# THE SUN FROM BIG BEAR

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**Abstract**

Big Bear Solar Observatory (BBSO) is located high in a mountain lake in Southern California. It is one of very few solar observatories in the world capable of making high resolution observations of the sun. The cloudless skies of the southwestern US give the observatory more than 300 sunny days a year. The location in the lake 2 km above sea level provides a natural inversion that limits the near-ground effects of atmospheric turbulence. The prevailing westerly winds limit high altitude effects of atmospheric turbulence because the observatory is so close to the Pacific Ocean.

The primary telescope has an aperture of 65 cm and is outfitted with sophisticated instruments to measure the sun's magnetic fields and surface flows. We are presently adding a high-order adaptive optics system. The observatory also takes a leadership role in space weather studies, including monitoring and predicting solar activity and geomagnetic storms that can impact satellites, telecommunications, the power grid and passengers on polar flights.

**Keywords:** Solar Observations and Instrumentation

## Introduction

Big Bear Solar Observatory (BBSO) is located in a mountain lake with over 300 sunny days a year and superb seeing conditions. A picture of the observatory is shown in Figure 1. The telescopes under the dome are shown and described in Figure 2. BBSO is the largest university-based solar observatory in the United States, possibly the world. It carries out as extensive a program of solar observations as any observatory.

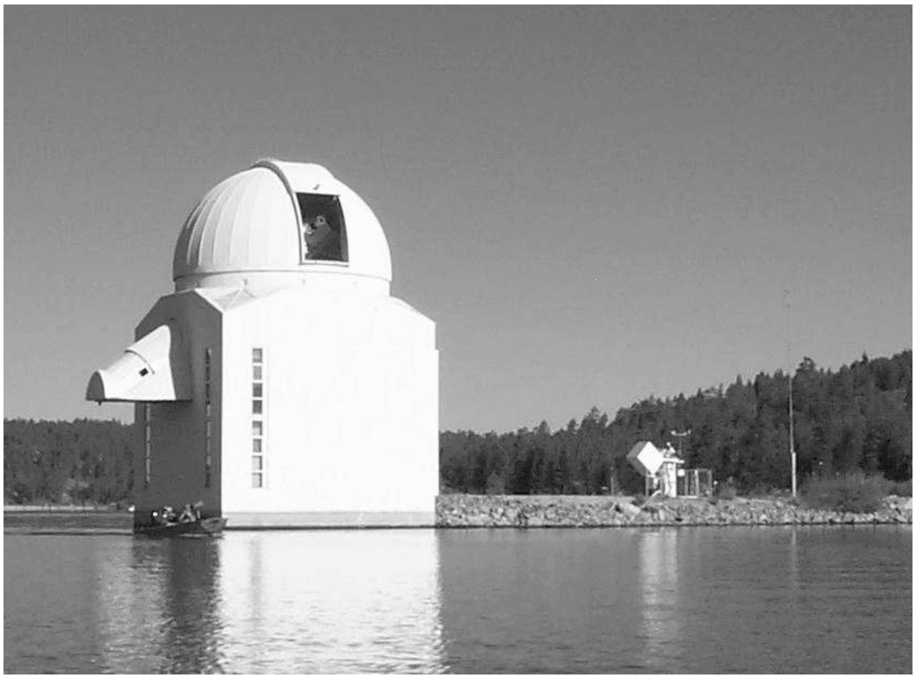

*Figure 1.* Big Bear Solar Observatory

NJIT took over operation of BBSO on July 1, 1997. We have made fundamental changes to the observatory, and our research group has been very productive, as evidenced by over 100 publications in the past four 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 twelve Ph.D. students; three have recently graduated. One earned a faculty position, and the other two work in high tech industry in New Jersey. Generally, each stu-

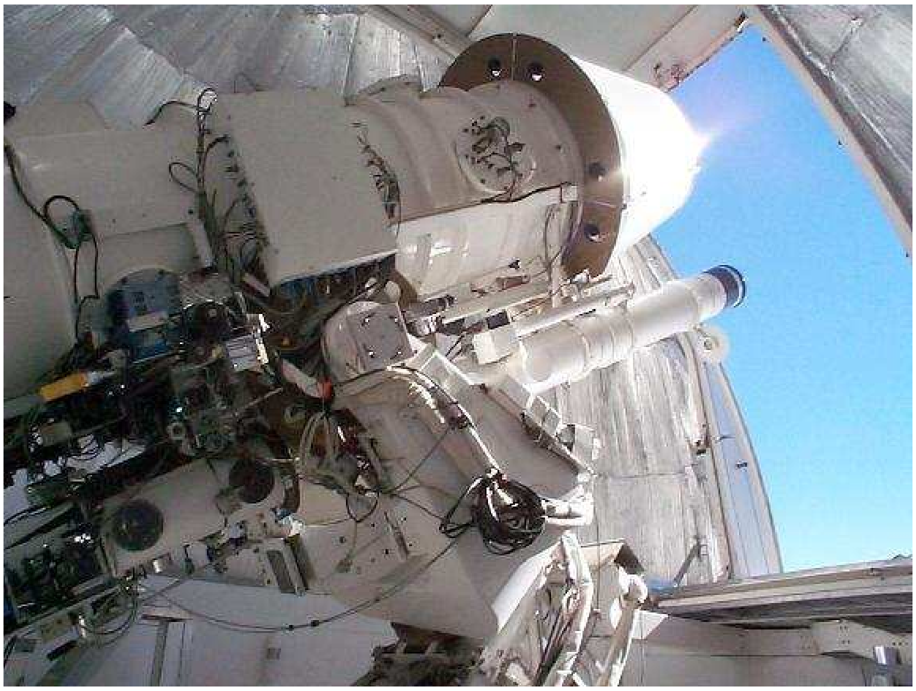

*Figure 2.* The observatory's telescopes are specially designed for solar observations. The top floor of the observatory contains a single fork mount supporting the four main telescopes: a 65 cm (26 inch) reflector, a 25 cm (10 inch), a 20 cm (8 inch), and a 15 cm (6 inch) refractor for Earthshine observations. The telescopes are equipped with highly specialized filters and cameras that isolate small portions of the visible, as well as the near infrared and ultraviolet portions, of the Sun's spectrum.

dent 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; Alexander Nindos, University of Maryland; several from Korea and China; 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. Data requests come to BBSO almost daily 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. High Resolution Observations of the Sun on the 65 cm Telescope

## 1.1 Overview

High resolution observations of the sun are essential to solving many of the outstanding problems of solar astronomy. The current high resolution solar telescopes are in the one meter class. These are limited because the Fried parameter (roughly speaking, the largest aperture telescope that would have diffraction limited seeing) of a good daytime site is about 10 cm. This problem can be partially overcome by post-image processing, like speckle reconstruction and phase diversity (e.g. Paxman et. al. 1999, Keller 1999). However, to get full benefit from existing telescopes, one needs adaptive optics to correct wavefront aberration. The sun is a unique magnetic plasma laboratory from which fundamental advances are tantalizingly within our grasp.

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 BBSO 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. National Solar Observatory (NSO) site surveys (Beckers et al., 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. Over the last four years, we have sharply reduced the dome seeing. 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. 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 real-time speckle reconstruction.

Our major scientific objectives in our high resolution work are:
– understanding the build-up of magnetic stresses in active regions due to complex flows, such as magnetic channels.
– 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 our Fabry-Pérot interferometer to do narrow band reconstructions in strong chromospheric absorption lines, like H$\alpha$ and others, to study small-scale features, like Ellerman bombs.

## 1.2 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 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. We have recently replaced the old videomagnetograph by a Digital Vector Magnetograph (DVMG), which is a much more precised instrument utilizing 12-bit architecture (rather than the 8-bit video system). As a result we obtain more precise magnetograms with far fewer integrations. In Figure 3, 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.

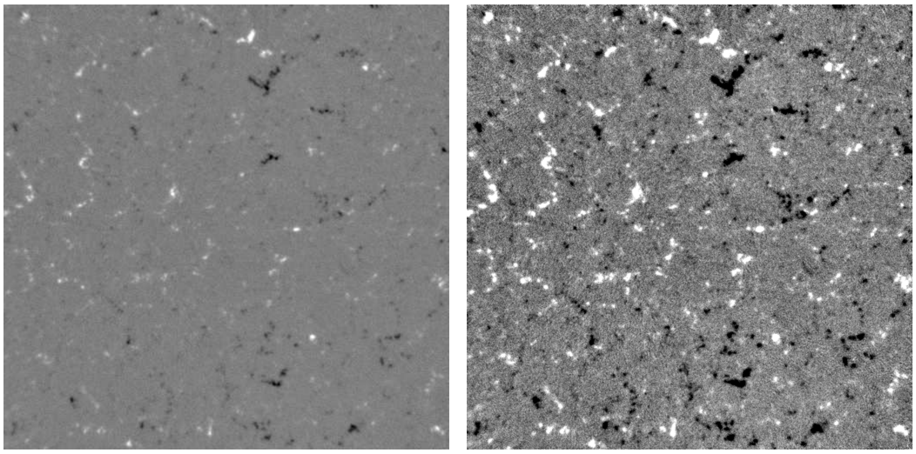

*Figure 3.* Longitudinal magnetograms from 26 April 1999 using the DVMG. The field of view is $235'' \times 235''$ and the cadence is 1 min. The images are scaled between polarizations of $\pm 1.5\%$ (left-panel image) and $\pm 0.3\%$ (right-panel image) to show the intranetwork fields more clearly. 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.

## 1.3 Magnetic Fields and Flare Producing Active Regions

After the upgrade/improvement of several instruments (e.g., the new DVMG and our comparable IR magnetograph system), 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$\times$1K camera. A DVMG vector magnetogram during a flare is shown in Figure 4. Our studies here will concentrate on the following topics:

**1.3.1 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 Huairou

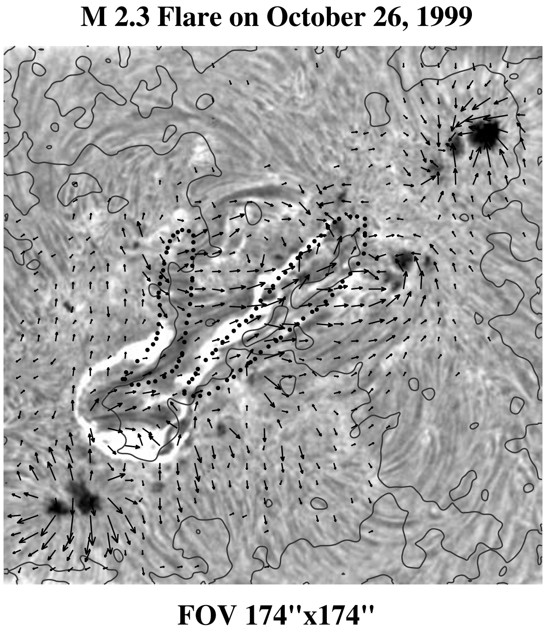


*Figure 4.* A DVMG vector magnetogram from October 26, 1999. The background is an H$\alpha$ image during an M2.6 flare. Arrows indicate the transverse fields, and the thin, solid black lines are the neutral lines of line-of-sight magnetic fields. Strong magnetic shear is clearly visible in the areas near flare ribbons, as encircled by the heavy dotted lines.

Solar Observatory Station (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.

## 1.4 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 planned 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).

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.

## 1.5 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 Solar Maximum Mission (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 the Burst and Transient Source Locator (BATSE) on-board the Compton Gamma Ray Observatory (CGRO) 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 H$\alpha$ 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 5. 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 these observations, but it is dedicated to its valuable mission of serving a broad community of users.

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

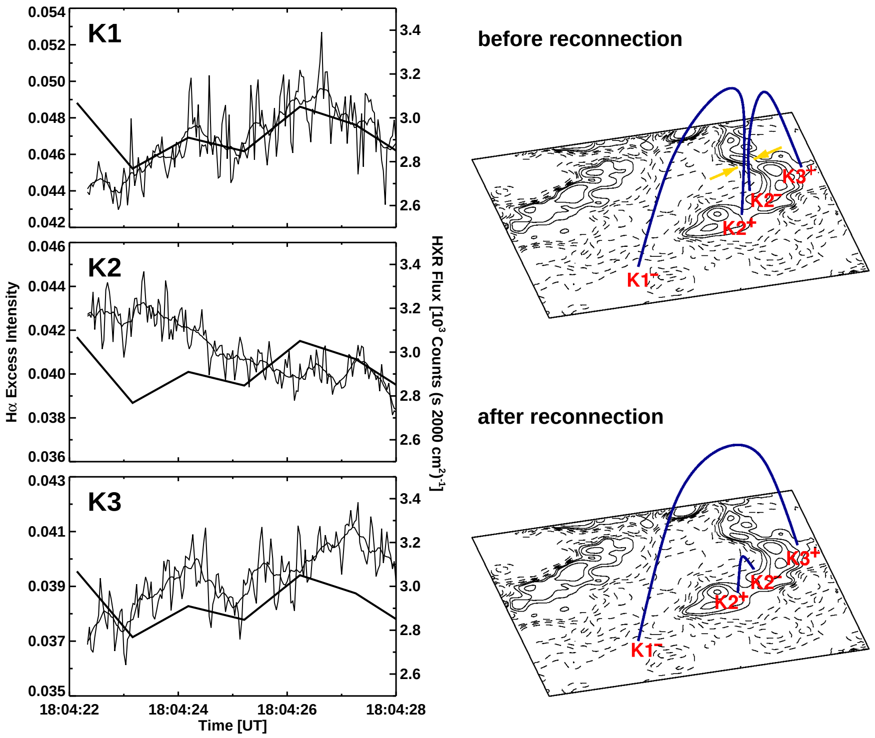


*Figure 5.* In the right panels, three observed flare kernels are shown before and after reconnection. Only K1 shows a good correlation with the hard X-ray flux, as shown in the left panels. The H$\alpha - 1.3$ Å appears in the highly structured lines in K1, K2 and K3. The X-ray flux appears as the slowly 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 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 5 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, $\mathrm{H}\alpha - 1.3\text{Å}$ emission is temporally correlated (92%) with the hard X-ray flux, so it is identified as the site of electron precipitation. Importantly, the $\mathrm{H}\alpha - 1.3\text{Å}$ 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 plan 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.

## 2. Infrared Observations

IR solar astronomy is a science whose time has come because of new camera and filter technologies. BBSO's new IR camera is a $320 \times 240$ InGaAs IR detector. InGaAs is the natural material for studies at 1.6 $\mu$m because it has a 1.6 $\mu$m 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 $\mu$m), so that one can see deeper into the sun at that wavelength. Second, the earth's atmosphere is more benign in the near IR, implying more stable images with greatly reduced effects of seeing.

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.

## 2.1 Broad-Band IR Photometry Near the Sun's Opacity Minimum

Foukal and his colleagues reported that many faculae are dark in the near IR, while they are bright in visible light (see review by Foukal and Morran, 1994). Such a result would sharply constrain models of flux tubes (Spruit, 1976). 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 6 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 will study:

– Granulation: While granular contrast is lower in the IR, the improved seeing in the IR makes up for it (see Figure 6). 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 $\mu$m. 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 pho-

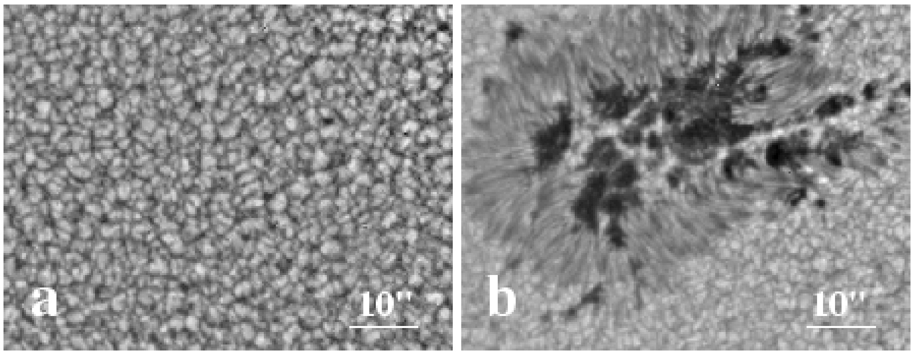


*Figure 6.* Unprocessed, single exposure (0.13 ms) IR images of the quiet sun and a sunspot region, demonstrating our excellent image quality.

tospheric surface (Duvall et al., 1996; Duvall, 1999; Kosovichev, 1999). By comparing with granulation at shorter wavelengths, we can study the height variation of convection.

– 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 $\mu$m (J. Wang et al., 1999). Over the next three years, we plan 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).

## 2.2 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).

## 2.3 Space Weather and 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. In studies of space weather, we need synoptic observations which are contemporaneous with our high resolution observations, such as Figure 4. We require both because the solar phenomena we plan to study may well have a small-scale origin, but also have a large-scale manifestation.

**(a) Full-Disk Observations**

These are the backbone of the synoptic program (Denker et al., 1999). The 2K$\times$2K H$\alpha$ images show the full solar disk 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 H$\alpha$ 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.

**2.3.1 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.

## 3. Near Infrared Filtergraph/Polarimeter

Each new instrument in solar physics is generally a sufficiently small project that it can be viewed a part of a Ph.D. thesis project. To illustrate this, we discuss a unique instrument we are building for BBSO to measure fields in the near infrared.

Photospheric magnetic fields must be measured in order to model the generation and propagation of heliospheric plasma inhomogeneities. Narrow pass band birefringent filters play a very important role in solar magnetographs which measure the strength and direction of magnetic fields on the sun. Currently, most magnetographs operate in the wavelength range of visible light from 400 to 700nm. According to the Zeeman effect, the splitting of a magnetically sensitive line $\Delta\lambda$ is proportional to $g\lambda^2 B$, where $g$ is the Landé factor, $\lambda$ is the wavelength, and $B$ is the magnetic field strength. Usually, large sunspots posses strong magnetic fields in the order of 2000 to 3000 Gauss. However, in other solar features such as plages or small bipoles in filament channels, the magnetic fields are only about 1000 to 1500 Gauss. There are also weak, sub–kilogauss fields in other structures such as the intra–network magnetic fields. The Zeeman splitting induced by a sub–kilogauss field is too small to be measured in the visible spectrum. For example, BBSO's digital magnetograph at the 25 cm vacuum refractor uses the Ca I line at $\lambda = 610.3$ nm with $g = 2$. If $B = 1000$ Gauss then $\Delta\lambda = 4.7 \times 10^{-13} g\lambda^2 B = 3.5$ pm. However, for the near infrared line Fe I 1564.85 nm with $g = 3$ the Zeeman splitting $\Delta\lambda = 35$ pm is about an order of magnitude larger. Therefore, weaker magnetic field strengths can be measured more precisely using near–infrared lines. The use of infrared lines as probes of solar magnetic features has been discussed in detail in Solanki et al. (1992). Since this imaging magnetograph system scans the profile of the infrared Fe I line, it does not have to cope with magnetograph saturation which is frequently encountered in visible light magnetograph system for field strengths above 2000 Gauss.

The imaging magnetograph system is designed for observations in the near–infrared at Fe I 1564.85 nm). The magnetograph consists of an interference prefilter, a polarization analyzer, a wavelength–tunable birefringent filter and a wavelength–tunable Fabry–Pérot filter. This system is expected to achieve a clean narrow pass band of 11.3 pm. It can be tuned across a spectral line to obtain line profiles of two–dimensional field of view. The FWHM of the interference prefilter is about 3 nm it is followed by an innovative Lyot–filter for near–infrared observations (Wang et al. 2001) designed by Jingshan Wang (NJIT Ph.D. student). The FWHM of the Lyot–filter is .25 nm Finally, a Fabry–Pérot filter manufactured by Queensgate Instruments restricts the pass band to 113 mÅ. It has a clear aperture of 70 mm, the free spectral range is .52 nm, the finesse is about 50, and the transmission is expected to be better than 75%. One of the design goals for this magnetograph system is high light throughput without sacrificing spatial resolution. The maximum field–of–view of BBSO's 65 cm telescope is $240'' \times 240''$. The diffraction limit at 15,64.85 nm is $0.5''$. Therefore, we need a camera with a large format, $1,024 \times 1,024$ pixel detector to exploit the capabilities of the 65 cm telescope. Currently, we us a near–infrared InGaAs CCD camera manufactured by Sensors Unlimited. The images are digitized at 12–bit and have $320 \times 240$ pixels. The quantum efficiency of the camera is about 90% in the wavelength range from 1000 to 1700 nm. Even though we obtained many scientifically interesting results with this camera system, it has several drawbacks: small format, high dark counts, and a moderate signal–to–noise ratio. So we are replacing this camera with one having the larger format.

This system will enable us to polarimetry in the near IR with the same tried-and-true techniques used in visible light, rather than resorting to more complicated, less-reliable mixtures of twin Fabry-Pérots, and the like.

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