

## 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 has been providing primary, backbone support for BBSO. Over 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 have had successful observing campaigns utilizing BBSO's new high order adaptive optics (AO) system. Further successful campaigns exploited our new near infrared magnetograph. In parallel, BBSO has reached the final stages in building its 1.6 meter clear aperture, off-axis New Solar Telescope (NST). The first-light of this telescope is expected in Fall 2007 with the initial commissioning phase to be completed about the time this proposal's funding would start. We anticipate that, over the next 5 to 10 years, the AO equipped NST will be the prime U.S. facility for high resolution studies of the Sun. Further, the NST will be an essential testbed for the 4-meter Advanced Technology Solar Telescope (ATST).

*The instrumentation tasks (first two should be completed under current support) to be finished are:*

1. Initial commissioning of the NST into routine operation of NIR imaging.
2. Integrating 96 actuator active optics system to NST that will fully correct in near infrared.
3. Integrating visible and near infrared vector magnetograph systems to NST.
4. Advanced commissioning of the NST into its full scientific capability.

*Using the aforementioned instruments, the highlights of the proposed scientific programs are listed below. As we realize the limitation until an higher order AO is built, we will concentrate on the sciences that can be routinely achieved with 0.2'' diffraction limited images in near infrared. Therefore, the infrared imaging magnetograph system (IRIM) will be the essential focal plane instrument. With AO-96, NST should also occasional deliver diffraction limited images in visible with a spatial resolution close to 0.05''.*

1. High cadence and high resolution studies of solar flare emissions. These observations will provide details of flare energy precipitation on 0.2'' spatial scales and 0.1 sec temporal scale that will only can be achieved by NST.
2. Comprehensive studies of vector magnetic fields associated with flares, 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. This study will be advanced significant with IRIM on NST, because of high polarization sensitivity, stable atmosphere in IR with a resolution of 0.2''.
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. This kind of data also did not exist before NST and recent launch of Hinode. NST and Hinode will be complementary in this study.
4. Sustained sub-arc second resolution studies of the quiet solar atmosphere. In particular, we will concentrate on two topics that use the spatial feature of NST: (1) With IRIM, we will observe directly the newly discovered transverse magnetic component weaker than intranetwork fields. (2) we will address the the energy source of coronal heating, from the high resolution observations of footpoint motion of flux ropes.

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

*Intellectual merit:* We will obtain and use the highest quality datasets, while developing and applying analytical tools to attack a number of critical, leading-edge problems in solar research. The NST will play a crucial, leading role in the advances in solar physics over 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 analytical tools will aid precise predictions of space weather. Further, BBSO is taking the lead in developing the next generation in 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 NSF-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 four year NSF grant started. This grant is one of two backbone grants supporting BBSO. BBSO has been one of two solar observatories in the US with a telescope, instrumentation and a site that enables diffraction. The other is the National Solar Observatory (NSO) with its somewhat larger aperture Dunn Solar Telescope. This upper limit on aperture is about the radically change, BBSO will soon be observing with its 1.6 m clear aperture NST with adaptive optics (AO) and state of the art polarimeters in the visible and near-infrared (NIR). Further, over the next decade, NSO will be building the Advanced Technology Solar Telescope (ATST) in Hawaii. The 4 m ATST will benefit from its NST predecessor, which is also off-axis. The NST will dominate U.S. ground-based observations until the middle of the next decade. Even after the ATST, the NST will have an essential role for the community because the broad and important service mission of NSO, the NST will be the 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 has been 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 systematic, 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. Meanwhile, even though we devoted considerable effort to 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 \$500 K for new equipment for the observatory. It is also paying the NST projector manager and optical engineer.

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 faculty positions in the U.S.. 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. Six additional former BBSO post-docs got professorship outside US.

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), Ken Libbrecht (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](http://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 highlights some of our scientific achievements under current NSF support. Our publications, in the form of BBSO Bluebooks, are also available on our website ([solar.njit.edu/preprints](http://solar.njit.edu/preprints)).

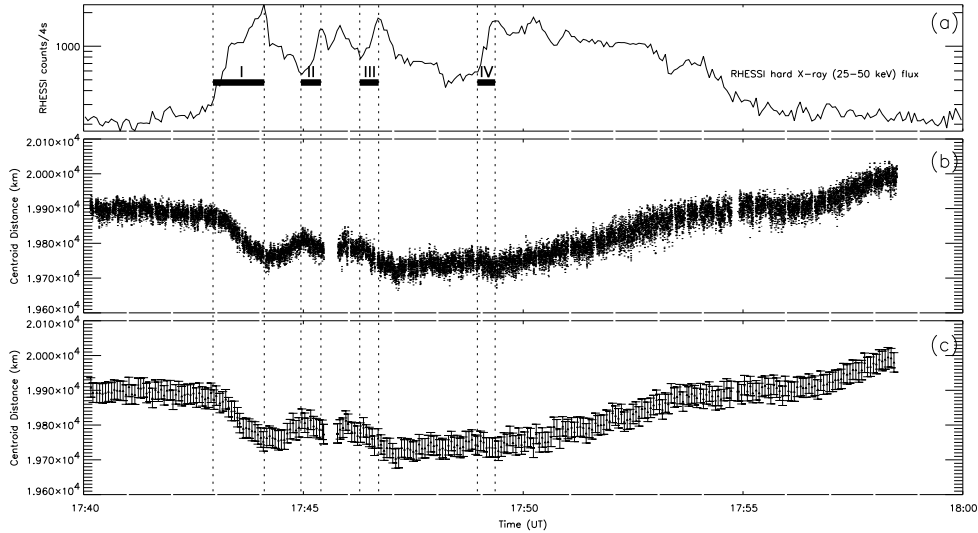


Figure 1: Top: RHESSI HXR light curve of the 2002 September 9 flare, in the energy band of 25 to 50 keV for which the time resolution is 4 s. Middle: Time profile of centroid distance between the two conjugate kernels, for which the cadence is 40 ms. Bottom: Time profile of centroid distance with error 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).

### 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. The flare was observed at BBSO in 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 exhibits a number of separate spikes. The separation between the two centroids **decreases** during the rising periods of four HXR spikes, then it increases after the peak time of the flare exhibiting the expected separation motion.

These results were confirmed recently with even clearer evidence. 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. These phenomena are not well understood at all with existing flare models.

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

Recently, we presented a new observational result of rapid changes in 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  $\delta$  spot structure and associated major flares for seven events. The results are quite consistent for all the events: part of the penumbral segments in the outer  $\delta$  spot structure decayed rapidly after a major flare; 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 flare emission. In two events for which vector magnetograms were available, we find that the transverse field associated with the penumbral decay areas decreased, while it increased in the central darkened regions. Both events also show

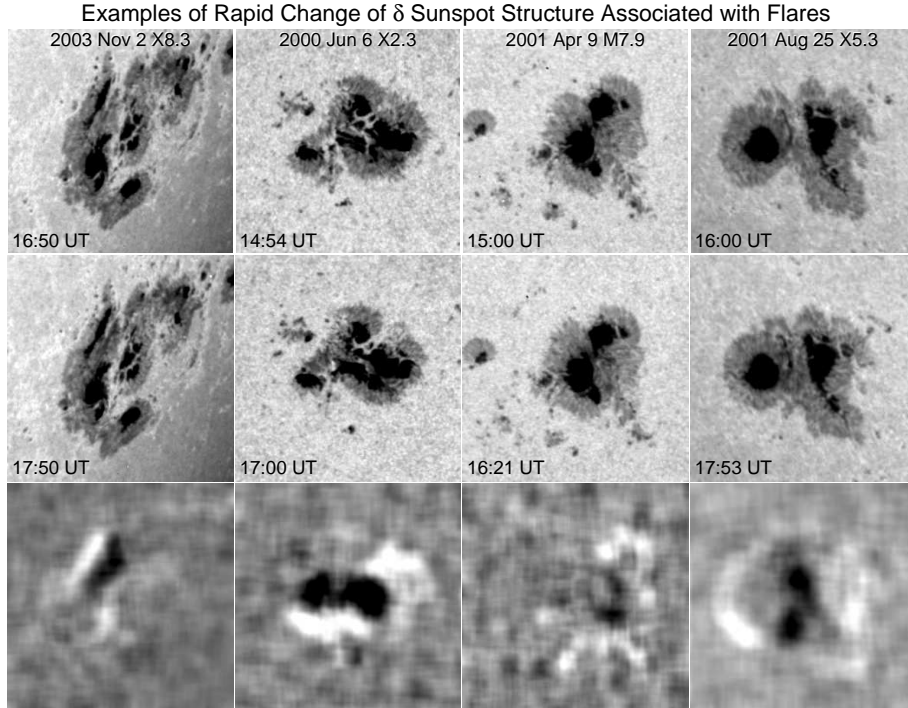


Figure 2: TRACE WL images revealing the rapid change of  $\delta$  sunspot structure associated with four major flares. The top, middle, and bottom rows show the pre-flare images, post-flare images, and the difference images between them, respectively. The white feature in the difference image indicates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

an increase in the magnetic shear after the flares. To explain these observations, we proposed a reconnection picture in which the two components of a  $\delta$  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 examples of such rapid changes in 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  $\delta$  regions, in the directions parallel and perpendicular to the flaring neutral lines, respectively. Using the method of Center of Mass (CoM) calculation, we found that: (1) Converging motions correspond to a gradient increase; diverging motion, a 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 evidence of magnetic reconnection at, or close to the photosphere.

Furthermore, we presented results of a statistical study of rapid penumbral decay associated with over 400 flares (Chen et al. 2007). We found that the rapid structure change in 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, which represents the early stages of flux-rope eruptions in the low corona (Jing et al., 2005). In addition, certain temporal correlations between the reconnection rate and flare emission were found. With a large sample, Jing et al. (2004) comprehensively investigated the relationship amount filament eruptions, flares, CMEs and emerging flux regions (EFRs).

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 activity. The current operational codes are for the detection of flares (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 program, which 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 sketches some highlights our scientific accomplishments over the past three years. Beyond those, and due to 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](http://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  $\delta$  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 Penumbra 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.

## C. Proposed Research

The research we propose here is built on our long experience, but with the excitement of a new solar telescope with three times the aperture of the old solar telescope. The NST is the culmination of a decade of re-instrumentation at BBSO. The NST will enable us to probe spatially and temporally phenomena that have been tantalizingly just beyond our grasp. Before proposing the first science taking advantage of the NST, we give a brief overview of the instruments that will make the science possible.

### C.1. Current Instrumentation Projects

#### C.1.1. New Solar Telescope

The 1.6 m off-axis NST is the central instrumentation project at BBSO at this time. The telescope is nearing completion with system integration to occur in Big Bear during September 2007 with engineering first light at the end of that month. We anticipate a year long commissioning phase during which we will be able to make ever more sophisticated observations with the NST. The first light scientific observations will occur early in the commissioning phase at the Nasmyth bench, which is affixed to the outside of the primary mirror cell. The NST will be largely operational at the beginning of funding from this proposal.

The new, larger dome, required to house the NST, is fully operational and all construction under the dome (such as the extension of the support pier) has been completed and awaits the telescope. 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, which resides after the SM. The heat stop is completed and its attachment at prime focus is being assembled. The Optical Support Structure (OSS) is being built by DFM of Longmont, CO and is nearly completed as of this writing. The NST will be installed in Big Bear during September of 2007 with engineering first light to follow immediately. The first draft of the BBSO headquarters control system software has been written and is undergoing testing. This software is not required for first light scientific observations because we can use the mature control software from DFM, which is not optimal but is functional.

In parallel with the NST development, we have been modifying the AO system (primarily a newly designed optical feed) to operate with the NST, which feed light to our visible light (VIM) and NIR (IRIM) Fabry-Pérot based polarimeters. The light for the AO, VIM and IRIM is fed through the telescope's polar axis to the coude room on the floor beneath. The VIM and IRIM hardware also function at the Nasmyth bench (mounted on the outside of the mirror cell of the primary), but with tip/tilt rather than AO corrections. This bench will ultimately be very useful in far IR studies of the solar atmosphere.

We had successfully operated our AO system (76 element deformable mirror AO systems) on BBSO's old 0.6 m telescope. A number of papers have been published to describe this AO system (and its twin at NSO), as well as 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, which can produce on fully correct image each minute with a 1 K by 1 K camera.

We understand that using in the NST, the AO 96-will be able to carry out full correction most of time in near infrared. In the ideal case, for the seeing characterized by a median Fried parameter of 24cm at 1.6  $\mu$  and 6cm in 0.5  $\mu$  at BBSO (ATST Site Survey Report), the AO correction Strehl ratio for NST is 0.84 and 0.18 at 1.6  $\mu$  and 0.5  $\mu$  respectively. Therefore, to achieve full science capability of NST in visible light observations, we will seek future funding to build an AO system with approximately 350 elements. We have designed the AO optical train, so that the both DM's can be subsequently used in multi-conjugate adaptive optics experiments/observations.

### C.1.2. Focal Plane Instrumentation

The IRIM system developed by BBSO is in 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 opacity minimum, exposing the deepest photospheric layers that can be seen. IRIM is a tandem system, which includes a 4.2 nm interference filter, a unique 0.25 nm birefringent Lyot filter, and a Fabry-Perot etalon. IRIM 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 1 July 2005 using BBSO's 65 cm telescope. Stokes V profiles were 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 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 prepared for integration into the NST.

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 control computer's disk is filled by storing all the raw data, so the chances are slim of obtaining a sequence containing the long term evolution of an active region, and catching flares during the observations. We have established a 32-node parallel

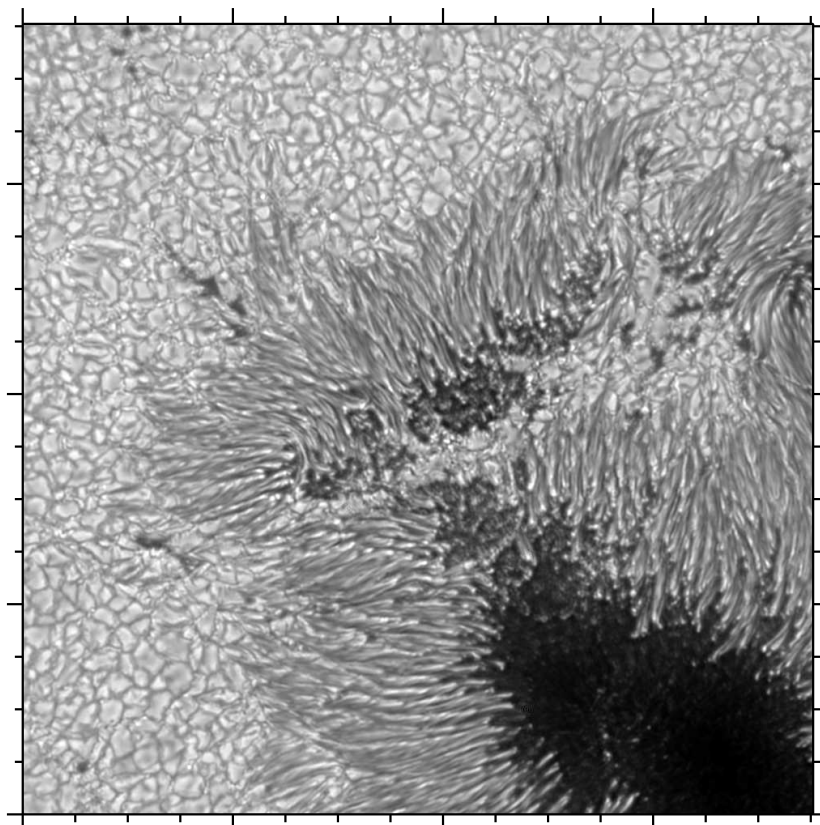


Figure 3: A diffraction-limited image obtained at BBSO on April 29, 2005 with the AO-76 system and speckle reconstruction.

computing cluster, so that we can perform real-time speckle reconstruction with a cadence of about 1 minute, and diffraction limited images will be achieved all the time during the entire observing period. Operation of the system to carry out Blind Multi-Frame De-convolution and Phase-Diversity processing will be implemented in the near future.

### C.1.3. Milestones of NST Commissioning

We do understand that the integration of NST, AO and Focal plane instruments is a complicated process. However, we are confident that most of them will be achieved before the start date of the proposal for the following reasons: (1)Telescope alignment will be done by subcontracting to expert. (2)AO and all focal plane instruments are all existing hardware that have been tested in the old 60 cm telescope. (3) To maximize the science return, we will adopt the concept of continuing commissioning, i.e., start available scientific observations at different stages of commissioning. Table 1 lists the milestones of NST milestones, and corresponding scientific observations. Please note that initial scientific operation will not be done with active mirror control that is the most complicated component in the commissioning process.

Date	NST Milestone	Scientific Observations	Spatial Resolution
September, 2007	Telescope Installation		
October, 2007	Nasmyth 1st Light	Sunspot and plage structure in NIR	0.5''
December, 2007	Light to Coude Feed	Flare emission and magnetic fields in NIR	0.5''
April, 2008	AO-96 completed	High resolution of atmosphere and magnetic fields	0.3''
June, 2008	Active mirror control	Higher resolution observations	0.2''
After 2009	Begin AO-350 Project	Highest resolution observation in visible	0.05''



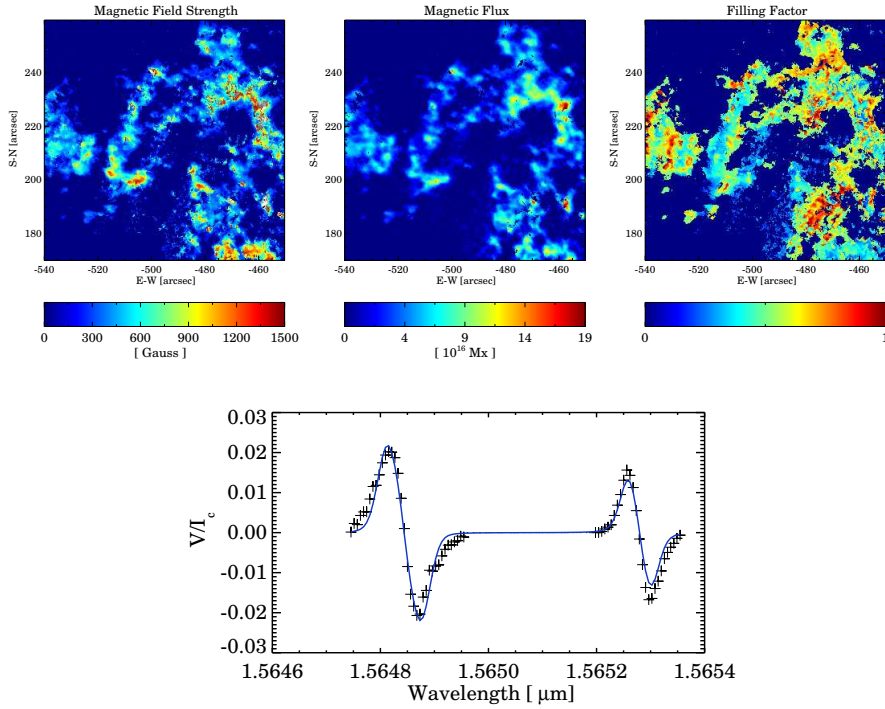


Figure 4: A sample result of IRIM observations with the adaptive optics system at BBSO. It includes the true-field strength (a), magnetic flux (b) and filling factor (c) maps of NOAA Active Region 10781 (Cao et al., 2006). The bottom plot is the example of Stokes-V fitting using the two prominent NIR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

Table 1: Milestones of NST Commissioning

## C.2. Proposed Scientific Research

Our proposed scientific research has two aims. The primary aim is to take advantage of the unique high resolution capabilities of the NST to probe what has just beyond our reach, but builds on our earlier research. Along with high spatial resolution, we will also use the NST as a “light bucket” for some very high temporal cadence observations.

### C.2.1. 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 changing on time scales from tens of milli-seconds to a few seconds (van Beek, de Feiter, & de Jager 1974, 1976; Hoing, 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; Trotter et al. 2000; Kurt et al. 2000). These high-cadence optical observations are exploited to study the elementary bursts. For example, Wang et al. (2000) reported fine temporal structures of order 300 – 700 ms in  $H\alpha$  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.

Understanding the cause of fragmentation is important as it directly points to the nature of flare energy release. There exist two contrasting theoretical scenarios describing the scales of energy release. From the magnetohydrodynamic (MHD) point of view, magnetic reconnection and the formation of electric current sheets occur on macroscopic scales, as has been manifested by accumulating observations of progressive magnetic reconnection in dynamic two-ribbon flares (e.g., Svestka 1976). The 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  $H\alpha$  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). However, previous BBSO observations could not resolve the spatial structure of flare emission due to a resolution of about 1 *arcsec*. Therefore, NST will provide unprecedented mapping of flare, first with 0.2'' in NIR, then below 0.1'' in visible in the future.

In addition to the  $H\alpha$  off-band observations, we found that high resolution/cadence observations at 1.6  $\mu$  can pin down the location of electron precipitation. Xu et al. (2004, 2006) discussed 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  $\mu$ 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 the NIR flare emissions with the hard X-ray data of RHESSI.

With NST observations, we expect to find: (1) the characteristic time scale of elementary bursts, (2) simultaneity of the elementary bursts at the magnetically conjugate foot-points, (3) spatial scale of the elementary bursts. Joint observations with RHESSI HXR and OVRO microwave will also reveal the electron distribution in these elementary bursts. The observations in broadband NIR can be achieved immediately at the Nasmyth

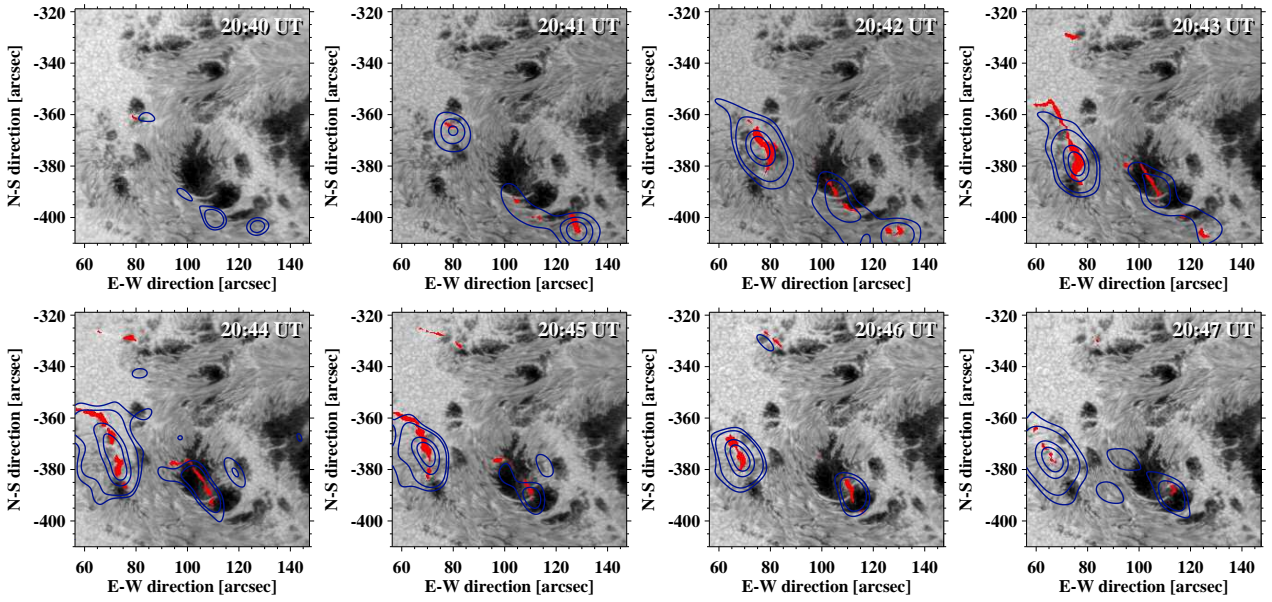


Figure 5: NIR time sequence (AO corrected) of the X10 flare from 20:40 UT to 20:47 UT on 2003 October 29. RHESSI HXR contours (blue) correspond to the 50 - 100 keV channel with 60 integration. The local NIR intensity maxima are shown in red. Two flare ribbons are correlated with strong HXR kernels. HXR 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.

station. Polarimetry and spectroscopic properties of flare emission can be obtained when AO correction is implemented in the Coude room.

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:

With a minimum of 0.2'' spatial resolution and 100ms cadence of NST observations, we expect to find **1. Detailed trajectory of footpoint motion. 2. The 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 an contracting motion as Ji et al. (2004b) found?** The observations will be done in H $\alpha$  and HeI 10830.

### **C.3. 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  $\delta$  spots and the enhancement of sunspot structure near the flaring neutral lines (Liu et al. 2005). This results is statistically confirmed and characterized with an investigation of over 400 events (Chen et al., 2007). We anticipate that NST will advance us to the final physical understanding of these phenomena.

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.

As the observational evidence is solid, the scientific objective of this part of the proposed research is straightforward: to understand the physics of the observed magnetic field changes, we need high cadence, high resolution and highly stable vector magnetograms. Obviously, IRIM on the AO equipped NST will be ideally suitable for this purpose. Depends on the number of spectral position in operating IRIM, we will have a cadence of a few minutes. The anticipated polarization accuracy will be better than  $10^{-3}$ . The spatial resolution will be around 0.2'' for direct imaging, and 0.4'' for magnetograms. Using the well calibrated IRIM data, we will target at these two topics with the data we did not have before: (1) the structure of full vector fields after correction of geometric projection effect; (2) the spectroscopic properties of the areas undergoing rapid structure change that reveal the temperature and density changes.

We understand that accumulating flare events will take sometime. Therefore, we must initially use the rich archive of BBSO vector magnetograms that covers almost 10 years' observations. Data analysis tools will be fully developed and physical insight will be gained through analyzing data. We estimate that between 50 and 100 events will be studied this way.

In parallel, vector magnetograph data are being obtained by the recently launched Hinode. Joint Hinode/NST observations will be complementary: NST observes magnetic fields in NIR, while Hinode mainly in visible; NST has much larger aperture, while Hinode has continuous seeing-free coverage. The high cadence observa-

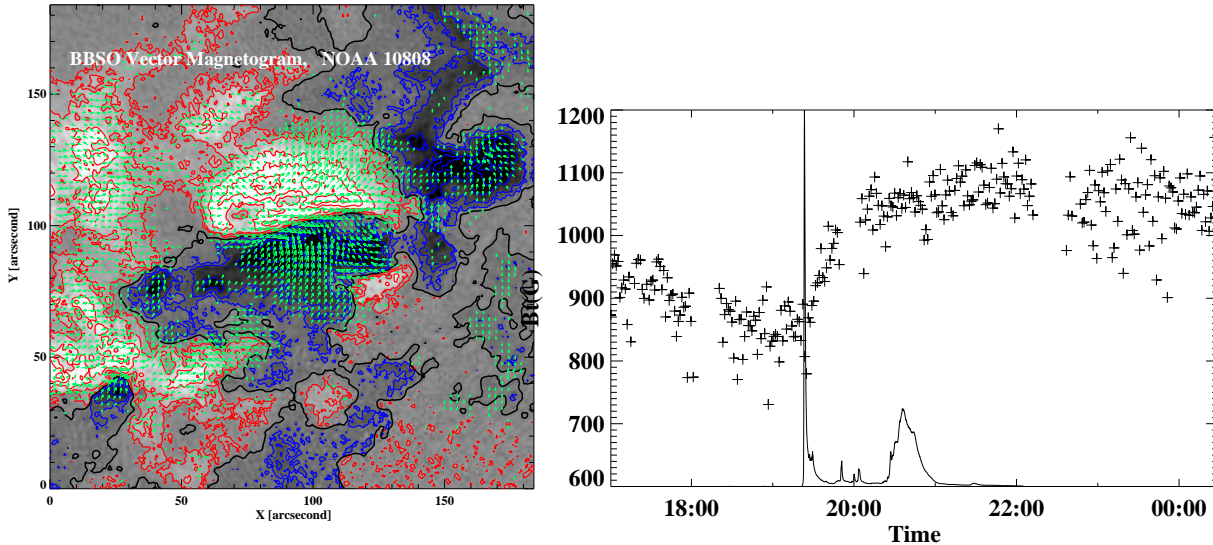


Figure 6: Left, a BBSO vector magnetogram of September 13, 2005. Right: The time profile of the mean transverse field strength in the section of the neutral line close to the initial flare core. The timing of the flare is indicated by the 10 GHz OVSA microwave light curve.

tions from the Hinode filtergraph observations is essential to detect and characterize the rapid sunspot structure change. However, it has some technical difficulty that vector magnetograph observations are difficult at this moment. On the other hand, analyzing lower-cadence Hinode spectro-polarimeter observations will enable us to study spectral line profiles of the areas that sustain structural changes, therefore we can come to understand more detailed physical characteristics (e.g., temperature, density and more accurate polarimetry) of the rapid changes of active region structure associated with flares. In the same line as the spectral tunability of IRIM, 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 similar properties to other events studied by us before: enhancement of sunspot structure at the flaring neutral line, and peripheral penumbral decay. From two vector magnetograms covering the X3.4 flare, we can see 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. Again, analysis of Hinode data will help us to develop data analysis tools that will be applied of NST high resolution data.

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,  $\delta$  or non- $\delta$  configuration, and filament eruption association or not. Preliminary results indicate that the field changes are more detectable in  $\delta$  sunspots, and when associated with sigmoid configuration and long-duration flares.

#### C.4. 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 right after the flare, indicating sudden converging motion toward the magnetic neutral line starting right after the flare.

Applying our CoM method and other tools, we studied the short-term evolution of magnetic fields associated

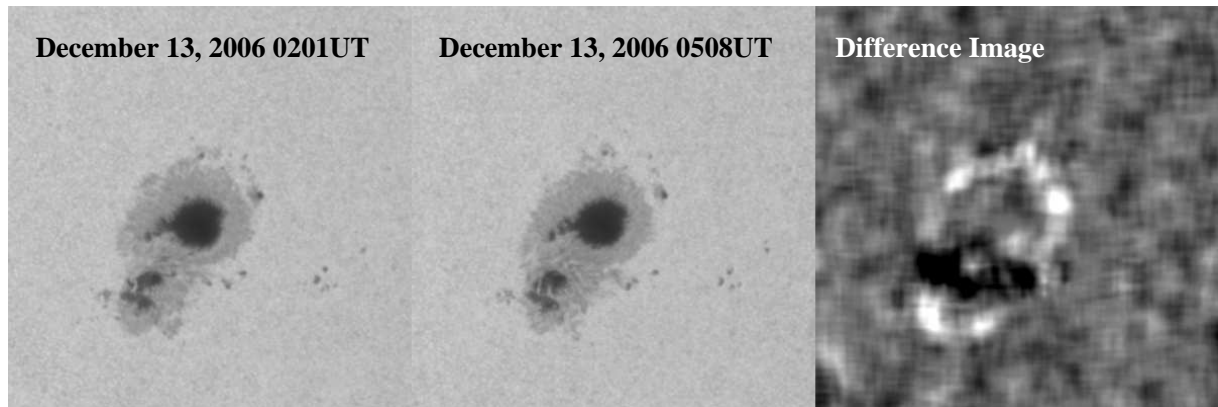


Figure 7: Left: TRACE WL image at 0201 UT before the onset of the X3.4 flare on 2006 December 13. Middle: WL image after the flare at 0508 UT. Right: the difference between post- and preflare WL intensity. The peripheral penumbral decay is evident by a bright ring in the difference image while the enhancement of sunspot structure at the flaring neutral line is seen as a dark band.

with five additional flares in  $\delta$  sunspots (Wang 2006). We concentrated on the analysis of magnetic gradient along the flaring neutral lines. Obvious changes in 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  $\delta$  regions, in the directions 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 argue 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 beneath the  $0.1''$  resolution limit. Figure 8 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 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:

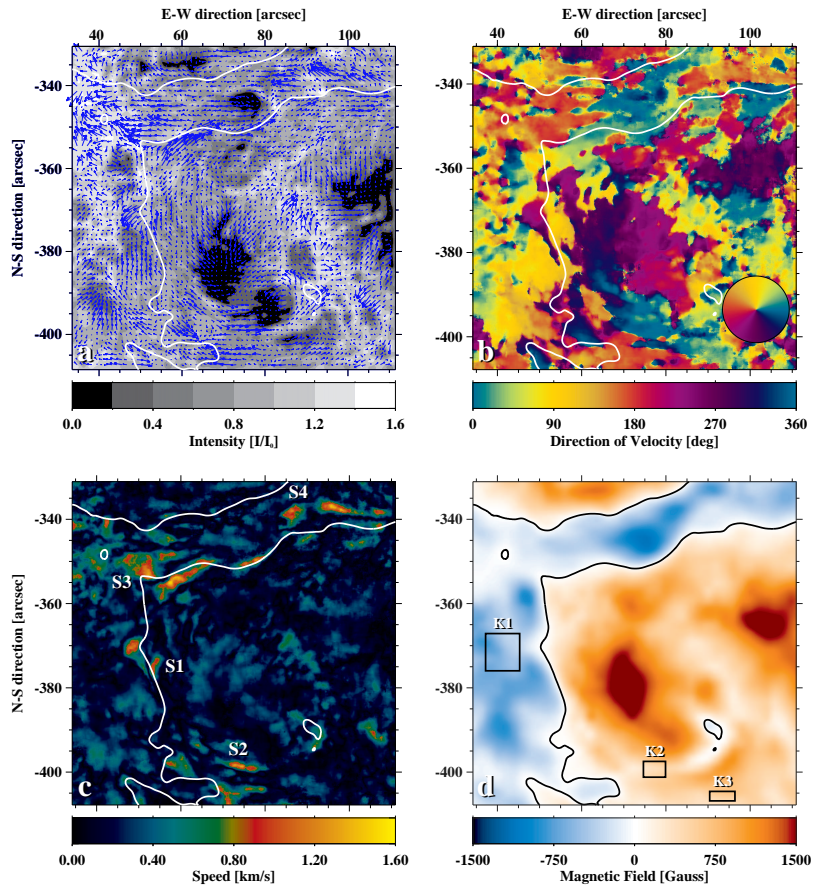
- (1) Do active regions always show the changes in the flows associated with flares as discussed above? What are the spatial distributions of the flow evolution?
- (2) Are shear flows unusually strong before major flares, and spatially located close to flaring neutral lines?
- (3) What is the physical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

### C.5. High Resolution Near IR Observations of Non-Flaring Solar Atmosphere

Although our proposed research focuses on the high resolution observations of solar activity, the NST will certainly provide unprecedented data to understand the dynamics of magnetic structure in quiet atmosphere. In the initial phase of NST operation, the 96-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

Figure 8: 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.



topics based on the recent scientific advances in these areas. NST is timely to push the study further.

### **C.5.1. Quite Sun Magnetic Fields below Intranetwork Fields**

This specific scientific objective is 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. A similar claim has been made with 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.

According to Harvey et al. (2007), this newly discovered magnetic component is not present in chromosphere. Therefore, it is nature to search its signature slightly below the photosphere. IRIM observes at around 50km below the visible photosphere, therefore, it is highly likely that we will be able to observe and characterize this new magnetic component in the quite sun.

### **C.5.2. 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<sup>-2</sup> s<sup>-1</sup> 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 magnetograms, and 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. In particular, LCT requires stable high resolution image sequences, that is possible with AO corrected NST NIR observations. To achieve this objective, we will push our polarization accuracy to be below  $10^4$  with IRIM.

## **D. 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 $\alpha$  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. (4) BBSO has a rich data archive. Therefore, the risk of funding BBSO is minimized.



<b>Name</b>	<b>Role</b>	<b>Tasks</b>
Goode	PI	Overall Supervision and NST Development
Wang	Co-PI	Coordination in Scientific Projects
Cao	Co-PI	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, Vincent	Staff	NST and BBSO Instrumentation

**Table 2:** Role and Tasks of Team Members

For the early part of the first year when we finish commissioning the NST, more resources will be devoted to instrumentation. Starting in the middle of the first year, scientific research using the NST will become the dominant effort.

## E. References Cited

- Aschwanden, M. J. 2002, *Particle Acceleration and Kinematics in Solar Flares*, Kluwer Academic Publishers
- Aschwanden, M. J., Schwartz, R. A., & Alt, D. M., 1995 *Electron Time-of-Flight Differences in Solar Flares*, Ap.J., 447, 923-935
- Aschwanden, M. J., Benz, A. O., Dennis, B. R., & Schwartz, R. A., 1995, *Solar Electron Beams Detected in Hard X-Rays and Radio Waves*, Ap.J., 455, 347-365
- Aschwanden, M. J., Benz, A. O., & Schwartz, R. A., 1993, *The Timing of Electron Beam Signatures in Hard X-Ray and Radio: Solar Flare Observations by BATSE/Compton Gamma-Ray Observatory and PHOENIX*, Ap.J., 417, 790-804
- Aschwanden, M. J., Kliem, B., Schwarz, U., Kurths, J., Dennis, B. R., & Schwartz, R. A., 1998, *Wavelet Analysis of Solar Flare Hard X-Rays*, Ap.J., 505, 941-956
- Aschwanden, M. J., Nightingale, R. W., Alexander, D., 2000, *Evidence for Nonuniform Heating of Coronal Loops Inferred from Multithread Modeling of TRACE Data*, Ap.J., 541, 1059-1077
- Bastian, T. S., & Vlahos, L. 1997, in "Coronal Physics and Space Observations", ed. Trottet, p. 68
- Benka, S. G., & Holman, G. D. 1994, *A Thermal/nonthermal Model for Solar Hard X-ray Bursts*, Ap.J., 435, 469-481
- Cao, W., Jing, J., Ma J., Xu, Y., Wang, H. & Goode, P.R., 2006, *Diffraction-limited Polarimetry from the Infrared Imaging Magnetograph at Big Bear Solar Observatory*, PASP, 118, 838-844
- Carmichael, H. 1964, in Proc. AAS-NASA Symp., *The Physics of Solar Flares*, ed. W. N. Hess (Washington, DC: NASA), 451
- Chen, W., Liu, C., & Wang, H., 2007, *Statistical Study of Rapid Penumbra Decay Associated with Flares*, ChJAA., in press,
- de Jager, C. & de Jonge, G. 1978, *Properties of Elementary Flare Bursts*, Solar Physics, 58, 127-137
- Deng, N., Liu, C., Yang, G., Wang, H., & Denker, C., 2005, *Rapid Penumbra Decay Associated with An X2.3 Flare in NOAA Active Region 9026*, Ap. J., 623, 1195-1201
- Deng, N., Xu, Y., Yang, G., Cao, W., Liu, C., Rimmele, T. R., Wang, H., & Denker, C., 2006, *Multiwavelength Study of Flow Fields in Flaring Super Active Region NOAA 10486*, Ap. J., 644, 1278-1291
- Denker, C., Yang, G., & Wang, H., 2001, *Near Real-Time Image Reconstruction*, Solar Physics, 202, 63-70
- Denker, C., Mascarinas, D., Xu, Y. Cao, W., Yang, G., Wang, H., Goode, P. R. and Rimmele, T., 2005, *High-Spatial-Resolution Imaging Combining High-Order Adaptive Optics, Frame Selection, and Speckle Masking Reconstruction*, Solar Physics, 227, 217-230
- Denker, C., Tritschler, A., Rimmele, T. R., Richard, K., Hegwer, S. L. & Woger, F., 2007, *Adaptive Optics at the Big Bear Solar Observatory: Instrument Description and First Observations*, PASP, 119, 170-182
- Didkovsky, L., Dolgushyn, A., Marquette, W., Hegwer, S., Ren, D. Fletcher, S. Richards, K., Rimmele, T. R. Denker, C. and Wang, H. 2003, *High-order Adaptive Optical System for Big-Bear Solar Observatory*, Proc. SPIE, 4853, 630-639
- Ding, M. D., Qiu, J., Wang, H., & Goode, P. R. 2001, *On the Fast Fluctuations in Solar Flare Ha Blue Wing Emission*, Ap.J., 552, 340-347

- Forbes, T. G., & Priest, E.R., 1995, *Photospheric Magnetic Field Evolution and Eruptive Flares*, Ap.J., 446, 337-389
- Fu, G., Shih, F.Y. & Wang, H., 2007, *Automated Detection of Filament Eruptions*, IEEE Trans on CSVT, 17, 79-85
- Furth, H. P., Killeen, J. & Rosenbluth, M. N. 1963, Phys. Fluids, 6, 459
- Hagyard, M. J., Venkatakrishnan, P., & Smith, J. B., Jr., 1990, *Nonpotential Magnetic Fields at Sites of Gamma-Ray Flares*, Ap. J. Suppl. 73, 159-163
- Harvey, J. W., Branston, D., Henney, C. J. & Keller, C. U., 2007, *Seething Horizontal Magnetic Fields in the Quiet Solar Photosphere*, Ap.J. Letters, 659, L177-180
- Hirayama, T. 1974, *Theoretical Model of Flares and Prominences. I: Evaporating Flare Model*, Sol. Phys., 34, 323-338
- Holman, G. D. 1985, *Acceleration of runaway electrons and Joule heating in solar flares*, ApJ, 293, 584-494
- Hoyng, P., van Beek, H. F. & Brown, J. C., 1976, *High time resolution analysis of solar hard X-ray flares observed on board the ESRO TD-1A satellite*, Solar Physics, 48, 197-254
- Hudson, H.S., 1991, *Solar flares, microflares, nanoflares, and coronal heating*, Solar Physics, 133, 357-369
- Hudson, H. S., 2000, *Implosions in Coronal Transients*, Ap.J. Letters, 531, L75-78
- Hudson, H.S., Wolfson, C.J., & Metcalf, T.R., 2006, *White-Light Flares: A TRACE/RHESSI Overview*, Sol. Phys., 2006, 234, 79-93
- Ji, H., Wang, H., Schmahl, E. J., Moon, Y. & Jiang, Y., 2003, *Observations of the Failed Eruption of a Filament*, Ap.J. Letters, 597, L161-164
- Ji, H., Wang, H., Schmahl, E. J., Qiu, J. & Zhang, Y., 2004a, *Observations of Nonthermal and Thermal Hard X-Ray Spikes in an M-Class Flare*, Ap. J., 605, 938-947
- Ji, H., Wang, H., Goode, P. R., Jiang, Y., Yurchyshyn, V., 2004b, *Traces of the Dynamic Current Sheet during a Solar Flare*, Ap.J. Letters, 607, L55-58
- Ji, H., Huang, G., Wang, H., Zhou, T., Li, Y., Zhang, Y. & Song, M., 2006, *Converging Motion of  $H\alpha$  Conjugate Kernels: The Signature of Fast Relaxation of a Sheared Magnetic Field*, Ap.J. Letters, 636, L173-176
- Jing, J., Yurchyshyn, V. B., Yang, G., Xu, Y. & Wang, H., 2004, *On the Relation between Filament Eruptions, Flares, and Coronal Mass Ejections*, ApJ, 614, 1054-1062
- Jing, J., Qiu, J., Lin, J., Qu, M., Xu, Y. & Wang, H., 2005, *Magnetic Reconnection Rate and Flux-Rope Acceleration of Two-Ribbon Flares*, ApJ, 620, 1085-1091
- Jing, J., Lee, J., Liu, C., Gary, D.E. & Wang, H., 2007, *Hard X-ray Intensity Distribution Along  $H\alpha$  Ribbons*, Ap.J. Letters, submitted
- Kaufmann, P., Strauss, F. M., Laporte, C., & Opher, R. 1980, *Evidence for quasi-quantization of solar flare mm-wave radiation*, A&A, 87, 58-62
- Kaufmann, P., Correia, E., Costa, J. E. R., Dennis, B. R., Hurford, G. J., & Brown, J. C. 1984, *Multiple energetic injections in a strong spike-like solar burst*, Sol. Phys., 91, 359-376

- Kaufmann, P., Raulin, J.-P., Correia, E., Costa, J. E. R., de Castro, C. G. Gimenez, Silva, A. V. R., Levato, H., Rovira, M., Mandrini, C., Fernandez-Borda, R., & Bauer, O. H., 2001, *Rapid Submillimeter Brightenings Associated with a Large Solar Flare*, Ap.J. Letters, 548, L95-98
- Kiplinger, A. L., Dennis, B. R., Emslie, A. G., Frost, K. J., & Orwig, L. E., 1983, *Millisecond time variations in hard X-ray solar flares*, Ap.J., 265, L99-104
- Kiplinger, A. L., Dennis, B. R., Orwig, L. E., & Chen, P. C. 1988, Proc. First Max'91 Workshop, Kansas City, p. 214
- Kliem, B., Karlicky, M. & Benz, A.O., *Solar flare radio pulsations as a signature of dynamic magnetic reconnection*, 2000, A&A, 360, 715-728
- Kopp, R. A. & Pneuman, G. W. 1976, *Magnetic reconnection in the corona and the loop prominence phenomenon*, Sol. Phys., 50, 85-98
- Kurt, V. G., Akimov, V. V., Hagyard, M. J., & Hathaway, D. H. 2000, in Ramaty, R. & Mandzhavidze, N. (eds.) High Energy Solar Physics: Anticipating HESSI, ASP Conference Series, Vol. 206, p. 426
- LaRosa, T. N. & Moore, R. L. 1993, *A Mechanism for Bulk Energization in the Impulsive Phase of Solar Flares: MHD Turbulent Cascade*, ApJ, 418, 912-918
- Lin, J., & Forbes, T. G., 2000, *Effects of reconnection on the coronal mass ejection process*, JGR, 105, 2375-2392
- Liu, C., Deng, N., Liu, Y., Falconer, D., Goode, P. R., Denker, C., & Wang, H., 2005, *Rapid Change of  $\delta$  Spot Structure Associated with Seven Major Flares*, Ap. J., 622, 722-736
- Liu, C., Deng, N., Lee, J., & Wang, H., 2006, *Large-Scale Activities in the 2003 October 29 Flare*, Ap. J., 642, 1205-1215
- Liu, C., Lee, J., Gary, D. E. & Wang, H., 2007, *The Ribbon-like Hard X-Ray Emission in a Sigmoidal Solar Active Region*, Ap.J. Letter, 658, L127-130
- Lites, B. W. and Hinode Team, 2007, *Ubiquitous Horizontal Magnetic Fields in the Quiet Solar Photosphere as Revealed by HINODE Measurements*, AAS Meeting 210, 063.03
- Lu, E. T., & Hamilton, R. J. 1991, *Avalanches and the distribution of solar flares*, Ap.J. Letters, 380, L89-92
- Moore, R.L., Sterling, A.C., Hudson, H.S., & Lemen, J., 2001, *Onset of the Magnetic Explosion in Solar Flares and Coronal Mass Ejections*, Ap.J., 552, 833-848
- Parker, E.N., 1988, *Nanoflares and the solar X-ray corona*, Ap.J., 330, 474-479
- Parker, E. N. 1989, *Solar and stellar magnetic fields and atmospheric structures - Theory*, Sol. Phys., 121, 271-288
- Priest, E. R., Foley, C. R., Heyvaerts, J., Arber, T. D., Mackay, D., Culhane, J. L. & Acton, L. W., 2000, *A Method to Determine the Heating Mechanisms of the Solar Corona*, Ap.J., 539, 1002-1022
- Qiu, J. & Wang, H., 2006, *On the Temporal and Spatial Properties of Elementary Bursts*, Solar Physics, 236, 293-311
- Qiu, J., Ding, M., Wang, H., Denker, C., & Goode, P. R., 2000, *Ultraviolet and Ha Emission in Ellerman Bombs*, Ap.J. Letters, 544, L157-160

- Qiu, J., Ding, M. D., Wang, H., Gallagher, P. T., Sato, J., Denker, C., & Goode, P. R. 2001, *Asymmetric Behavior of Ha Footpoint Emission during the Early Phase of an Impulsive Flare*, ApJ, 554, 445-450
- Qiu, J., Lee, J., Gary, D. E., & Wang, H. 2002, *Motion of Flare Footpoint Emission and Inferred Electric Field in Reconnecting Current Sheets*, ApJ, 565, 1335-1347
- Qu, M., Shih, F. Y., Jing, J. & Wang, H., 2003, *Automatic Solar Flare Detection Using MLP, RBF, and SVM*, Sol. Phys., 217, 157-172
- Qu, M., Shih, F. Y., Jing, J. & Wang, H., 2004, *Automatic Solar Flare Tracking Using Image-Processing Techniques*, Sol. Phys., 222, 137-149
- Qu, M., Shih, F. Y., Jing, J. & Wang, H., 2005, *Automatic Solar Filament Detection Using Image Processing Techniques*, Sol. Phys., 228, 119-135
- Qu, M., Shih, F. Y., Jing, J. & Wang, H., 2006 *Automatic Detection and Classification of Coronal Mass Ejections*, Sol. Phys., 237, 419-431
- Ren, D., Hegwer, S. and Rimmele, T. R. et al. 2003a, *The Optical Design of a High Order Adaptive Optics for the NSO Dunn Solar Telescope and the Big Bear Solar Observatory*, Proc. SPIE, 4853, 593
- Rimmele, T. R., 2004 *Recent advances in solar adaptive optics*, 2004, SPIE, 5490, 34
- Schmieder, B., Hagyard, M. J., Ai, G., Zhang, H., Kalman, B., Gyori, L., Rompolt, B., Demoulin, P., & Machado, M. E., 1994, *Relationship Between Magnetic Field Evolution and Flaring Sites in AR 6659 in June 1991*, Solar Physics, 150, 199-219
- Sturrock, P. A. 1966, *Model of the High-Energy Phase of Solar Flares*, Nature, 211, 695-697
- Sturrock, P. A., Kaufman, P., Moore, R. L. & Smith, D. F. 1984, *Energy release in solar flares*, Solar Phys., 94, 341-357
- Sudol, J. J., & Harvey, J. W., 2005, *Changes in the Longitudinal Magnetic Field during Solar Flares*, Ap. J., 635, 637-658
- Sui, L. & Holman, G.D., 2003, *Evidence for the Formation of a Large-Scale Current Sheet in a Solar Flare*, Ap.J. Letters, 596, L251-254
- Sui, L., Holman, G.D. & Dennis, B.R., 2004, *Evidence for Magnetic Reconnection in Three Homologous Solar Flares Observed by RHESSI*, Ap.J, 612, 546-556
- Svestka, Z. 1976, "Solar Physics", (Dordrecht: Reidel)
- Svestka, Z., & Cliver, E. W. 1992, in IAU Colloq. 133, Eruptive Flares, ed. Z. vestka, B. V. Jackson & M. E. Machado (New York: Springer), 1
- Tan, C., Jing, J., Abramenko, V., Pevtsov, A. A., Song, H., Park, S.H. & Wang, H., 2007, *Statistical Correlations between Parameters of Photospheric Magnetic Fields and Coronal Soft X-Ray Brightness*, Ap.J., in press
- Trottet, G., Rolli, E., Magun, A., Barat, C., Kuznetsov, A., Sunyaev, R., & Terekhov, O. 2000, *The fast and slow H $\alpha$  chromospheric responses to non-thermal particles produced during the 1991 March 13 hard X-ray/gamma-ray flare at 08 UTC*, A&A, 356, 1067-1075
- van Beek, H. F., de Feiter, L. D., & de Jager, C. 1974, In: Space research XIV; Proceedings of the Sixteenth Plenary Meeting, Berlin, East Germany, Akademie-Verlag GmbH, p. 447

- van Beek, H. F., de Feiter, L. D., & de Jager, C. 1976, In: Space research XVI; Proceedings of the Open Meetings of Working Groups on Physical Sciences, Berlin, East Germany, Akademie-Verlag GmbH, p. 819
- Veronig, A.M., Karlicky, M., Vrsnak, B., Temmer, M., Magdalenic, J., Dennis, B.R., Otruba, W. & Potzi, W., 2006, *X-ray sources and magnetic reconnection in the X3.9 flare of 2003 November 3*, A&A, 446, 675-690
- Wang, H., 1992, *Evolution of Vector Magnetic Fields and the August 27 1990 X-3 Flare*, Solar Physics, 140, 85-98
- Wang, H., & Tang, F., 1993, *Flux Emergence and Umbra Formation After the X-9 Flare of 1991 March 22*, Ap. J. Letters, 407, L89-L90
- Wang, H., Ewell, M. W., Zirin, H., & Ai, G., 1994, *Vector Magnetic Field Changes Associated with X-class Flares*, Ap. J., 424, 436-443
- Wang, H., Gallagher, P., Yurchyshyn, V., Yang, G., & Goode, P. R., 2002a, *Core and Large-Scale Structure of the 2000 November 24 X-Class Flare and Coronal Mass Ejection*, Ap. J., 569, 1023-1031
- Wang, H., Qiu, J., Denker, C., Spirock, T., Chen, H., & Goode, P. R. 2000, *High-Cadence Observations of an Impulsive Flare*, Ap.J., 542, 1080-1087
- Wang, H., & Qiu, J. *Relationship between Flare Kernels in Ha Far-Blue Wing and Magnetic Fields*, 2002, Ap.J., 568, 408-412
- Wang, H., Liu, C., Qiu, J., Deng, N., Goode, P. R., & Denker, C., 2004a, *Rapid Penumbra Decay Following Three X-Class Solar Flares*, Ap. J. Letters, 601, L195-L198
- Wang, H., Qiu, J., Jing, J., Spirock, T. J., Yurchyshyn, V., Abramenko, V., Ji, H., & Goode, P. R., 2004b, *Evidence of Rapid Flux Emergence Associated with the M8.7 Flare on 2002 July 26*, Ap. J., 605, 931-937
- Wang, H., 2005, *Properties of Remote Flare Ribbons Associated with CMEs*, Ap. J., 618, 1012-1019
- Wang, H., Liu, C., Deng, Y., & Zhang, H., 2005, *Re-Evaluation of the Magnetic Structure and Evolution Associated with the Bastille Day Flare on 2000 July 14*, Ap. J., 627, 1031-1039
- Wang, H., 2006, *Rapid Changes of Magnetic Fields around Flaring Neutral Lines*, Ap.J., 649, 490-497
- Xu, Y., Cao, W. Liu, C., Yang, G., Qiu, J., Jing, J., Denker, C. & Wang, H., 2004, *Near-Infrared Observations at 1.56 Microns of the 2003 October 29 X10 White-Light Flare*, Ap.J. Letters, 607, L131-134
- Xu, Y., Cao, W. Liu, C., Yang, G., Jing, J., Denker, C., Emslie, G. A. & Wang, H., 2006, *High-Resolution Observations of Multiwavelength Emissions during Two X-Class White-Light Flares*, Ap.J., 641, 1210-1216
- Yang, G., Xu, Y., Cao, W., Wang, H., Denker, C., & Rimmele, T. R., 2004, *Photospheric Shear Flows Along the Magnetic Neutral Line of Active Region 10486 Prior to An X10 Flare*, 2004, Ap. J. Letters, 617, L151-L154