NJIT, was the PI of the project. A number of papers have been published to describe these two AO systems and the scientific results (Ren et al., 2003a; Didkovsky et al., 2003; Denker et al., 2005; Rimmele, 2004; Yang et al., 2004; Denker et al., 2007; Xu et al., 2004, 2006). Figure 3 shows a sample image obtained on April 29, 2005 with the BBSO AO system. To improve the image quality further on the AO corrected images, we have built a real time speckle system, that processes data in real time.

In parallel to the NST effort, we are modifying the operating BBSO adaptive optics system so that it will be appropriate for the NST. This entails using the current deformable mirror system, but designing and implementing a new optical train in the BBSO coude room, which is immediately beneath the telescope room. The light from the adaptive optics will feed the visible light polarimeter and infrared imaging magnetograph (IRIM). We understand that using in the NST, the AO 76 will be able to carry out full correction most of time in near infrared. For visible light, we will seek future funding to build an AO system with approximately 350 elements.

B.2.3. Imaging Magnetograph Systems

The IRIM system developed by BBSO has been put into preliminary operation (Cao et al., 2006). It is one of the first imaging spectropolarimeters working at 1565 nm and is used for the observations of the Sun at its

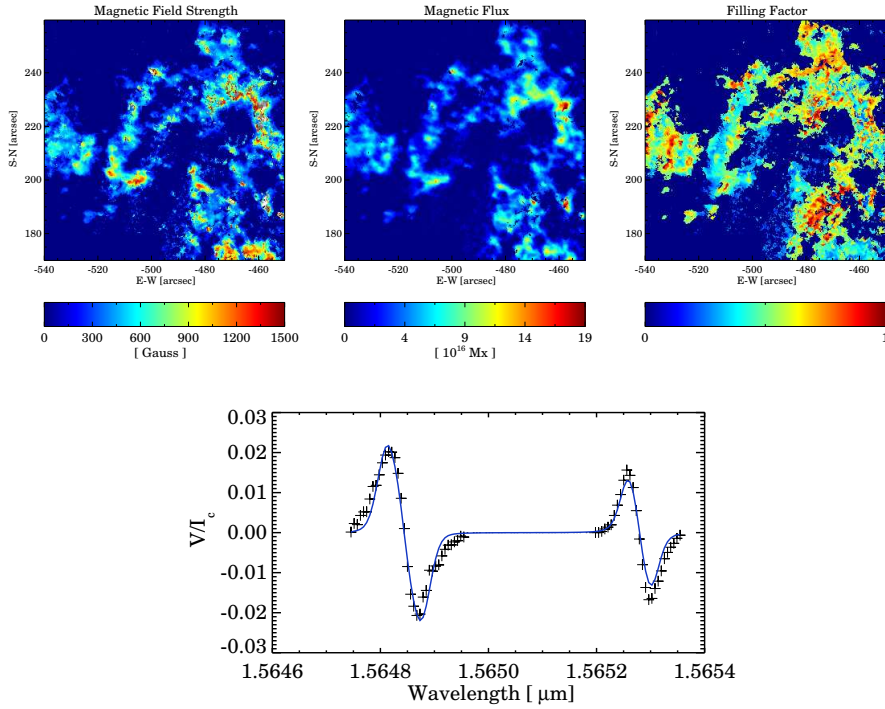


Figure 4: The sample result of recent IRIM observations with the adaptive optics system at BBSO. It includes the true-field strength (a), magnetic flux (b) and filling factor (c) maps of NOAA Active Region 10781 (Cao et al., 2006). The bottom plot is the example of Stokes-V fitting using two NIR lines simultaneously.

opacity minimum, exposing the deepest photospheric layers. The tandem system, which includes a 4.2 nm interference filter, a unique 0.25 nm birefringent Lyot filter, and a Fabry-Perot etalon, is capable of providing a bandpass as low as 0.01 nm in a telecentric configuration. Benefiting from the correlation tracking system and a newly developed adaptive optics system, the first imaging polarimetric observations at 1565 nm were made at the diffraction limit on 2005 July 1 using BBSO's 65 cm telescope. Stokes V profiles are obtained from the Fabry-Perot etalon scan data provide access to both the true magnetic field strength and the filling factor of the small-scale magnetic flux elements. Figure 4 shows the sample images obtained by IRIM and an example of the Stokes V profile in the two adjacent NIR lines. In parallel to the IRIM development, we are building a separate Visible Imaging Magnetograph (VIM) that has obtained the first light of observations (Denker et al., 2006). Both magnetograph systems are being integrated to NST.

B.3. Sub-arcsecond, Sub-second Structure of Flares

It was first discovered in high-resolution hard X-ray and microwave observations that flare bursts consist of fine structures on time scales from tens of milli-seconds to a few seconds (van Beek, de Feiter, & de Jager 1974, 1976; Hoynq, van Beek, & Brown 1976; Kiplinger et al. 1983, 1988; Kaufmann et al. 1980, 1984, 2001; Aschwanden, Benz & Schwartz, 1993; Aschwanden, Schwartz, & Alt, 1995; Aschwanden et al. 1995, 1998). These are the so called "elementary bursts" (de Jager & de Jonge 1978). In recent years, effort to search for small scale structures has also been made in optical wavelengths, typically $H\alpha$ observations (Wang et al. 2000; Trottet et al. 2000; Kurt et al. 2000). These high-cadence optical observations are exploited to study the elementary bursts because of their good spatial resolution, with which we can hopefully determine some spatial properties of elementary bursts. For example, Wang et al. (2000) reported fine temporal structures of order 300

– 700 ms in H α off-band emission, and found that these fine structures only occur at flare kernels whose light curves are well correlated with the hard X-ray emission. These observations confirm that flare energy release is fragmented (cf. Hudson et al. 2006).

Understanding the cause of fragmentation is important as it directly points to the nature of flare energy release. From the theoretical point of view, there exist two contrasting scenarios on the scales of energy release. From the magnetohydrodynamic (MHD) point of view, magnetic reconnection and the formation of electric current sheets occur at macroscopic scales, as has been manifested by accumulating observations of progressive magnetic reconnection in dynamic two-ribbon flares (e.g., Svestka 1976). Existence of a macroscopic electric current sheet conveniently provides a mechanism that could accelerate electrons and heat flare plasmas simultaneously (Holman 1985; Benka & Holman 1994). However, this MHD approach does not relate directly to the proper scales of the physical development of the reconnection process.

On the other hand, the discovery of fine temporal structures in flares leads scientists to consider that magnetic energy release primarily occurs on small scales. Lu & Hamilton (1991) proposed that the coronal magnetic fields are in a self-organized critical state, and solar flares are avalanches of many small scale events. In their *ad hoc* cellular automaton model, only one scale, which is determined by the minimum size of energy dissipation, is meaningful, while flares of different sizes are due to different numbers of such small events. In terms of the physical mechanisms, the most popular belief is that solar flares comprise many small scale reconnections (Sturrock et al. 1984; Parker 1989; Bastian & Valhos 1997). LaRosa & Moore (1993) proposed another mechanism that the MHD turbulent cascade rapidly dissipates the bulk kinetic energy of the outflows from many separate reconnection events. According to both models, the lower limit of the time scale depends on the characteristic size of the elementary flux tube. From a different point of view, it has been discussed that along the length of the pre-reconnection current sheet, a tearing mode instability may occur to trigger reconnection and form magnetic islands (Furth et al. 1963), the size and periodicity of which determine the properties of the observed structures. Formation of magnetic islands by tearing-instabilities and subsequent interactions between these magnetic islands, namely the dynamic magnetic reconnection (Kliem et al. 2000 and references therein), are considered to account for fast variations in non-thermal emissions on “elementary burst” timescales (Aschwanden 2002 and references therein).

In reality, during magnetic energy release in a flare, it is difficult to clearly separate different physical mechanisms that control the scales of energy release. However, it is possible that different mechanisms are characterized by differing time scales and properties, such as periodicity, so that it is still meaningful to discuss what physical mechanism dominates a specific time and spatial scale. With the ever advancing resolving capability of the observing instruments, determination of the spatial scales corresponding to the time scales will greatly help elucidate the physical picture of the flare energy release.

Since 1999, we have carried out a high cadence flare-watch campaign. We look at the far blue wing of the H α line in an attempt to locate sites of non-thermal beam precipitation in the impulsive phase of solar flares. The campaign has yielded fruitful results in the high resolution study of flares and related phenomena (Wang et al. 2000; Qiu et al. 2000, 2001, 2002; Qiu & Wang, 2006; Ding et al. 2001; Wang & Qiu 2002; Ji et al., 2003, 2004a,b, 2006). The AO equipped NST will allow us to advance this study to a spatial resolution well below 1 arcsec. Combining BBSO and RHESSI data, We expect to find: (1) the characteristic time scale of elementary bursts, (2) periodicity of the signals, (3) simultaneity of the elementary bursts at the magnetically conjugate foot-points, (4) spatial scale of the elementary bursts and (5) the HXR spectra and their evolution of these bursts.

In addition to the H α off-band observations, we found that high resolution/cadence observations at 1.6 μ can pin down the location of electron precipitation. Xu et al. (2004, 2006) presented high resolution observations of an X10 white-light flare in solar active region NOAA 10486 obtained with the Dunn Solar Telescope (DST) at the National Solar Observatory/Sacramento Peak (NSO/SP) on 2003 October 29. The investigation focused on flare dynamics observed in the NIR continuum at 1.56 μ m. This is the first report of a white-light flare observed at the opacity minimum. The spatial resolution was close to the diffraction limit of the 76 cm aperture DST. The data benefited from the newly developed AO system and the NJIT NIR camera. Figure 5 compares

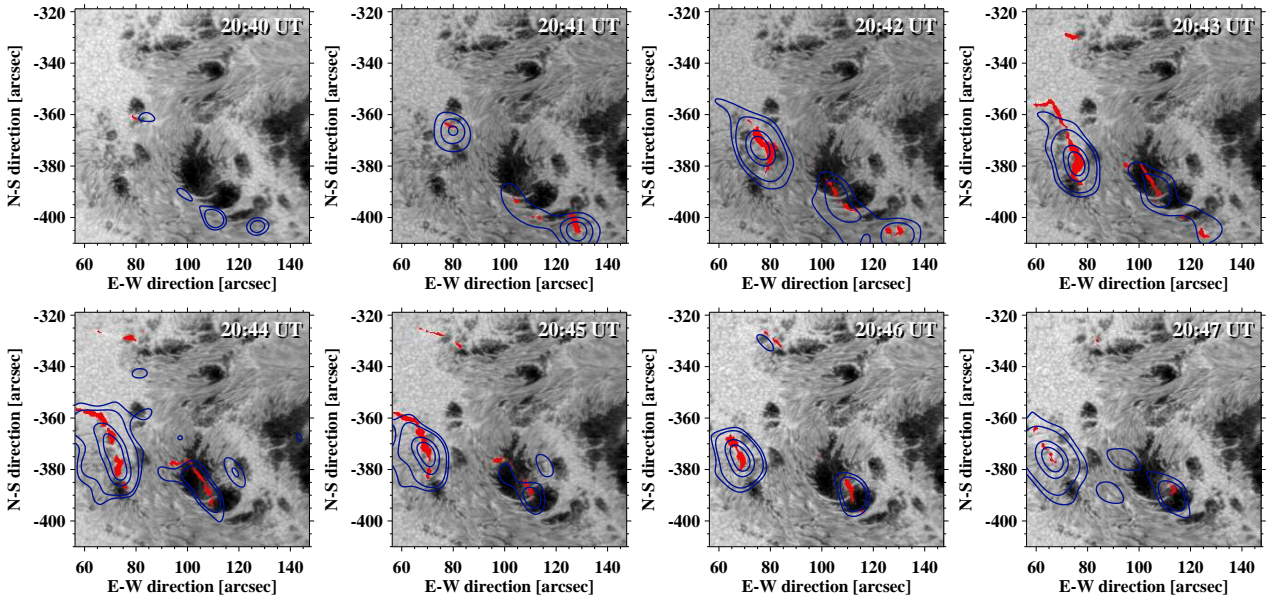


Figure 5: NIR time sequence of the X10 flare from 20:40 UT to 20:47 UT on 2003 October 29. RHESSI HXR contours (blue) correspond to the 50 - 100 keV channel with 60 integration. The local NIR intensity maxima are shown in red. Two flare ribbons are correlated with strong HXR kernels. HXR contour levels are drawn at 0.17, 0.25, 0.60, and 0.80 of the maximum intensity, except for the first two frames, where they correspond to 0.7 and 0.8 for the first frame and 0.4, 0.6, and 0.8 for the second, when the HXR kernels were weaker.

the NIR flare emissions with the hard X-ray data of the RHESSI.

As an added feature to the high cadence, high resolution flare study, we will investigate the motion of flare footpoints. It is well accepted that solar flares are due to the sudden release of magnetic energy by magnetic reconnection (Forbes & Priest 1995). In the classical two-dimensional "CSHKP" reconnection model of a two-ribbon flare (Carmichael 1964; Sturrock 1966; Hirayama 1974; Kopp & Pneuman 1976), oppositely directed magnetic field lines are stretched by eruption to form a vertical current sheet where reconnection occurs. According to this model, the two footpoints (FPs) of a flare, residing in areas of opposite magnetic polarities, are expanding outward and away from each other as the flare proceeds (Svestka & Cliver 1992). Furthermore, it is well recognized that flare ribbon expansion is the chromospheric signature of progressive magnetic reconnection in the corona, in which new field lines reconnect at higher and higher altitudes. This picture, together with a simplified MHD reconnection model, yields a crude method of measuring the electric field in the reconnection region. The product of the horizontal velocity of the ribbon expansion and local longitudinal magnetic field is a measure of an effective electric field strength along the current sheet (Lin & Forbes 2000 and references therein). The value of the effective electric field is usually taken as a measure of the reconnection rate. Meanwhile, the behaviors of hard X-ray and/or $H\alpha$ footpoints are often used to infer the reconnection scenario during flares. Recent ground-based observations along with RHESSI observations raise a challenging question to this classical physical picture: two flare ribbons may first contract then separate. The second part is predicted by the CSHKP model, while the first part is not explained. Ji et al. (2004b) showed such inward motion was even evident for the individual flare peaks in a multi-peak event, as shown in Figure 1. Please note that the contracting motion occur in a period of 0.5 to 2 minutes, therefore, high cadence data are extremely important.

The explanation of the contracting motion of footpoints and loop-top are in the preliminary stage. Ji et al. (2004b) proposed that they are caused by the current sheet pinch motion in the frame of CSHKP model, which enhanced vertical current sheet in reconnection region, that in turn enhanced the energy release rate to produce HXR spikes and pushed footpoint together; however, it can not explain the drop of altitude of HXR loop-top

source. On the other hand, Veronig et al. (2006) modelled a collapsing magnetic trap embedded in a standard 2D magnetic reconnection model. They can reproduce the altitude decrease of flare X-ray loop-top and the observed the RHESSI spectra. However, inward motion of footpoints is not expected in this explanation. We also note the “implosion” proposed by Hudson (2000) that may predict contracting loop-top with the inward motion of the footpoints. As pointed out by Hudson, the detection of such implosion requires high cadence, high resolution observations of flare footpoints during the impulsive phase. Our observations are therefore uniquely suitable for this purpose: to understand the physics, the more advanced observations of flares with high cadence and high resolutions are needed, in combination of BBSO optical and RHESSI HXR imaging. In addition, quantitative analysis will provide important information for in depth modelling. We expect to answer the following questions:

1. Do all the flares show inward footpoint motion in the early phase of the flares, and are all these inward footpoint motion associated with loop-top contraction? 2. Is there a relationship between the speed and magnitude of the inward motion and the energy release of the flares? 3. For each of the sub-peaks in a multi-peak flare, do we see such a contracting motion as Ji et al. (2004b) found? 4. Can we suggest a magnetic reconnection model that can fit both initial inward motion and subsequent expansion? This model should also explain the rapid and permanent changes of magnetic fields associated with flares, as we will discuss next.

B.4. Quantitative and Systematic Studies of Evolution of Magnetic Fields Associated with Flares

As we have discussed in §B.1, we have begun to understand the consistent pattern of changes in magnetic fields in core regions of flares and CMEs. The most outstanding changes are the decay of penumbral structure in the outer side of δ spots and the enhancement of sunspot structure near the flaring neutral lines (Liu et al. 2005). This result is statistically confirmed and characterized with an investigation of over 400 events (Chen et al., 2007).

As the observational evidence is solid, the scientific objective of part of research is straightforward: we will understand the physical and statistical significance of observed sunspot structure change associated with flares. These will be studied with data from three sources, that are highly complementary: the rich vector magnetograph archive at BBSO covering the past solar cycle, the new high resolution data from NST and vector magnetograms from Hinode.

For limited events studied, we also found that the magnetic shear near the flaring neutral lines may increase after the flares (Wang 1992; Wang & Tang 1993; Wang et al. 1994, 2002, 2004b; Liu et al. 2005). The shear angle is defined as the angular difference between the observed azimuthal angle of transverse fields and that of the extrapolated potential fields (Hagyard et al. 1990). Wang et al. (1994) also defined another physical parameter, the weighted magnetic shear, which is the shear angle weighted by the transverse field strength. Most of the events studied so far were observed by BBSO. However, results of such a shear angle increase were also reported with HSO vector magnetogram data of AR 6659 on 1991 June 6 during the X12 flare (Schmieder et al. 1994), and the Marshall Space Flight Center (MSFC) vector magnetogram data of the famous AR 10486 on 2003 October 29 during the X10 flare (Liu et al. 2005). Figure 6 shows another recent example of transverse field enhancement along the flaring neutral line, on September 13, 2005.

Although we have found penumbral decay to be associated with over 100 events, rapid changes of vector fields have only been analyzed for less than 10 events. Thus a significant effort is required to analyze vector magnetogram data sets. We will analyze the existing BBSO vector magnetograms for over 50 well observed M-class or larger events, and determine the change of vector magnetic fields associated with flares. As penumbral decay and umbral enhancement are well observed for many of these events, previous results based on WL and line-of-sight magnetic field observations will guide the analysis of vector magnetograms. As data analysis tools have been established in the past few years, we anticipate that it is easy to analyze a large amount of data. In this step, these analysis tools will be further matured and streamlined.

Using Hinode data, we expect to obtain more quantitative results on the evolution of magnetic fields associated with flares, and detect even more subtle changes in magnetic structure for smaller flares. The high cadence

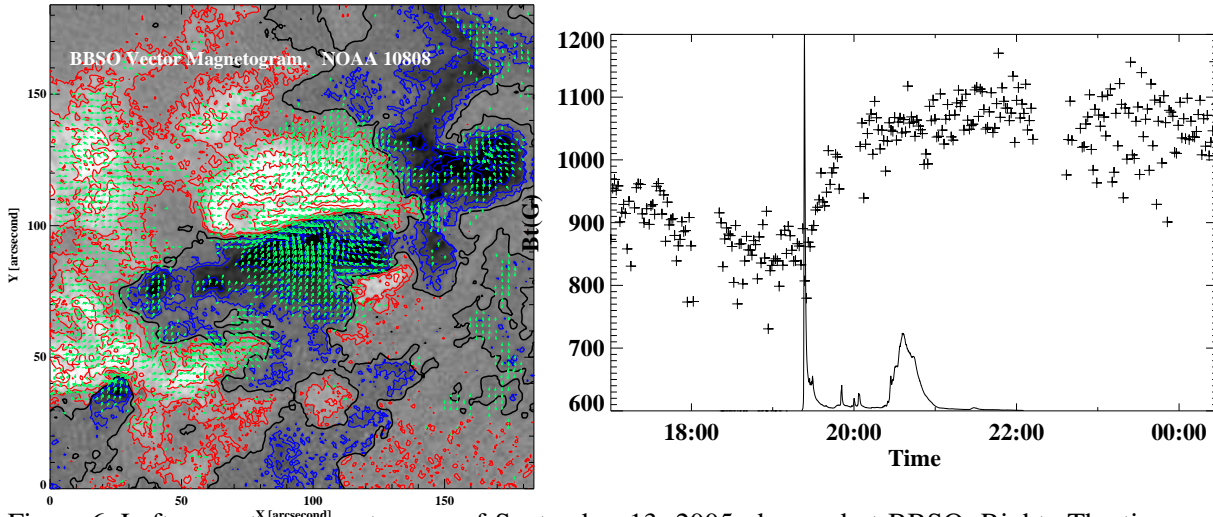


Figure 6: Left, a vector magnetogram of September 13, 2005 observed at BBSO. Right: The time profile of the mean transverse field strength in the section of the neutral line close to the initial flare core. The timing of the flare is indicated by the 10 GHz OVSA microwave light curve.

observations from the Hinode filtergraph observations is essential to detect and characterize the rapid sunspot structure change. However, analyzing spectro-polarimeter observations for selected events will enable us to study spectral line profiles of the areas that sustain structural changes, therefore we can reveal more detailed physical characteristics (e.g., temperature, density and more accurate polarimetry) of the rapid changes of active region structure associated with flares. This is critical in ultimate understanding the physics mechanism of the sunspot structure change.

In December 2006, Hinode obtained excellent coverage of AR 10930 that produced 3 X-class flares. Figure 7 shows the TRACE WL images and their difference image around the X3.4 flare. It is obvious that this region shows the similar properties as other events studied by us before: enhancement of sunspot structure at the flaring neutral line, and peripheral penumbral decay. From two vector magnetograms were available covering the X3.4 flare. They are shown in Figure 8. Consistent with the WL observations, the decrease and increase of transverse fields after the flare are quite obviously associated with the peripheral penumbra decay and central feature enhancement regions, respectively. Detailed analysis of this region using the full Hinode data set can already provide the answers to some of the physical questions aimed by this proposal. Analysis of Hinode data will help us to develop data analysis tools that will be applied of NST high resolution data.

The final stage of our study is the observations of vector magnetograms using NST. We anticipate the IRIM will provide unprecedented data with high resolution, high cadence and high polarization precision measurements of vector magnetic fields following the evolution active region before and after flares.

After analyzing a large number of events, we will find the physical difference in the regions with and without rapid changes of magnetic fields. The determining factors could include impulsive vs. long-duration events, sigmoid or non-sigmoid configuration, δ or non- δ configuration, and filament eruption association or not. Preliminary results indicate that the field changes are more detectable in δ sunspots, and when associated with sigmoid configuration and long-duration flares.

B.5. Surface Flows Associated with Flares and CMEs

In addition to the finding of the changes in magnetic fields associated with flares, we recently found another important and related phenomenon: the rapid changes in flow patterns associated with flares. We developed a “center-of-mass” (CoM) technique to detect the large-scale converging and shearing motions in the flaring active regions (Wang et al. 2005). We applied this technique to the 2000 July 14 Bastille day event and demonstrates that the center-of-mass separation of positive and negative magnetic flux suddenly began to decrease

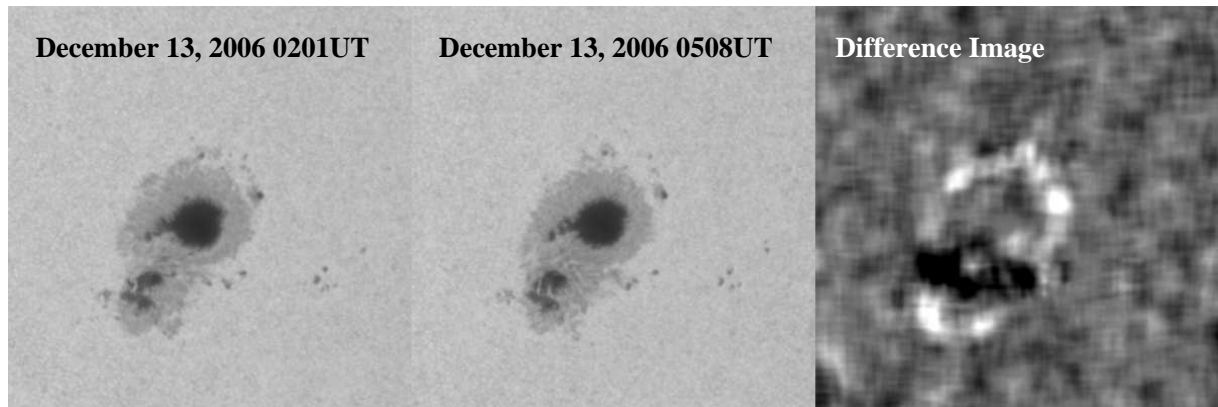


Figure 7: Left: TRACE WL image at 0201 UT before the onset of the X3.4 flare on 2006 December 13. Middle: WL image after the flare at 0508 UT. Right: the difference between post- and preflare WL intensity. The enhancement of sunspot structure at the flaring neutral line and peripheral penumbral decay are quite obvious.

right after the flare, indicating sudden converging motion toward the magnetic neutral line starting right after the flare.

Applying this CoM method and other tools, we studied the short-term evolution of magnetic fields associated with five additional flares in δ sunspots (Wang 2006). We concentrate on the analysis of magnetic gradient along the flaring neutral lines. Obvious changes of magnetic gradient occurred immediately and rapidly following the onset of each flare. Rapid gradient increase was found to be associated with three events, while decrease was found with the other two. The changes were permanent, therefore, not likely due to the effect of flare emissions. In addition, we evaluated the mean relative motions between two magnetic polarities in these δ regions, in the direction parallel and perpendicular to the flaring neutral lines, respectively. We derived the mean positions of two magnetic polarities using the method of CoM calculation, and found that: (1) Converging motions correspond to the gradient increase; diverging motion, the decrease; (2) For all the events, there appeared a sudden release of magnetic shear associated with each flare, signified by a decrease of CoM separation between 500 and 1,200 km in the direction parallel to the neutral lines. Combining the findings presented in several papers, we propose that these are evidences of magnetic reconnection at or close to the photosphere. When an active region is away from the solar disk center, the reconnected transverse fields would cause an apparent increase of the flux in the polarity toward the limb, and a decrease for the polarity closer to the disk center. This observational pattern was indeed found for all 10 available events that have been studied.

Obviously, this motivates us to include the flow field studies in our data analysis along with magnetic field evolution, which will provide another key piece of information to understand the triggering of flares and CMEs. We also need to resolve this shear paradox: the magnetic shear from vector magnetograph observations appears to increase after flares, while sunspot shear motion seems to be relaxed. A possible explanation is that the former is confined near the flaring neutral line to reflect the local magnetic connectivity, while the latter reflects the larger scale magnetic structure of the active region.

The CoM method only provides the average flow motion of two opposite polarity sunspots. This needs to be compared with two dimensional flow fields derived by local correlation tracking. To observe these flows and magnetic field structure in detail and to understand their basic nature, we need high-resolution and high-cadence observations. Obviously, AO equipped NST will achieve required higher resolution by finally advancing us beyond the 0.1'' resolution limit. Figure 9 presents the very first clear demonstration of the shear flow of the active region before the X10 flare on 2003 October 29. We note that these observations were taken using the BBSO speckle imaging system (Denker et al. 2001), which was "evacuated" to NSO/SP when the Big Bear environs were evacuated for several days during a large forest fire. During this interim we were fortunate to record significant events in one of the most unusual active regions in many years. With the aid of AO system

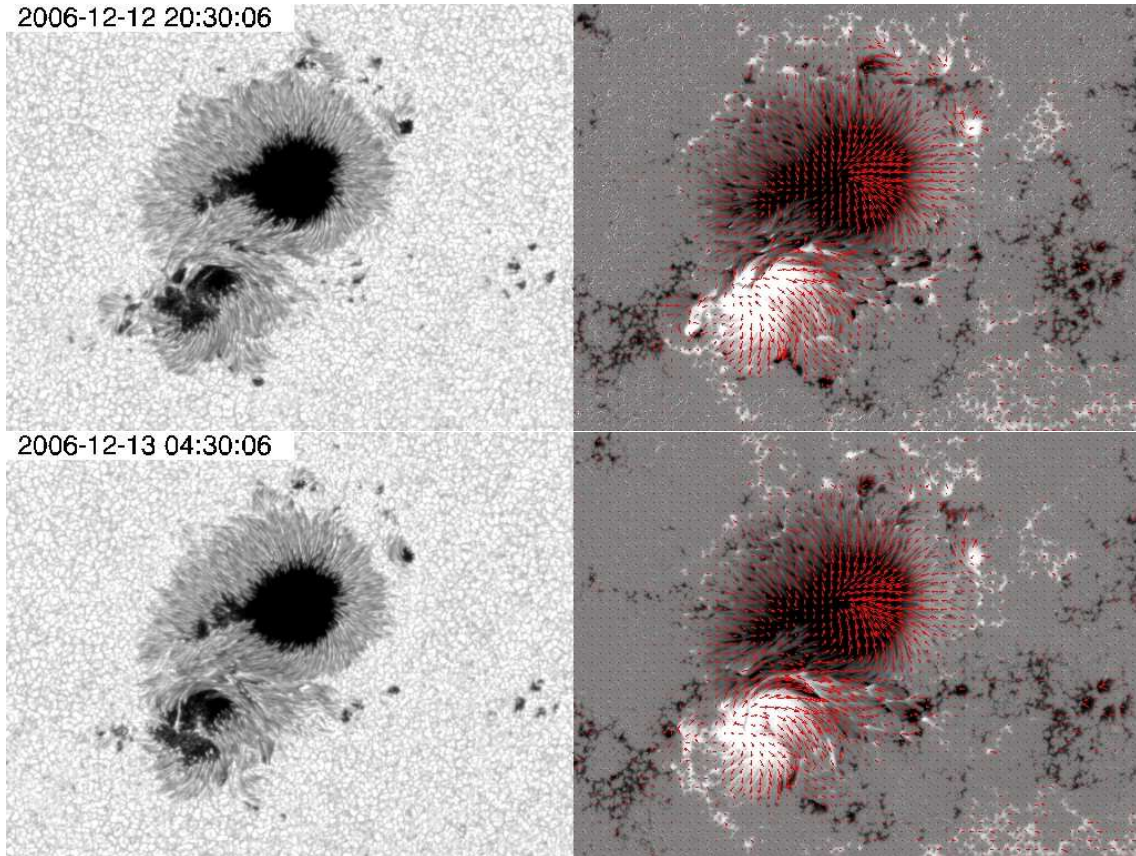


Figure 8: High resolution vector magnetogram processed from Spectro-Polarimeter of SOT. The top images are preflare observation at 2030 UT on December 12, while the bottom images are postflare observations at 0430 UT on December 13. Left panels show G-band images, while right panels show transverse magnetic vectors overlying on longitudinal magnetograms.

in the Dunn Telescope, diffraction-limited images were obtained with high cadence and they were analyzed carefully. The shear flows are very obviously associated with flaring neutral lines (Yang et al. 2004; Deng et al. 2006). This is the only X-class flare observation in existence which is covered completely with $0.2''$ resolution in WL. In the NST era, this kind of observations will not be rare anymore. The tools that we developed in the last few years to study the flow fields will be readily applied to the NST data when available.

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

- (1) Do active regions always show the changes in the flows associated with flares as discussed above? What are the spatial distributions of the flow evolution?
- (2) Are shear flows unusually strong before major flares, and spatially located close to flaring neutral lines?
- (3) What is the physical implication of shear relaxation in the large scale and shear increase in a small area near the flaring neutral line?

B.6. High Resolution Near IR Observations Non-Flaring Solar Atmosphere

Although our proposed research focuses on the high resolution observations of solar activity, NST will certainly provide unprecedented data to understand the dynamics of magnetic structure in quiet atmosphere. In the initial phase of NST operation, the 76-element AO system can routinely provide correction in near infrared only, therefore, our scientific objectives will be tied to this instrumental capability.

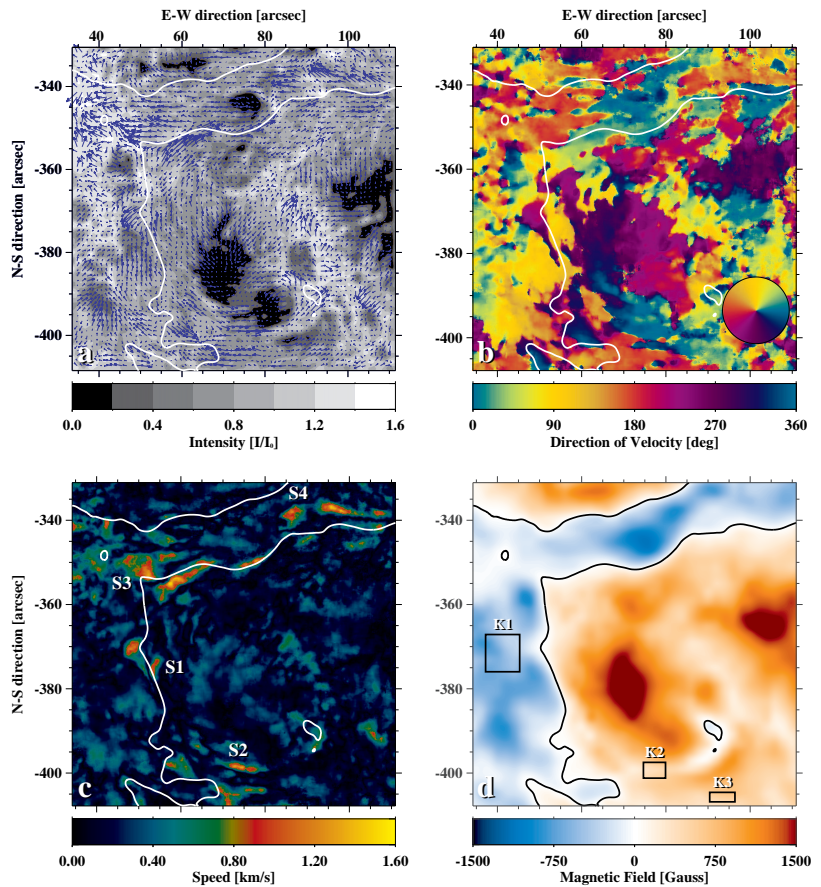
For several scientific reasons, observing in the near IR would result in a significant step forward in our understanding of the sun. First, the sun has an opacity minimum in the near IR (at about $1.6 \mu\text{m}$), so that

one can see deeper into the sun 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. We will concentrate on the following two topics:

B.6.1. Contribution of Footpoint Motion to Coronal Loop Heating

Aschwanden et al. (2000) found that for coronal loops, the heating is concentrated in the footpoints (at altitudes of 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 heating. We can address the controversy by focusing 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 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 the above events are important. We know from experience that such footpoint motion is hard to observe and characterize in lower resolution ($1''$) magnetograph and filtergraph observations. In recent study (Tan et al., 2007), we found that the energy of the a proxy for Poynting flux ($E = \frac{1}{4\pi} |V_h| \cdot |B_z|^2$) ranges in $10^{6.7} - 10^{7.6}$ erg cm $^{-2}$ s $^{-1}$ for the majority of ARs, that is sufficient to heat the corona due to random motions of magnetic flux tubes footpoints in the photosphere. This Poynting flux has a good correlation with the coronal brightness. Our observations had two limitations: (1) the velocity observations is based on tracking of MDI

Figure 9: Photospheric flows and magnetic field configuration of NOAA 10486 on 2003 October 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. I/I_0 in (a) is the normalized intensity relative to quiet photosphere (Yang et al. 2004). Strong shear flows are found along flaring neutral line, denoted by S1 through S4; while K1 through K3 mark flare kernels.



magnetograms, the resulting error is high. (2) The transverse magnetic field measurements were not available, so the proxy that we used may not be valid. Obviously, NST observations will overcome both limitations. With that, we can derive accurate dynamic properties of small scale magnetic fields and their contribution to the coronal heating.

B.6.2. Quite Sun Magnetic Fields below Intranetwork Fields

This specific scientific objective motivated by recent discovery of Harvey et al. (2007). They found that the photospheric magnetic field outside of active regions and the network has a ubiquitous and dynamic line-of-sight component that strengthens from disk center to limb as expected for a nearly horizontal orientation. Similar claim has been made by the initial Hinode results (Lites et al., 2007). We propose to put great effort to measure this fields directly with high resolution, as well as high polarization accuracy. The key to the success of this project is the carefully calibrated Stokes Q,U,V measurement in the quiet region with IRIM.

C. Personnel and Management

In order to develop the state-of-art instruments and carry out the frontier research, we must have a balanced, first-class instrumentation and science team. Our precious resources are shared by these two parts. Three professors will have their own distinct but linked responsibilities as listed in the Table I. The research team and the instrumentation team are also identified in the table. We are very cautious that if the NST’s scientific operation is delayed, BBSO can still deliver scientific results with the following leverage: (1) Our IRIM and VIM system can be used at NSO/SP as we have done in last few years. (2) Our global H α network has 6 stations for full disk observations, plus one station in China for high cadence flare observations. (3) Many data analysis tools developed can be applied to NASA mission data easily. Therefore, the risk of funding BBSO is minimized.

Name	Role	Tasks
Goode	PI	Overall Supervision and NST Development
Wang	Co-PI	Coordination in Scientific Projects
Cao	Assistant Professor	Focal Plane Instrumentation
Liu	Post-doc	High Cadence Flare Studies
Yurchyshyn	Research Professor	Active Region Flows and CMEs
Jing	Post-doc	Evolution of Magnetic Fields
Sung-Hong Park	Graduate Student	IRIM and NIR Research
Spirock, Varsik, Fear	Staff	NST and BBSO Instrumentation

Table 2: Role and Tasks of Team Members

In the first year, more resources are devoted in instrumentation. Starting from year 2, scientific research using the NST will become the top priority.

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