Title of Investigation: Studies of Solar Atmosphere and Magnetic Fields

Principal Investigator: Philip Goode, NJIT

Co-PI: Haimin Wang, NJIT

Proposal Summary

New Jersey Institute of Technology (NJIT) took over operation of Big Bear Solar Observatory (BBSO) on July 1, 1997. Our first NSF grant started on January 1, 1998. In the past two and half years since that grant started, the observatory has undergone fundamental changes which are marked by significant achievements in science, instrumentation and education. We have produced over sixty scientific papers. We also have solved BBSO's long-standing dome seeing problems, so that the observatory is able to take its place as one of two in the US capable of high resolution observations of the sun. Based on our solid record, we propose a three-year program of solar physics research at BBSO, which will cover the maximum of solar cycle 23. Our program will emphasize high resolution and high cadence studies of solar activity and magnetic fields. Our research also requires instrument development for us to better perform the proposed high resolution and/or high cadence observations.

Scientific Programs:

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

2) Comprehensive studies of vector magnetic fields in flare-producing active regions.

3) High cadence (30 to 1000 fps) Hα and He D3 flare observations to understand the energy release process of flares.

4) An extensive observational program directed at infrared (IR) investigations of plages, sunspots, granulation and small-scale magnetic fields.

5) High resolution studies require a complementary synoptic program – many small-scale phenomena have ancillary large field manifestations. Thus, we also propose an extensive program of synoptic observations, and interpretation thereof – calibrated, comprehensive, with continuous studies of the whole sun at the highest possible resolution and cadence.

6) As a service to the community, we will also continue our successful BBSO Activity Reports and Warnings (`www.bbso.njit.edu/cgi-bin/ActivityReport`). Daily full-disk data and data from our 25 cm telescope which lead to our reports and forecasts are available by anonymous ftp (`ftp.bbso.njit.edu`).

New Instruments and Facilities:

1) New generation, digital, visible light, vector magnetograph system employing state-of-the-art digital cameras and a new Fabry-Pérot magnetograph/spectrograph system.

2) Parallel computing system for real-time speckle reconstruction to obtain real-time diffraction limited images.

3) Near IR magnetograph and imaging systems, including a unique narrow band Lyot filter and an IR Fabry-Pérot filter.

1. Results from Prior NSF Support (ATM-9714796, $663,127, 1/1/1998 - 12/31/2000)

NJIT took over operation of BBSO on July 1, 1997. On January 1, 1998, we obtained our first NSF grant. We have made fundamental changes to the observatory, and our research group has been very productive, as evidenced by over 60 publications in the past two and a half years. Our major achievements include both scientific research and requisite instrumental upgrades. The instrumental advances were essential to improve the quality of our observations, especially in high resolution, and these resulted in a significantly broader and increased scientific output.

BBSO highly prizes its special role in the education of the next generation of scientists who build instruments. We have eight Ph.D. students; one has just graduated, and has been offered a postdoc residing in NASA/GSFC. Three more will graduate over the next year. Generally, each student builds the additional instrumentation necessary for his/her Ph.D. work. This broadens the education of the student, while strengthening the observatory. The typical new instrument needed by a solar observatory constitutes a small enough project that one graduate student can manage all aspects of its development. Our typical student will receive a Ph.D. in Applied Physics, Electrical and Computer Engineering or Computer Science. Such training prepares our students for a scientific career, while ensuring broader career opportunities.

BBSO has an unpaid, outside Advisory Board which meets annually to critique our efforts. The board's report is made to BBSO management and passed on to the upper management of NJIT. The current members of the board are Lou Lanzerotti (Lucent, Chair), Tim Brown (HAO), Karen Harvey (SRC), Steve Koonin (Caltech), Jeff Kuhn (UH) and Ron Moore (MSFC). We respect their advice and use it to improve the observatory.

Since NJIT took over BBSO, its telescope time and data have been open to the community. Many scientists have had observing time; a partial list includes Steve Koonin, Ken Libbrecht, Hal Zirin, and others from Caltech; Sara Martin, Helio-Research; George Fisher and Chris Johns-Krull, UC Berkeley; Terry Kucera, GSFC; Richard Canfield, Montana State University; N. Gopalswamy, Catholic University; A. Nindos, University of Maryland; several from China under our NSF-INT US-China Exchange Program; several from Korea under our NSF-INT US-Korea Exchange Program; Oddbjorn Engvold, Norway; and M. Koschinsky, Germany. Several Ph.D. students from around the world are using BBSO data as a central part of the work on their theses (especially under NSF-INT support). Data requests come to BBSO almost every week from around the world. We only ask that users of our telescopes and data acknowledge BBSO in their resulting publications. Many observers use our data to help plan their observing campaigns.

1.1 Results from Scientific Programs

(a) Sub-Arcsecond Resolution Observations

Denker and Wang (BBSO #1017) studied the center of a flare-producing delta sunspot with $0.2''$ resolution, and revealed important shear flow patterns which are associated with flares. We note that several excellent, high resolution images have been sent to Solar Physics, and each was published as a frontispiece. Denker et al. (BBSO #1037 and #1064) summarized BBSO high resolution studies. Application of speckle reconstruction to high resolution magnetograms was presented (BBSO #1022). We note that there were several significant papers (BBSO #1015, 1031, 1036, 1049, 1052 and 1058) resulting from joint observations between BBSO (operating near the diffraction limit of the 65 cm telescope) and various instruments aboard SOHO and TRACE. We have also collaborated on the interpretation of sub-arcsecond resolution observations at the Dunn Solar Telescope to find that solar oscillations are driven by a thermally induced collapse of the solar surface, Goode et al. (BBSO #1013). For a discussion of the dynamics of the collapse, see BBSO #1054.

(b) Coronal Heating Problem

We have addressed this long-standing problem from several perspectives, especially using joint BBSO and SOHO observations. A paper by Chae et al. (BBSO #1015) found solid evidence that explosive events are associated with magnetic reconnection. Wang et al. (BBSO #1005) found reenforcing results for Hα jets. For the first time, Hα and UV macrospicules were compared carefully, and their properties were studied extensively (BBSO #1014). We have discovered chromospheric upflow events (BBSO #1052) and identified them with transition region explosive events (BBSO #1031). We explained the two phenomena as the first and second stages of a two-stage magnetic reconnection (BBSO #1036). Another kind of quiet sun phenomenon, mini-filament eruptions, has been studied extensively by a visitor to BBSO from Beijing Observatory, Dr. J. Wang (BBSO #1016).

(c) Quiet Sun Magnetic Fields

BBSO continues to play a leading role in the study of quiet sun magnetic fields. This is due to our excellent seeing and high sensitivity magnetograms. Using high sensitivity BBSO magnetograms, Zhang (a Ph.D. student in Beijing Observatory who is jointly supervised by Haimin Wang) was the lead author on a series of papers from our group on intranetwork magnetic fields, including their lifetime, flow patterns, and their possible contribution to coronal heating (BBSO #1008, #1019, #1021, #1042, #1068 and #1069).

Using our PtSi/Si IR camera, Wang et al. (BBSO #1001) studied the magnetic properties of faculae at 1.6 μm, where we see immediately beneath the photosphere.

Woodard and Chae (BBSO #1030) have revealed the non-potential nature of quiet sun magnetic fields, and related that to small-scale brightenings.

(d) Active Sun

An NJIT Ph.D. student, J. Gao has finished writing pattern recognition software to automatically detect the onset of solar flares and filament disappearance (BBSO #1064). This software will be used in our "round-the-world" Hα network to provide an early warning of major solar events, and trigger a more rapid cadence when filament eruptions and/or flares are detected. We have also studied a number of flares from the perspective of the energy release process and associated magnetic reconnection (BBSO #1059, #1062, #1067 and #1075).

Wei Li, Director of Huairou Solar Observing Station (HSO) of Beijing Observatory, visited BBSO for several months, and she finished a significant paper on the evolution of electric currents in the flare-rich region of October 1991. This paper has been accepted by Ap.J.

A complete catalog of filament eruptions from 1991 to 1994 has been compiled and published (BBSO #1004). The new catalog covering the period from 1995 to 2000 is being compiled. Solar prominences have been compared in Hα and He II 304 Å, and we derived their temperature structure from the comparisons (BBSO #1027).

(e) Synoptic Observations

BBSO synoptic observation programs were enhanced significantly after we took over (BBSO #1002, BBSO #1029). The improvements include calibration and careful flat-fielding. The two most important components are: (i) Ca II K full disk observations and (ii) Hα full disk observations. At the 1999 SPD meeting in Chicago, Goode and co-authors used BBSO K-line data and MDI oscillation data to show that there is a close correlation through P_8, in even orders, between the evolving latitudinal signal in our K-line data and that seen in a Legendre expansion of the temporal evolution of MDI-measured solar oscillation frequencies. Several related papers have been produced (BBSO #1023, 1025 and 1053). Such on-going work using the synoptic data help illuminate the relation between the solar atmosphere and the changing near-surface interior.

Much of the aforementioned scientific work, in §1.1a-e, was predicated on the re-instrumentation work we did at BBSO.

1.2 Instrumentation

(a) Dome Seeing

Over the last two years, we have reduced the dome seeing by about a factor of three (from about $1.2''$ to $0.4''$), Goode et al. (BBSO #1056), so that BBSO could take its place as one of the two high resolution (fraction of an arc second diffraction limited telescope at a site with sub-arc second seeing) solar observatories in the US. To achieve this, we moved the control electronics from the dome floor to the floor below (the $2^{\rm nd}$ floor). We now have full control of the telescope from the $2^{\rm nd}$ floor which we thermally isolated from the dome floor. We achieved all of this without missing a day of observing time over our first winter. Subsequently, we painted the dome floor and walls with a special white, TiO_2 reflecting paint, installed a new exhaust system and we extended the 65 cm telescope creating laminar flow in front of the entrance window (adopting the CLEAR design concept). Most recently, we have installed a water-cooled shutter covering much of the dome's entrance slit. We have confirmed the improvement in seeing in several ways. These include comparing the output of the two NSO seeing monitors at BBSO (one outside atop a mast and the other under the dome), and comparing other measures of seeing from our sub-arcsecond resolution observations, both in IR and visible, before and after the changes (Goode et al. BBSO #1056). Of course, our objective is to be as close to the diffraction limit of the 65 cm telescope as our site allows.

(b) Fast Frame Cameras

One of the new digital camera systems (256×256) we have installed operates at more than 100 frames each second. It has been used to obtain magnetograms, perform speckle imaging and increase the effective spatial resolution (BBSO #1022). The system has also been used for high resolution and high cadence spectral scans (Lee, Ph.D. thesis, BBSO #1052).

(c) Digital Vector Magnetograph

Our project to make a new digital vector magnetograph system (DVMG) is essentially completed. What remains is to fully automate its operation. The DVMG uses a 1K×1K SMD camera and has no moving parts. The DVMG will markedly increase the sensitivity and accuracy of our magnetograms – representing a significant improvement over the old, supplanted videomagnetograph. The operational DVMG system is currently being upgraded to include our new Fabry-Pérot. The approach here reflects our approach to instrumentation in general – each new system builds on its predecessor. The DVMG was built on an earlier version which couldn't measure vector fields. The visible light imaging magnetograph (VIM) – which will use the Fabry-Pérot – will utilize the DVMG experience. The DVMG is part of the Ph.D. thesis work of Tom Spirock. Ultimately, the DVMG will reside on the 25 cm telescope, and the VIM will reside on our scientific workhorse, the 65 cm telescope.

(d) IR Magnetograph

We have installed a new infrared (IR) magnetograph system at BBSO. For this, we purchased an InGaAs camera – a camera in which NJIT played an important developmental role. The camera is optimized between 0.9 and 1.6 μm, and has a quantum efficiency better than 70% over that range. We also have developed the necessary optical, electrical and computer software components for the system. Another important part of our infrared instrumentation is the development of a narrow bandpass filter system which combines a Lyot filter and an IR Fabry-Pérot filter – the IR imaging magnetograph (IRIM). Another Ph.D. student, Jingshan Wang is working on this project. His design has been finished and approved by outside experts (BBSO #1045). The fabrication of the filter should be finished this year.

(e) Correlation Tracker

We have made substantial progress in building a correlation tracker and will finish it by the summer of 2000. This is part of the Ph.D. thesis project of another graduate student. This device will significantly improve the high resolution observations proposed here, especially the magnetograms. As well, it can be used as a scanning device for 2D imaging.

(f) Global Hα Network

We have successfully established a three-station Hα observing network at BBSO, Kanzelhöhe Solar Observatory in Austria, and the Yunnan Observatory in China. All three stations use the same kind of 2K$\times$2K cameras, with a pixel resolution of 1 arcsec and temporal resolution of 1 minute. The data are processed with the software developed over the last two years. This allows us to monitor solar activity round-the-clock. The hardware for this network was supported by a separate NSF grant; however, the work to set up this network was supported primarily by this grant.

The preceding discussion is a highlight of some of our accomplishments during the past two years. Below, we list selected publications supported by our present ATM grant. Because of limited space, we can only list *thirty* of the *sixty* of them. Please check the BBSO home page (`www.bbso.njit.edu`) for a complete list.

Selected BBSO Publications (1/1998 to 5/2000)

BBSO 1003: "Local Properties of the Sun's Seismic Events", P.R. Goode, L.H. Strous and T.R. Rimmele, 1998, Proceedings of IAU Symposium 185.
BBSO 1006: "SUMER Measurements of Non-Thermal Motions", J. Chae, U. Schühle and P. Lemaire, 1998, Ap.J., 505, 957.
BBSO 1013: "On the Origin of Solar Oscillations", P.R. Goode, L.H. Strous, T.R. Rimmele and R.T. Stebbins, 1998, Ap.J. Letters, 495, 27.
BBSO 1014: "Comparison of Hα and He II 304 Macrospicules", H. Wang, 1998, Ap.J., 509, 461.
BBSO 1015: "Photospheric Magnetic Field Changes Associated with Transition Region Explosive Events", J. Chae, H. Wang, C.Y. Lee, P.R. Goode and U. Schühle, 1998, Ap.J. Letters, 497, L109.
BBSO 1016: "Mini-Filament Eruptions on the Quiet Sun", J. Wang, W. Li, C. Denker, C.Y. Lee, H. Wang, P.R. Goode, A. MacAllister and S. Martin, 2000, Ap.J., 530, 1071
BBSO 1017: "High Spatial Resolution Observations of a Small Delta Spot", C. Denker and H. Wang, 1998, Ap.J., 502, 493.
BBSO 1022: "New Digital Magnetograph at Big Bear Solar Observatory", H. Wang et al., 1998, Solar Physics, 183, 1.
BBSO 1023: "Solar Asymmetries from SOHO/MDI Splitting Data", P.R. Goode, W.A. Dziembowski, M.P. DiMauro, A.G. Kosovichev and J. Schou, 1998, Proceedings of SOHO 6/GONG Workshop.
BBSO 1027: "Comparison of Prominences in Hα and He II 304 Å", H. Wang, J. Chae, J.B. Gurman and T.A. Kucera, 1998, Solar Physics, 183, 91.
BBSO 1031: "Chromospheric Upflow Events Associated with Transition Region Explosive Events", J. Chae, H. Wang, C.Y. Lee, P.R. Goode and U. Schühle, 1998, Ap.J. Letters, 540, 123.
BBSO 1032: "Hard X-ray and Microwave Flux Spectra of the 1991 November 2 Solar Flare", C.Y. Lee and H. Wang, 2000, Solar Physics, in press.
BBSO 1037: "Properties of Sunspots and Pores", C. Denker, T.J. Spirock, P.R. Goode and H. Wang, 1998, Proceedings of NSO/SP Summer Workshop.
BBSO 1038: "The Excitation of Solar Oscillations", P.R. Goode, L.H. Strous, T.R. Rimmele, R.F. Stein and Å. Nordlund, 1998, Proceedings of NSO/SP Summer Workshop.
BBSO 1041: "EUV Jets and Hα Surges in Solar Microflares", J. Chae, J. Qiu, H. Wang and P.R. Goode, 1999, Ap.J. Letters, 513, L75.
BBSO 1044: "Studies of Microflares and C5.2 Flare of September 27, 1998", H. Wang, J. Chae, J. Qiu, C.Y. Lee and P.R. Goode, 1999, Solar Physics, 188, 367.
BBSO 1045: "Solar Near-Infrared Filter System", J. Wang, H.Wang, N.M. Ravindra, P.R. Goode, F. Tong, T.J. Spirock and S. Yang, 2000, Optical Engineering, submitted.

BBSO 1047: "Stray Light Correction in Magnetograph Observations Using the Maximum Entropy Method", J. Chae, H.S. Yun, T. Sakurai and K. Ichimoto, 1998, Solar Physics, 183, 245.
BBSO 1051: "Active Region Loops Observed with SUMER on Board SOHO" J. Chae, H. Wang, J. Qiu and P.R. Goode, 2000, Ap.J. in press.
BBSO 1052: "Dynamical Characteristics of Small-Scale Hα Upflow Events on the Quiet Sun", C.Y., Lee, J. Chae and H. Wang, 2000, Ap.J. submitted.
BBSO 1054: "Dynamics of the Excitation of Solar Oscillations", L.H. Strous, P.R. Goode and T.R. Rimmele, 1999, Ap.J., in press.
BBSO 1056: "Measuring of Seeing from Solar Scintillometry and the Spectral Ratio Technique", P.R. Goode, H. Wang, W.H. Marquette and C. Denker 2000, Solar Physics, in press.
BBSO 1057: "Non-Coplanar Magnetic Reconnection as a Magnetic Twist Origin", J. Chae 2000, Solar Physics, submitted.
BBSO 1058: "Counter-Streaming Mass Flow and Transient Brightening in Active Region Loops", J. Qiu, H. Wang, J. Chae and P.R. Goode, 1999, Solar Physics, 190, 145.
BBSO 1059: "Comparison of April 29, 1998 M6.8 and November 5, 1998, M8.4 Flares", H. Wang et al., 2000, Ap. J., in press.
BBSO 1061: "The Dynamics of the Excitation of Solar Oscillations", L.H. Strous, P.R. Goode and T.R. Rimmele, 2000, Ap.J. in press
BBSO 1062: "EUV Flare Loop Emissions in an Eruptive Event", J. Qiu, H. Wang, J. Chae and P.R. Goode, 2000, Solar Physics, in press.
BBSO 1064: "Synoptic Observations of the Sun from Big Bear Solar Observatory", P.R. Goode, C. Denker, W.H. Marquette and H. Wang, 1999, Proceedings of 11th Cambridge Workshop.
BBSO 1069: "Interaction Between Network and Intranetwork Magnetic Fields", Z. Zhang, J. Wang, C.Y. Lee and H. Wang, 2000, A&A, in press.
BBSO 1074: "High Resolution H alpha Observations of Proper Motions in NOAA 8668: Evidence for Filament Mass Injection by Chromospheric Reconnection", Chae, J., C. Denker, T. Spirock, H. Wang and P.R. Goode, 2000, Solar Physics, in press.
BBSO 1075: "High Cadence Observations of an Impulsive Flare", H. Wang, J. Qiu, C. Denker, T. Spirock, H. Chen and P.R. Goode, Ap. J., submitted.

2. Proposed Research

After substantial achievements in the last three years, we are motivated to attain the next level of understanding of solar magnetic fields and the solar atmosphere. Such understanding depends on higher resolution and higher cadence observations. Our scientific objectives will center on energy release and transport on different scales in the solar atmosphere, as well as the associated evolution of magnetic fields. This requires continuing effort in instrument development, and a dedicated scientific team to make and analyze new observations. We propose a number of research topics for the next three years, each of which is associated with high resolution and/or high cadence studies. We divide them into two parts – scientific research and instrumentation. The instrumentation is that which is needed to enhance various aspects of the science we plan to do. Because of the wide-range and diverse scope of the projects proposed here, and due to the page limit of the proposal, we can only briefly describe each topic. To summarize the observational topics:

– high resolution observations sharpened by speckle reconstruction

– high resolution vector magnetograph observations

– high resolution IR observations

– high cadence flare observations

– supporting synoptic observations and solar activity predictions

2.1 Scientific Programs

2.1.1 High Resolution Observations on the 65 cm Telescope

(a) Diffraction Limited Observations

As determined from speckle reconstruction, the typical Fried parameter for our site is now more than 10 cm through the 65 cm telescope under the dome. Even an occasional 10 cm value is taken as a benchmark of excellent seeing. However in BBSO, this quality of seeing often persists for the length of many days. NSO site surveys (Beckers, 1997) taken outside the dome, argue for the potential of much better seeing, still. Our studies (Goode et al., 2000) indicated a Fried parameter of upwards of 20 cm at BBSO is possible. Since the start of our current NSF-ATM support, we have sharply reduced the dome seeing (see §1.2). We will continue to exploit BBSO's significantly improved resolution to obtain long sequences of reconstructed diffraction limited images in both active regions and the quiet sun. These "movies" will track the motion of small-scale magnetic flux tubes, and the interaction between convection and magnetic fields. These movies will be sharpened by using the speckle masking technique which has been adapted to BBSO by Denker (1998). At this time, the images are reconstructed off-line which limits us to about two hours of data. This would be sufficient for the work proposed here. But with the expectation of doing a better job with longer sequences of data, we are in the process of building a parallel computer cluster, for on-line speckle reconstruction (see §2.2.2).

Our major scientific objectives are:

– understanding the build-up of magnetic stresses in active regions due to complex flows, such as magnetic channels (Wang, 1997).

– understanding the interaction between magnetic fields and convective motion in the quiet sun, and the process of formation of pores.

– three color photometry of center-to-limb variation of small-scale magnetic fields, such as filigree, umbral dots, plage and pores. These data will enable us to determine their temperature structure variation with altitude.

– using the Fabry-Pérot interferometer to do narrow band reconstructions in strong chromospheric absorption lines, like Hα and others, to study small-scale features, like Ellerman bombs.

(b) Small-Scale Magnetic Fields and Coronal Dynamics

Small-scale magnetic reconnection may be a miniature of larger scale magnetic reconnection which causes solar flares. The foremost problem here is to more accurately determine the distribution and evolution of intranetwork (IN) and network fields, and their velocity patterns. This is critical in any effort to understand the interaction between magnetic fields and convective motion.

The best BBSO videomagnetograph sequences have demonstrated that larger chromospheric ejections are associated with magnetic reconnection when intranetwork fields are pushed toward the network boundary, and reconnect with opposite-polarity network elements. However, such an identification is still vague because it depends on the sensitivity of the magnetograms. As discussed earlier, we recently have made significant progress in improving the sensitivity of BBSO magnetic field measurements (Wang et al., 1998a) by implementing our DVMG. In Figure 1, we show two longitudinal magnetograms resulting from a 60 s integration using the DVMG. This system has a better than 1 G sensitivity and $1''$ resolution. With our new system, we have made some progress in determining the causal role of small-scale magnetic fields in chromospheric and coronal dynamical events.

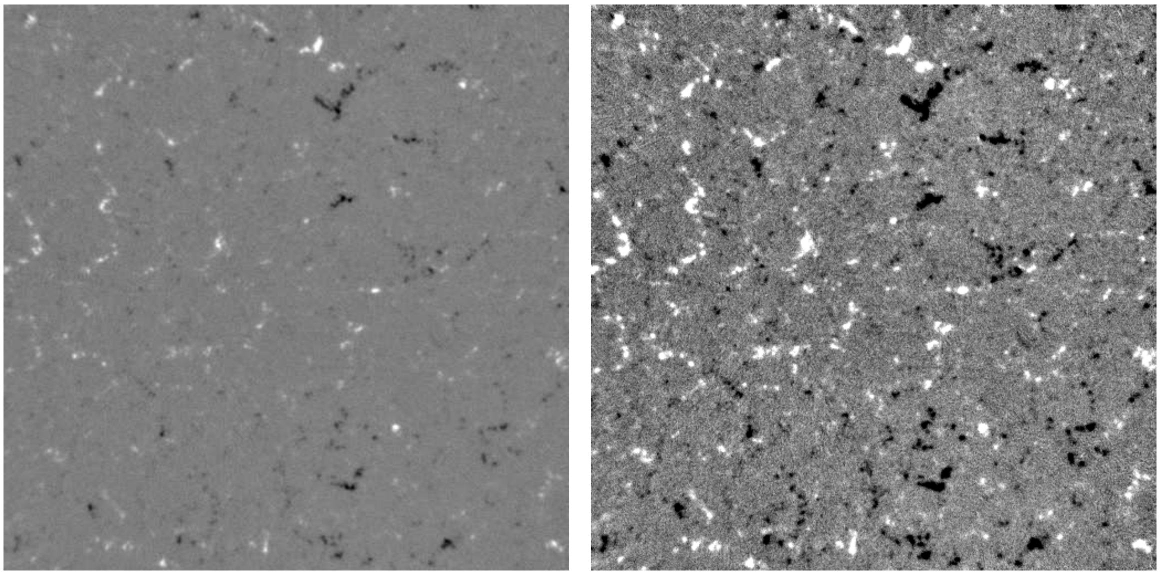


Fig. 1. Longitudinal magnetograms from 26 April 1999 using the DVMG. The field of view is 235×235" and the cadence is 1 min. The images are scaled between polarizations of ±1.5% (left-panel image) and ±0.3% (right-panel image) to show the intranetwork fields more clearly. Unlike an old videomagnetogram, the images here are flat-fielded and calibrated. Such high quality images are common with DVMG, and were very rare with the videomagnetograph.

Over the next three years, we propose to:

– emphasize the study of the interaction between intranetwork fields and network fields, and their relation to coronal dynamics, in part by comparing Hα images from BBSO, and X-ray and UV/EUV observations from Yohkoh, SOHO and TRACE.

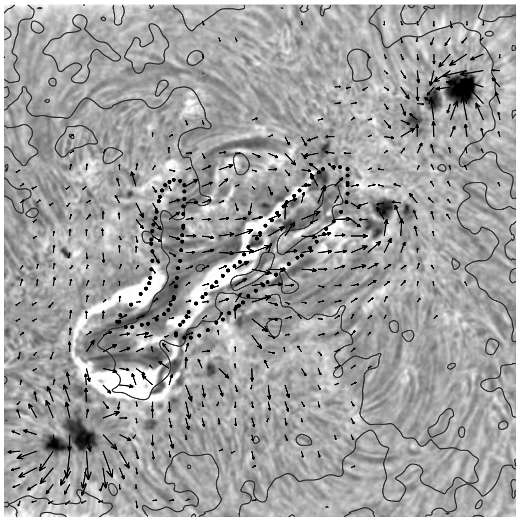
– understand the physics of microflares, jets and explosive events, and their magnetic origins. This is further motivated by our recent work on identifying two kinds of microflares – those due to the eruption of twisted loops, and those due to interacting loops (H. Wang et al., 2000).

– continue to investigate the significance of these small-scale events (microflares) in coronal heating.

2.1.2 Magnetic Fields and Flare Producing Active Regions

After the upgrade/improvement of several instruments (e.g., the new DVMG and IR magnetograph system, see §2.2.3), and with data from Yohkoh, TRACE and SOHO through the coming solar maximum, we are in an excellent position to obtain unprecedented observations elucidating the evolution of magnetic fields and the physics of solar flares. Our studies will be aided by our recent upgrade to our DVMG employing a 1K×1K camera. A DVMG vector magnetogram during a flare is shown in Figure 2. Our studies here will concentrate on the following topics:

M 2.3 Flare on October 26, 1999



FOV 174"x174"

Fig. 2. A DVMG vector magnetogram from October 26, 1999. The background is an Hα image during an M2.6 flare. Arrows indicate the transverse fields, and the thin, solid black lines are the neutral lines of line-of-sight magnetic fields. Strong magnetic shear is clearly visible in the areas near flare ribbons, as encircled by the heavy dotted lines.

(a) Study of Emerging Flux Regions

Observations have revealed evidence that magnetic flux loops are twisted by convective motion beneath the surface. When the tangled flux tubes emerge through the surface, complicated magnetic configurations and apparent flow motions appear in the photosphere (Tanaka, 1991; Wang, 1991; Lites et al., 1998). From a sequence of photospheric vector magnetograms, we can reconstruct the structure of flux tubes before their emergence. BBSO has the advantage of constant good observing conditions, and it often coordinates "round-the-clock" observations (Wang et al., 1989) with HSO in Beijing, China. Such continuous observations are necessary for the reconstruction of sub-photospheric magnetic structures (a too simple analogy: imagine a tree emerging from under water – where apparent motions, at the water's surface, of rising branches toward the trunk actually reveal the tree's structure. Further, if the branches were twisted, a rotational motion of the branches would be apparent at the surface). To elucidate the interaction between convection and magnetic fields, we anticipate reconstructing flux tube structures for a number of major complicated active regions using our continuous data.

(b) Magnetic Field Changes Associated with Solar Flares

One of the important results that BBSO obtained during the last solar maximum is the finding that the photospheric magnetic field shear may increase after solar flares (Wang, 1992; Wang et al., 1994b). Magnetic shear is defined as the difference between measured fields and potential fields. This finding is not inconsistent with the principle of conservation of energy, because the energy is stored in the full three-dimensional space running from the photosphere to the corona. It appears that a photospheric increase does not always occur. However, it may actually be that sometimes it is simply too small for us to have detected with the old videomagnetograph system. The DVMG will enable us to do the proposed work. We expect to be able to do better still with our upgrade to a calibrated digital Fabry-Pérot vector magnetograph, the VIM, and an IR Fabry-Pérot magnetograph system, the IRIM. We will be sensitive to significantly smaller changes in magnetic shear, and can definitively characterize its behavior. BBSO (with coordinated observing from HSO) will follow complicated active regions to study magnetic topology, shear and the electric current system. Space data (Yohkoh, TRACE and SOHO) will be combined to obtain the three-dimensional structure of magnetic loops. We have experience in performing multi-wavelength data comparisons from studying BBSO, OVRO, Yohkoh and CGRO data (Wang et al., 1994a, 1995, 1996). This experience will be useful for this proposed research.

One of the important tools for studying the evolution of magnetic fields in flare-producing active regions is the evolution of electric currents. They contain information on the non-potentiality of an active region. Studies like that done in BBSO by Li et al. (2000) will be carried out to study the evolution of currents. The currents are derived from accurate vector magnetograms. We will investigate the electric current systems carried to the surface by flux emergence, and the role of the evolution of current systems in triggering solar flares, filament eruptions and coronal mass ejections.

2.1.3 High Cadence Flare Observations

A significant problem in flare physics is to explain the sub-second structure in hard X-ray time profiles, which directly points to the critical issues about the nature of flare energy release and the properties of the source of particle acceleration. Using data from SMM with a cadence of 30 ms, Kiplinger et al. (1983, 1984) revealed a fast variation (over a few tenths of a second) of hard X-rays in many solar flares, which placed some constraints on models of non-thermal electron beams. The sub-second temporal structures observed by BATSE were also used to study the scales of magnetic loops in flares (Aschwanden et al., 1996). The nature of these sub-second peaks is not yet clear, but one hypothesis is that magnetic reconnection occurs almost continuously among small flux tubes, and non-thermal electrons are, thereby, constantly injected into the chromosphere on a sub-second time scale. Hard X-ray observations usually lack the spatial resolution required to test this scenario, while the previous effort at high cadence Hα observations by Kiplinger et al. (1989) was not lucky enough to detect a single flare. However, we can make dedicated observations to study particle precipitation along the tiny sub-footpoints composing the individual footpoints, like those denoted in Figure 3. The Dunn Solar Telescope (DST) of the National Solar Observatory (NSO) is the other high resolution solar observatory in the US with sufficiently good seeing to make the observations we propose, but it is dedicated to its valuable mission of serving a broad community of users.

We propose to make dedicated observations to study particle precipitation into the chromosphere at the footpoints of the flare loops. Our major target is to search for the high frequency variations in the chromospheric lines which are related to the high frequency variations in hard X-ray emission, and to examine the spatial scales of these temporal variations by exploiting the resolution limit of our facilities.

The key components of the innovatative, high cadence BBSO system consist of a 256 $\times$ 256, 12-bit Dalsa camera (110 fps), and a 1K by 1K SMD camera (30 fps with 2:1 binning, otherwise 15 fps). As an experiment, we will also use the Dalsa 64$\times$ 64 camera to observe at a cadence of more than 1000 fps, to learn whether there are even shorter lived temporal structures. Since the fine temporal structure of flares may range from a few milliseconds to a few seconds, and the spatial scales of these temporal structures are not clear, we need to have the flexibility to cover different image scales, fields of view and cadences. For the 256$\times$256 Dalsa camera, at its maximal cadence (9 ms), the duty cycle is 30% to allow time to dump the images from memory to disk. If we store the data directly to disk, we can achieve a cadence of about 50 ms with a 100% duty cycle. In Table 1, we list a few sample observing setups. We will experiment with most of them in our observations. The last row is for the Fabry-Pérot filter which will scan 20 spectral positions. Image selection, like the set up in the 5th and 6th rows, has proven to be very helpful in obtaining diffraction limited images.

Table 1. Sample Setups of High Cadence Flare Observations

Camera	Filter	Pixels	Image Selection	Duty Cycle	Cadence	Pixel Size	FOV
Dalsa	Lyot	256×256	No	30%	9 ms	0.3″	80″
Dalsa	Lyot	256×256	No	100%	50 ms	0.3″	80″
SMD	Lyot	512×512	No	30%	33 ms	0.3″	150″
SMD	Lyot	512×512	No	100%	100 ms	0.3″	150″
SMD	Lyot	512×512	1 out of 5	100%	1 s	0.3″	150″
SMD	Lyot	512×512	1 out of 100	100%	10 s	0.3″	150″
SMD	Lyot	1024×1024	No	100%	200 ms	0.15″	150″
Dalsa64	Lyot	64×64	No	30%	<1 ms	0.5″	32″
SMD	FP	512×512	No	100%	2 s	0.3″	150″

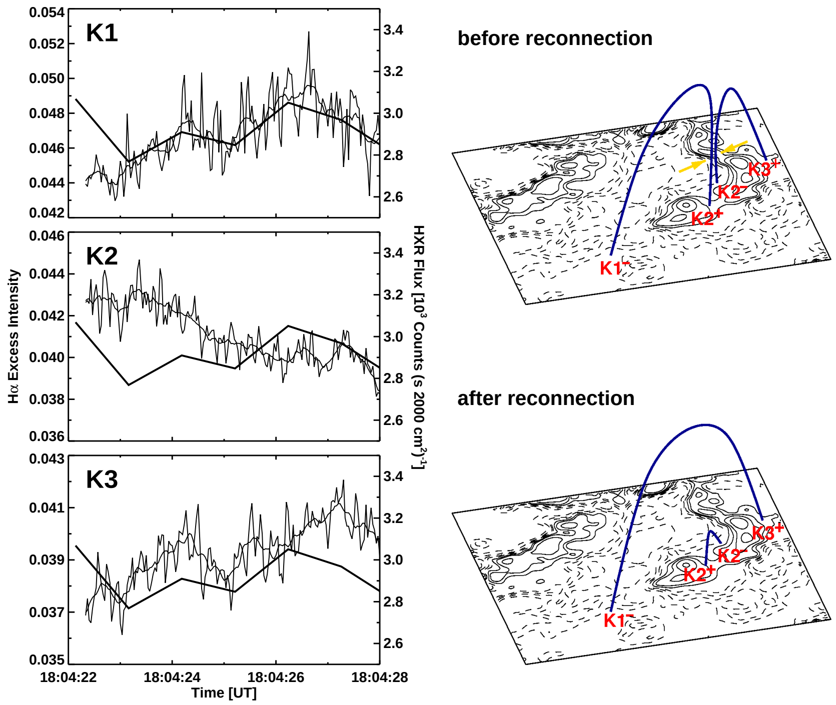


Fig. 3. In the right panels, three observed flare kernels are shown before and after reconnection. Only K1 shows a good correlation with the hard X-ray flux, as shown in the left panels. The H$\alpha - 1.3$ Å appears in the highly structured lines in K1, K2 and K3. The X-ray flux appears as the slowly varying lines (1 s cadence) in K1, K2 and K3. The X-ray data are from BATSE in its normal, non-flare, slow mode.

In our campaigns, we will observe in the far blue/red wing of Hα line, which responds sensitively and promptly to non-thermal electron beams. We also plan to observe the HeI D_3 line, which is an ideal line for the diagnosis of electron density in the flare atmosphere. In particular, the latter line can show emission or absorption depending on the column density of the electrons (Zirin, 1988). BBSO is the only observatory routinely observing in D_3, since we have a unique Lyot filter in D3. The initial operation will be for a single line position with our Lyot filters, which cannot be tuned very quickly. When the Fabry-Pérot system is completed, the observations will be extended to include several positions in the spectral lines. We expect the Fabry-Pérot VIM system to be on-line early in 2001. The spatial resolution of the observations will be between $0.2''$ to $0.5''$. To aid the high cadence, high resolution filtergram observations, we have had to improve our magnetograph observations to a $0.5''$ spatial resolution. The technique we have developed is to use image selection and registration before integrating a number of frames. This kind of resolution is now routinely achieved at BBSO with the DVMG.

In preliminary observations, we already caught a few flares. The results in Figure 3 demonstrate the power of our combined hard X-ray and high cadence (30 fps) BBSO flare observations. This flare was observed on August 23, 1999 (Wang et al., 2000b). The left panel shows the time profiles of H$\alpha - 1.3$ Å intensity (off-band gives pure non-thermal signal) at spatially resolved flare kernels during the impulsive phase, and the right panel shows the magnetic configuration before and after the reconnection. We found that at one kernel K1, which makes one footpoint of the flare loop, H$\alpha - 1.3$Å emission is temporally correlated (92%) with the hard X-ray flux, so it is identified as the site of electron precipitation. Importantly, the H$\alpha - 1.3$Å emission in K1 shows significant high frequency fluctuations on a time scale of a few tenths of a second. This is the first observational evidence of hard X-ray related high frequency fluctuations in chromospheric emission on such fine time scale.

Motivated by this exciting result, we propose observations to pinpoint the finer spatial and temporal structures in the individual footpoints. We expect a good number of flares through the solar maximum. Special attention will be paid to events that exhibit fine temporal structure. Our scientific objectives are:

– spatially resolving individual particle precipitation sites within a footpoint, and the related magnetic field configuration to determine the spatial scale(s) of magnetic reconnection.

– analyzing the properties of these “elementary bursts”, such as their energy and spatial distribution, to set constraints on the models of particle acceleration.

– comparing high cadence hard X-ray (from Yohkoh and later from HESSI which has some spatial resolution coming at the expense of temporal and spatial resolution, e.g., at its best spatial resolution of $2''$, the cadence would be 2 s) and chromospheric emission to understand the detailed process of heating of the lower atmosphere by non-thermal electrons.

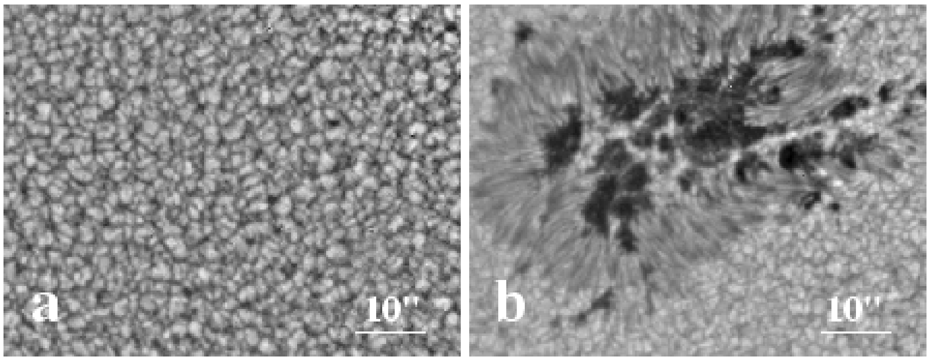


Fig. 4. Unprocessed, single exposure (0.13 ms) IR images of the quiet sun and a sunspot region, demonstrating our excellent image quality.

2.1.4 Infrared Observations

IR solar astronomy is a science whose time has come because of new camera and filter (see §2.2.3) technologies. BBSO's new IR camera is a 320×240 InGaAs IR detector. InGaAs is the natural material for studies at 1.6 μm because it has a 1.6 μm bandgap and therefore, is coated to minimize fringing at the wavelength of interest to us. NJIT faculty played a significant role in the development of this camera, and so we have benefited from their expertise in bringing this camera system into optimal operation.

For several scientific reasons, studying the sun in the near IR would result in a significant step forward in our understanding of the sun. First, the sun has an opacity minimum in the near IR (at about 1.6 μm), 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.

Third, one anticipates the greatest benefit of the IR to come in the measurement of magnetic fields because the atomic Zeeman splitting is considerably larger in the near IR (Zeeman splitting increases quadratically with wavelength), so that one can make much more precise measurements of the field and its evolution. Lin and Rimmele (1999) recently achieved near IR observations of granular magnetic fields. Their flux density sensitivity is 1 G, and they identified both strong ($\geq$ 1000 G) and weak ($\leq$ 500 G) magnetic field elements in the quiet sun. Our goal is to achieve observations of that quality, with a device for daily use, in both quiet sun and active regions.

(a) Broad-Band IR Photometry Near the Sun's Opacity Minimum

Foukal and his colleagues reported that many faculae are dark in the near IR, while they are bright in visible light (see review by Foukal and Morran, 1994). Such a result would sharply constrain models of flux tubes (Spruit, 1976). Detailed study of sunspot and facular contrast and relative areas in the IR would also facilitate microscopic analyses of the energy budget in solar active regions.

Using our PtSi/Si camera, Wang et al. (1998b) found no difference in the appearance of faculae, whether we looked in the IR or in visible light. The contradiction is probably due to the inferior resolution of the earlier observations. Still, one can even do much better than we did. The recent development of the InGaAs camera, which has a more than tenfold better quantum efficiency, enables us to carry out a wide range of photometric studies in near IR. Dark faculae may be just small pores seen in the layer about 50 km below the surface (as seen in visible light). Figure 4 shows diffraction limited IR images obtained in the quiet sun and active region. Such images are vastly superior to our earlier ones from the PtSi camera. We propose to study:

– Granulation:

While granular contrast is lower in the IR, the improved seeing in the IR makes up for it (see Figure 4). In observations using the BBSO 65 cm telescope, the size of a typical granule is about 3 to 4 times the size of the diffraction limit at 1.6 μm. We will emphasize studies of granular contrast, lifetime, properties of exploding granules and supergranule flow patterns derived from the proper motion of granules – all in the layer about 50 km (Foukal, 1990) beneath the visible photosphere. New SOHO helioseismology studies have demonstrated a complicated flow pattern, probably somewhat deeper beneath the photospheric surface (Duvall et al., 1996; Duvall, 1999; Kosovichev, 1999). By comparing with granulation at shorter wavelengths, we can study the height variation of convection. In this, we will collaborate with Arnold Hanslmeier (Univ. of Graz, Austria), an expert in granulation, and who is already our collaborator on the Hα network.

– Umbral Dots and Light Bridges:

Reduced scattered light and the lower contrast of umbrae in the IR make it much easier to study the morphology and evolution of umbral dots and light bridges. Successful measurements at 7700 Å were made by Ewell (1992). New BBSO observations were obtained at 1.6 μm (J. Wang et al., 1999). Over the next three years, we propose to concentrate on the magnetic structure of umbral dots and light bridges. Detailed study will provide a basic understanding of the interaction between convection and magnetic fields.

– IR Speckle Reconstruction

The high resolution IR observations will be compared with high resolution observations in visible light. In particular, we have developed speckle codes at BBSO from which diffraction limited images are regularly obtained. In the near IR, our speckle reconstructions have found Fried parameters upwards of 30 cm. Observations in two layers will shed light on the 3-D structure of flows and small-scale magnetic elements. We will concentrate on comparing flows at the two levels, as derived, using local correlation tracking and feature tracking (Strous et al., 1997).

(b) IR Spectroscopic and Polarimetry Observations

Lin's (1995) experiment has already demonstrated that the BBSO spectrograph system is particularly useful in measuring IR Stokes V profiles. The most important objective of BBSO IR observations here is to carry out superior observations of various solar features from intranetwork fields to big active regions, and to derive the temperature, velocity, true magnetic field strength and filling factors of these features. We have used our InGaAs system on the Littrow spectrograph of the 65 cm telescope, and have obtained high-quality data which we now obtain as needed.

Stokes Q and U profiles present a more difficult problem than does the V profile due to the severe instrumental polarization of the reflector. After we are making regular V profile observations, we will start working on the Q and U problem, because accurate vector magnetic field measurements are key to understanding the three-dimensional structure of magnetic fields. Fortunately, we do not need to start this process from scratch; both sites of the National Solar Observatory (Kuhn et al., 1994) have accumulated experience in correcting for instrumental polarization in IR observations. Their experience will be adapted for the BBSO system. In addition, the High Altitude Observatory (HAO) and Mees Solar Observatory (MSO) groups have developed spectral inversion codes which will help us in data reduction. Beyond the study of Stokes profiles, the IR spectroscopic study of dark faculae will be particularly interesting. If these regions are truly cooler, we should find a different spectral shape among the Fraunhofer lines and gain a clearer understanding of their temperature profile.

The scientific objectives of IR polarimetry are straightforward. In the active regions, it allows us to measure the magnetic fields accurately, so the 3-D structure can be extrapolated based on these measurements. Processes, such as magnetic reconnection, can be studied in detail by following evolution of the 3-D magnetic structure. In the quiet sun, such observations will allow us to accurately measure the filling factor and field strength, so we can identify and study the evolution of weak and strong magnetic field in small scales (Lin and Rimmele, 1999).

2.1.5 Synoptic Observations

Synoptic observations will continue to be one of the primary scientific objectives of BBSO. Accumulated synoptic data sets provide important archives from which one can determine the long-term variation of solar radiation fields and magnetic fields. They also provide important information elucidating the physics of the solar cycle. For our purposes, we need synoptic observations which are contemporaneous with our high resolution observations, such as Figure 2. We require both because the solar phenomena we propose to study may well have a small-scale origin, but also have a large-scale manifestation. We propose to continue to obtain and use the following data:

(a) Full-Disk Observations

These are the backbone of the synoptic program (Denker et al., 1999). The 2K$\times$2K Hα images show the full solar disk with $1''$ resolution. We supplement these with long exposure frames for prominences, as well as with off-band frames. These images fulfill a long-held dream – telling us what happens everywhere on the visible disk of the sun with sufficient cadence and resolution. We will implement pattern recognition software which will detect a filament eruption or flare, and trigger a more rapid cadence (about 10 s) during the event.

K-line and white-light images are taken at least once a day. Raw and corrected images and a plot of the K-line index can be seen on the BBSO CaK web page which is updated on a daily basis (`www.bbso.njit.edu/Research/cak_index.html`). We will continue to construct a CaK index, and develop an index of the latitudinal distribution of CaK brightness as the solar cycle progresses. We will continue to compare our index with the UV index from satellites.

In the near future, the SOLIS system will come on-line. This will not impact our Hα network. However, the need for our K-line and white light synoptic programs will have to be re-examined. Neither of them takes much time or effort. Our view is that we will continue, into the next minimum, with the ones that provide context for our high resolution observations, and help with our solar activity forecasting.

2.1.6 BBSO Activity Reports and Warnings

Accurate predictions of solar activity are most important for communication systems, safety of satellites and power grids.

At least once a day, BBSO now provides Solar Activity Reports which are a visible light survey of active regions. When warranted, BBSO also issues a BBSO Solar Warning forecasting rapid development and/or energetic solar flares in individual sunspot groups. This program was initiated November 24th, 1998. We also provide daily activity reports to the operation centers of solar missions to optimize their solar targeting. In addition to posting the reports and warnings on our web site, the warnings are sent via electronic mail to about 400 people who have requested them. Over the next three years, we will continue this project. Coverage through the activity maximum of the current cycle is especially important.

2.2 Instrumentation

We emphasize that all of the work proposed here can be done with existing instrumentation. But the instrumentation projects discussed in this section will enhance our ability to do the work proposed. Further, the new instrumentation will strengthen the observatory, and its scientific output, in the longer run.

2.2.1 New Imaging Magnetograph System

For the upcoming solar maximum, we need to make much more accurate measurements of the magnetic fields in flare-producing active regions. The DVMG stays on the 25 cm telescope. On the 65 cm telescope, we will place the VIM with its Fabry-Pérot filter providing the spectral line profile of the full Stokes vector when observing photospheric magnetic fields. This improvement will preclude Zeeman saturation where the fields are strong (in sunspots), and it will also provide filling factors for weaker fields. With the DVMG and VIM, we will be able to measure the magnetic field at two altitudes to determine the field's height variation. During 2000, we will expend a substantial effort to bring this system on-line.

2.2.2 Real Time Speckle Imaging

One of the difficulties in our high resolution observations is that each set of images takes hours of processing to construct a single diffraction limited image, using speckle imaging techniques. This effectively limits us to a short observing day ($\sim$2 hour) because the controlling computer's disk is filled by storing all the raw data. To circumvent these difficulties, we will purchase a 32-node parallel computing cluster, so that we can do real-time speckle reconstructions with a cadence of about 1 minute, and diffraction limited images can be achieved all the time during the entire observing period. We have already purchased a 4-node parallel system and are developing the software needed for image reconstruction under parallel processing. For our speckle observations, we will use our 256$\times$256 100 fps Dalsa camera. This work is the thesis project of one of our Ph.D. students. The real-time data will allow us to measure flow fields which will complement our vector magnetograms, and thereby substantially improve our forecasting of solar activity.

2.2.3 Infrared Imaging and Polarimetry

There are two basic approaches in IR imaging and polarimetry. At BBSO, using our InGaAs camera system, each of these is encompassed by a Ph.D. thesis project of one NJIT student:

Tom Spirock expects to finish the spectrograph-based vector magnetograph system this year. This system will obtain vector magnetograms with high spatial resolution and cadence. It uses our InGaAs camera, and a control system to automatically scan observed regions. All required hardware is in-hand. He has, largely, completed the other part of his thesis work – development of the DVMG.

Another student, Jingshan Wang, expects to finish his thesis this year, too. He is building a Lyot filter with a bandpass of 2.5 Å at 1.56 μm. This project is now in its construction phase. When this filter is finished, it will give us a 2.5 Å wide prefilter (narrower than the 5 Å free spectral range of the IR Fabry-Pérot). This would solve the longstanding problem of constructing a filter-based IR magnetograph, while avoiding the complications of using a double etalon. The new and unique Lyot prefilter would be used in conjunction with an IR Fabry Pérot system. With this prefilter we can, for the first time, achieve a spectral imaging magnetograph system in the near IR, the IRIM.

3. Education

Education is an important component of BBSO. We currently have eight Ph.D. students in our group, and each is working on a project in solar physics. NJIT pays a substantial part of the education of each graduate student. Every summer, we also have two to three undergraduate students working in the observatory, to do observations, data analyses and public tours. NJIT is one of very few universities in US which has a solar physics Ph.D. program. We believe that we are contributing substantially to the training of the next generation of solar astronomers and in general, astronomers who build instruments.

4. Personnel and Budget

Goode and Wang will oversee the operation and science goals of the observatory. Goode now resides in Big Bear year-round and directs the staff in the daily operation of BBSO. He also supervises the postdocs and students in residence at BBSO. Wang will direct the instrumentation program, which is primarily on campus at NJIT – taking advantage of the facilities there. The 14 man-months of support for scientists will be split among three researchers residing in Big Bear: Carsten Denker is an expert in high resolution solar research and speckle reconstruction; Jongchul Chae is an expert in small-scale solar dynamics and associated magnetic reconnection; and Jiong Qiu is an expert in the study of solar flares. Six months of support is requested for Dr. John Varsik, who will play a crucial role in the development of various instruments, and will spend part of his time in research on small-scale magnetic fields. The budget also includes one month of summer salary for Goode, and partial support for the staff at BBSO who keep the telescopes running and collect the data. The budgeted staff are William Marquette (site director and chief observer), Randy Fear (observer), Owen Pharis (electronics engineer) and Rochelle Bulrice (office manager). The budget also includes \$6,000 per year for travel and \$6,000 per year for publication charges and supplies. NJIT will provide an equipment match equivalent to \$100,000 per year. As well, NJIT will match with 1/4 of AY Goode's time allowing him the time to do his part of the proposed work. Wang's time will be contributed to this project. The first year's equipment match will mainly be used to upgrade cameras, including a new SMD 1M-30 camera for the magnetograph system. The second year's match will be used for an upgraded data archive system and a parallel computer cluster. The third year's equipment purchases will be focused on hardware for an adaptive optics system.

This ATM grant is one of the two backbone grants of BBSO. It supports researchers and provides almost half of the funds to the support observing staff. Over 90% of the funds are for salary and associated overhead. NJIT will provide a \$100 K match per year for the equipment to enhance the proposed work.

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