Next Generation Synoptic Telescope for Innovative Space Weather Research
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A Abstract

The Big Bear Solar Observatory (BBSO) is the only site that provides consistent and extended periods of good seeing from sunrise to sunset, which are required for combined high-resolution and synoptic observations to make sustained measurements of solar activity and its effects on the Sun-Earth system. We propose to build a next generation synoptic telescope – the Solar Activity Monitor (SAM), which is based on the design of the Swedish Solar Telescope (SST) – the World's most capable telescope for high-resolution studies of the Sun. Stockholms Digitalmekanik, the manufacturer of the SST, is marketing a miniature, cost-efficient version of the SST with an aperture of 25 cm, which is ideally suited for a synoptic telescope. We will use this instrument for our synoptic full-disk Hα and full-disk vector magnetic field observations. The new telescope will replace and extend the capabilities of the current Singer full-disk and 25 cm telescopes, which can no longer be operated with the advent of the New Solar Telescope (NST) at BBSO in mid-2006. Much of the scientific instrumentation of the synoptic telescopes can still be used and upgraded. The SAM telescope will be designed as a stand-alone telescope ensuring flexibility throughout its projected 20-year life-time. The science instruments are building blocks that can be added or removed to serve future science requirements. The NST is a 1.6-meter aperture telescope for high-resolution studies of the Sun. These instrumentation efforts – in high-resolution as well as in synoptic studies – will ensure and enhance BBSO's scientific productivity and help to maintain its leadership position in ground-based solar physics and space weather science. Most importantly, BBSO can continue to provide the community the most useful data sets for space weather forecasting, while beginning to provide the tools for the next generation of space weather forecasting.

B Summary Proposal Budget

The instrument budget is summarized in the following tables. The prices are either based on vendor price quotes provided or were taken from catalogues and price lists of the vendors. In addition, smaller items such as mounting plates, clamps, and other minor opto-mechanical components are not separately listed.

Description	**Total**
25 cm Turret Telescope ROM Price: 1,000,000 Swedish Kronas	$131,400.00
Total	**$131,400.00**

25 cm Turret Telescope: Stockholms Digitalmekanik AB, Johan Pettersson, Nordenflychtsvägen 64, SE-11251 Stockholm, Sweden, Phone: 011 46 8 618 16 42, Fax: 011 46 8 618 49 08, and WWW: http://www.digitalmekanik.se

Description	**Quantity**	**Cost**	**Total**
20’ Insulated Shipping Container	1	$4,000.00	$4,000.00
A/C and Heating	1	$2,000.00	$2,000.00
Man Door	1	$750.00	$750.00
Paint	1	$425.00	$425.00
Estimated Delivery/Pickup	1	$550.00	$550.00
Total			**$7,725.00**

Instrument Shelter: On-Site Storage-Solutions, Abi Feseha, Phone: (888) 667-4834 or (310) 836-6150, Fax: (310) 861-8600, and WWW: http://www.onsitestorage.com

Description	**Cost**
San Bernardino County Land Use Review	$2,000.00
Architectural Design	$2,000.00
2-Meter Diameter Concrete Pipes	$1,000.00
Concrete Foundations	$5,000.00
Steel Reinforcements	$3,000.00
Paint	$500.00
Installation	$8,000.00
Total	**$21,500.00**

Telescope Support Structure: Mapco, P. O. Box 1962, Big Bear City, CA 92314 – Zaharias Construction, P. O. Box 2644, Big Bear City, CA 92314

Description	**Company**	**Quantity**	**Cost**	**Total**
Objective Lens, $D = 250$ mm	Nu-Tek	\$12,000.00	1	\$12,000.00
Achromat	Nu-Tek	\$2,000.00	1	\$2,000.00
Plane Mirror Substrate, Zerodur, $D = 350$ mm	Bernhard Halle	\$5,000.00	2	\$10,600.00
Protective Aluminium Coating	Bernhard Halle	\$750.00	2	\$1,500.00
Optical Table, 5 ft. $\times$ 8 ft.	Newport	\$6,000.00	2	\$12,000.00
Opto-Mechanical Components	Newport	\$5,000.00		\$5,000.00
Grand Total				**\$42,500.00**

Opto-Mechanical Components: Nu-Tek Precision Optical Corporation, 1202 Technology Drive Suites L-P, Aberdeen, MD 21001, Phone: (410) 273-7070, Fax: (410) 273-7618 FAX, and WWW: http://www.nu-tek-optics.com – Bernhard Halle Nachfl. GmbH, Hubertusstrasse 10, D-12163 Berlin, Germany, Phone: (011) 49-30-7974296-0, Fax: (011) 49-30-7918527, and WWW: http://www.b-halle.de – Newport Corporation, 1791 Deere Avenue Irvine, CA 92606, Phone: (949) 863-3144 Fax: (949) 253-1680, and WWW: http://www.newport.com

The total cost for the SAM Project is $203,125.

C Project Description

The scientific productivity of Big Bear Solar Observatory (BBSO) has its foundation in a combination of high-spatial resolution and synoptic observations. Since New Jersey Institute of Technology (NJIT) took over operation of BBSO on 1 July 1997, more than 275 "Blue Books" have been released in the BBSO preprint series and the majority of them was published in peer-reviewed journals. The Solar Activity Monitor (SAM) will complement BBSO's efforts in high-resolution studies of the Sun. The 1.6-meter, off-axis, New Solar Telescope (NST) will become operational in late 2006 (Goode et al. 2003), and the proposed SAM will leverage those investments in high-resolution observation and enable new scientific discoveries, while ensuring the continuation of on-going synoptic research programs. The SAM is an innovative instrument that will greatly improve the BBSO synoptic observing program at BBSO. Without this instrument, the synoptic observing program at BBSO ceases to exist. SAM offers a variety of features exceeding the capabilities of the existing synoptic telescopes such as higher temporal resolution, spectral line scans, Hα dopplergrams, full-disk vector magnetograms, frame selection to achieve higher and consistent image quality, automated operation, increased duty cycle, and a streamlined data pipeline providing well-defined data products for space weather forecast and solar activity research.

C.1 Scientific Motivation

The principal high-precision, synoptic photometry effort at BBSO is focused on the evolution and dynamics of solar active regions with full-disk Hα observations and $300'' \times 300''$ field-of-view vector magnetograms. Our proposed new instrument will provide both full-disk Hα and full-disk vector magnetograms.

Currently, BBSO operates its 15 cm aperture Singer refracting telescope that takes high-cadence, high-resolution, full-disk Hα images (Denker et al. 1998) and is part of the Global Hα Network (GHN, Steinegger et al. 2001a) that BBSO established. The scientific objectives of the Hα full-disk observations include, among others, flare patrol, active region evolution, chromospheric differential rotation (Smith et al. 2003, Steinegger et al. 2001b), and space weather forecasting and predictions (Gallagher et al. 2001). In combination with space and ground-based observations, Hα full-disk observations of high temporal and spatial resolution have been proven to be a key diagnostic to determine the magnetic field topology between the photosphere, chromosphere, transition region, and corona. Hα full-disk observations provide a unique tool for studying the structure of the chromosphere. Round-the-clock high-resolution full-disk Hα data are extremely important for studying the correlation between filament disappearances/eruptions and Coronal Mass Ejections (CMEs) and for understanding the possible driving mechanisms.

BBSO also operates a 25 cm refracting telescope that takes vector magnetograms with a field-of-view of $300'' \times 300''$. The device is the Digital Vector Magnetograph (DVMG, Spirock et al. 2001). Both the 15 cm and 25 cm telescopes will be replaced by the SAM, which will also include a full-disk vector magnetograph system based on the DVMG and utilizing its hardware. Full-disk magnetograms are most useful in space weather studies, while we will construct ultra-high resolution magnetograms by observing with the NST. This combination of high and ultra-high resolution magnetograms coupled with full-disk Hα observations will present a formidable array of instrumentation to attack the problem of understanding space weather.

The SAM data products will enhance our understanding of the Sun-Earth system and assist in forecasting space weather. Solar storms can affect millions of people and endanger technological assets both in space and on the ground. Examples include the computer and memory upsets on satellites, threats to the safety of astronauts, increased exposure to radiation of airline passengers and crew members, disturbance of radio waves and telecommunications, and disruptions of the electricity grid. The SAM Hα full-disk telescope will replace BBSO's Singer full-disk telescope, which has been the "work horse" of BBSO's synoptic observing program. The Singer telescope has probably been the most productive synoptic instrument in the context of space weather studies.

Hα full-disk images (see Figure 1) contain a multitude of features such as prominences, filaments, flares, spicules and macro-spicules, plages, and fibrils. Filaments and flares are high-contrast features, which makes them easy to detect. Automated image processing is rapidly evolving in solar physics, especially considering the large volume. Based on BBSO Hα data, Qu et al. (2004) developed an automatic flare detection system using Support Vector Machines (SVMs), which not only detects the onset of a flare but also derives higher order data products such as the separation speed and direction of flare ribbons, flare area, and the magnetic reconnection rate in terms of the electric field. This work is currently extended and applied at BBSO to filaments and filament disappearances (Qu et al. 2005). Both applications rely on well calibrated, high-cadence, and high-spatial resolution Hα full-disk images. It is the explicit goal of the GHN to obtain this type of data. The SAM will be the only instrument in North/South America that fulfills these requirements. The Synoptic Optical Long-Term Investigations of the Sun (SOLIS, Keller et al. 2003a) and ISOON have similar capabilities but they are not typically used in high-cadence mode and the seeing conditions favor BBSO. The SAM will have a well established data pipeline and scientific support for feature recognition, the derivation of flow maps, and space weather forecasting capabilities. Without the SAM, the GHN would experience a 8–10 hour data gap in its duty cycle. Space weather studies and forecast would be severely impacted. Furthermore, in tandem with the NST, the SAM can uniquely exploit the synergies between high-resolution and synoptic solar observations. The observing modes of both instruments can be adapted on-site for any particular research program. This flexibility cannot be expected from an facility-class instrument such as SOLIS with its broad and disparate user community.

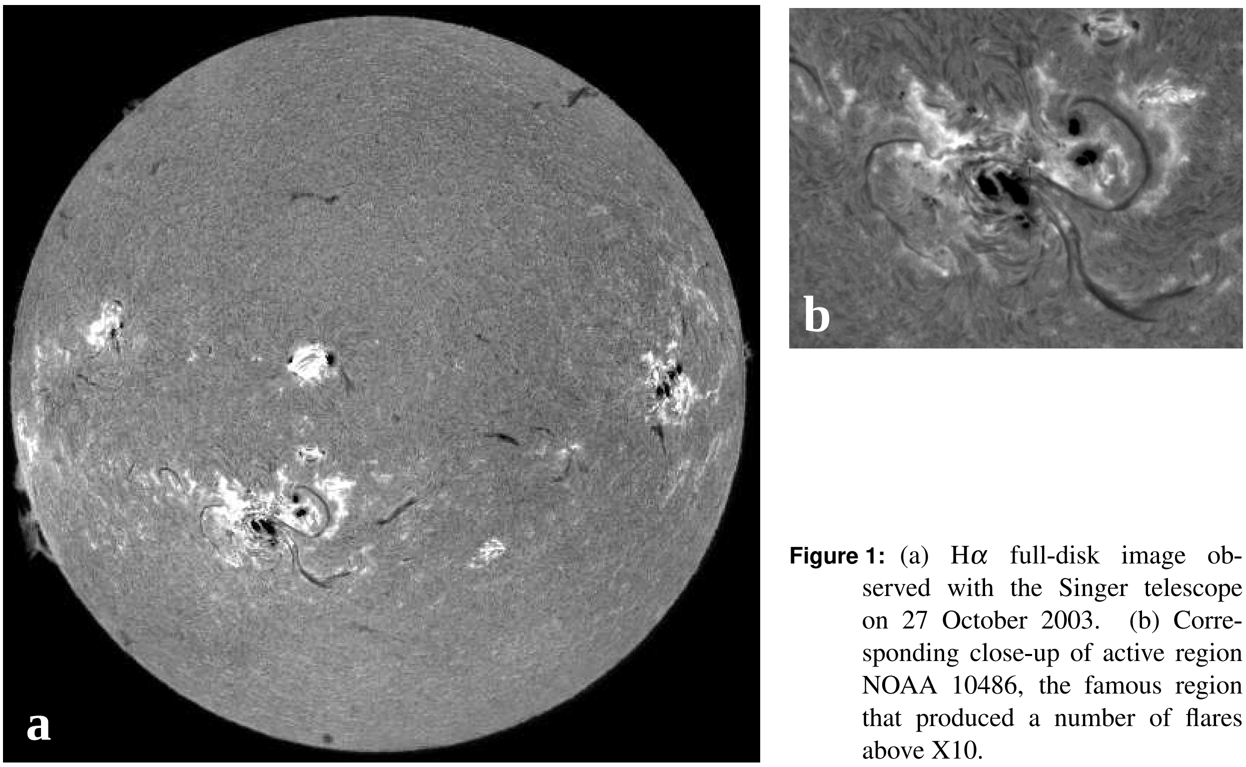

Figure 1: (a) Hα full-disk image observed with the Singer telescope on 27 October 2003. (b) Corresponding close-up of active region NOAA 10486, the famous region that produced a number of flares above X10.

One overarching topic in space weather studies is to find a comprehensive picture of the relation among filament eruptions, flares, and CMEs. Jing et al. (2004) performed a statistical study of 106 filament eruptions, which were automatically detected by a pattern recognition program analyzing BBSO Hα full-disk data from 1999 to 2003. This work produced the most complete filament disappearance catalogue thus far. Jing et al. (2004) also derived the sign of magnetic helicity and the orientation of the magnetic field associated with seven halo CMEs. They could then demonstrate that the geo-effectiveness of a halo CME can be predicted based on these two parameters.

We have found that a substantial fraction of filaments are undergoing lateral oscillation (Jing et al. 2003). We have investigated their excitation and damping. Based on the oscillation period, we can derive their magnetic topology. Using Hα data, we will expand our study to a large sample of events as they are observed, and in particular, understand the oscillation and the relation to the activation/eruption of filaments.

With the SAM, we will continue to combine Hα data with full-disk magnetograms, but now the latter will be vector fields from from BBSO, as well as continuing to be line-of-sight magnetograms from the Michelson Doppler Imager (MDI) and the Global Oscillation Network Group (GONG). Our purpose here is to analyze the magnetic configuration of erupting filaments and overlying arcades and compare with structure of interplanetary magnetic clouds as derived from the Advanced Composition Explorer (ACE) magnetometer data. Based on the limited cases that we have studied so far, we found evidence of a correlation between the orientation of the overlying arcade field and that of magnetic clouds (Yurchyshyn et al. 2001, 2003). This enables the real-time prediction of the geoeffectiveness of earth directed CMEs.

Large-format Hα full-disk images are extremely useful for flare studies and investigations of other explosive or eruptive events, especially when combined with high-spatial resolution and space data. Yurchyshyn et al. (2004), for example, examined the 2002 July 23 γ-ray flare in a multi-wavelength study of γ-rays, X-rays, and visible light. Based on Hα data and high-resolution magnetic field observations, they could explain the spatial displacement between γ-ray and hard X-ray sources as interactions between the erupting field and an overlying large-scale coronal field. Another example of combined high-resolution and synoptic observations has been presented by Moon et al. (2002), who observed homologous flares in an active region NOAA 8100. Computing the magnetic helicity injection rate due to photospheric shear motions, they could show that magnetic helicity injection was responsible for triggering the homologous flares, since the injection rate peaked exactly at the same time as the X-ray flux.

While NST provides very high resolution ($0.1''$) observations, our $1.0''$ resolution Hα synoptic observations will be complementary to the NST observations. Recently Yang et al. (2004) analyzed a time series of diffraction-limited white-light data prior to an X10 white-light flare on 29 October 2003. Local correlation tracking was used to measure photospheric proper motions. We find specific evidence of strong shear flows along the magnetic neutral line. These shear flows are well-defined and correlated with white-light flare kernels in the visible and infrared. Although the original data has the resolution of $0.1''$, the derived flow maps have a resolution comparable to Hα images, i.e., about $1.0''$. Hα time sequence data can be used to compare chromospheric dynamics with photospheric flows in flaring region and below erupting filaments.

Comprehensive studies of vector magnetic fields associated with flares, filament eruptions and CMEs, would help us understand the triggering of the events and the evolution of the magnetic topology. Therefore, as discussed, the SAM will include a full-disk vector magnetograph based on the DVMG system that is currently operated at BBSO.

One of the important results from BBSO obtained during the solar maximum of the early 1990's is the finding that the photospheric magnetic field shear may increase after solar flares (Wang 1992, Wang et al. 1994). Magnetic shear is defined as the difference between measured fields and potential fields. This finding is not inconsistent with the principle of conservation of energy, because the energy is stored in the full three-dimensional space running from the photosphere to the corona. In the last few years, the BBSO DVMG system allowed us to find some curious results: rapid and permanent flux changes after all eight X-class flares studied by us (Spirock et al. 2002, Wang et al. 2002). Very recently, we made another important discovery: a part of penumbral segments in the outer δ-spot structure decays rapidly after major flares. Meanwhile, the neighboring umbral cores and/or inner penumbral regions become darker (Wang et al. 2004, Liu et al. 2005). The MDI magnetograms confirmed this change of the magnetic topology associated with penumbral decay and RHESSI observations demonstrated that these sudden magnetic structure changes were spatially and temporally associated with the flare. The proposed new magnetograph system will remain to be the unique instrument to study the evolution of magnetic fields with a one minute cadence and a one arcsec resolution.

Hα data can be combined with NST magnetograms and RHESSI X-ray data to carry out statistical studies of micro-flares. RHESSI found many small events (probably thermal) that occurred in the range from 1 to 30 keV. The proposed Hα system would have a cadence of less than 10 s. We will identify a large number of RHESSI events from Hα observations, and obtain/classify their magnetic configuration (Liu et al. 2004). This will contribute to the solution of the long-standing coronal heating problem.

In addition, BBSO will follow complicated active regions to study magnetic topology, shear, and the electric current system. These observations will be coordinated observations with the Huairou Solar Observing Station (HSO) in China to improve the daily coverage. We have been jointly observing magnetic fields with HSO for several years, and obtain 22 hour coverage in the summer. Space data (such as SoHO and TRACE for now, and the Solar Dynamics Observatory (SDO) in the near future) will be combined with BBSO data to obtain the three-dimensional structure of magnetic loops.

In summary, the SAM will be an extremely versatile instrument for space weather studies, guide the NST target selection, provide the context to interpret high-spatial resolution observations, and provide the chromospheric link between photospheric and coronal observations both from ground and space.

- ❖ The scientific objectives of the synoptic observing program are focussed on solar activity, e.g., the relationship among flares, filament eruptions, and Coronal Mass Ejections (CMEs).
- ❖ The SAM will benefit the solar physics and space science communities and provide data to a diverse group of users in science, industry, and education.
- ❖ Long-term observations of solar activity are required to provide the context and framework for high-spatial resolution observations.
- ❖ Advances in technology and image processing encourage us to continuously improve and even replace our synoptic facilities while ensuring the continuity of the synoptic research objectives.

C.2 Site Considerations

BBSO exploits the excellent climatic conditions of Big Bear Lake in California to study the Sun. The observatory is located in the middle of Big Bear Lake to reduce the image distortion because the lake provides a natural inversion. At a mountain site, the Sun heats the ground and produces convection in the air just above the ground. Turbulent motions in the air near the BBSO observatory are also reduced by the smooth flow of the wind across the lake with its temperature inversion, instead of the turbulent flow that occurs over mountain peaks and forests. These conditions, combined with the usually cloudless skies over Big Bear Lake and the clarity of the air at 2,000 meters (6,750 feet) elevation, make the observatory a premier site for solar observations.

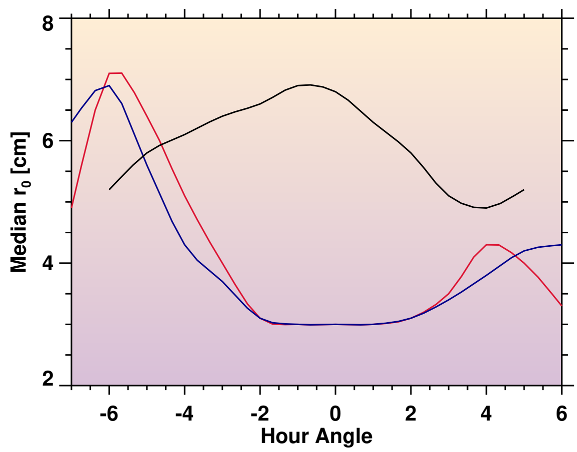

Figure 2: The median value of the r_0 measurements from the S-DIMM instrument at the three sites (**Big Bear**, **Haleakala**, and **La Palma**) as a function of hour angle (adapted from Figure 10.13 in Hill et al. 2004a).

The Advanced Technology Solar Telescope (ATST) site survey was initiated in 2000 and has identified at the end of a four-year survey three excellent sites for solar observing: Big Bear Solar Observatory, California – Mees Solar Observatory, Haleakala, Maui, Hawaii – Observatorio Roque de los Muchachos, La Palma, Canary Islands, Spain (Hill et al. 2004a). All three sites are suitable for high-spatial resolution observations. Haleakala and La Palma have strong advantages for coronal science. However, only BBSO – the mountain-lake site – provides consistently very good seeing conditions with extended periods of excellent seeing from sunrise to sunset (see Figure 2). Periods of excellent seeing are limited to one or two hours in the early morning for the pacific/atlantic mountain-island sites Haleakala/La Palma, where the seeing deteriorates once the ground heats up and a turbulent boundary layer has been established. The lake at BBSO effectively suppresses this boundary layer and makes the observatory ideally suited for high-resolution and synoptic observing programs.

In Table 1, we present some results of the ATST site survey. The ATST clear time fraction (CTF) of over 70% is comparable to the results of the GONG site survey (Hill et al. 1994) and corresponds to more than 3000 annual clear hours for scientific observation. This corresponds to about eight hours of observing time per day, which is essential for synoptic observations of solar activity. The seeing data in Table 1 is based on measurements of the Solar Differential Image Motion Monitor (S-DIMM, Beckers 2001).

	BBSO	**Haleakala**	**La Palma**
Median r_0 [cm]	6.04	3.53	3.42
Annual hours $r_0 > 7$ cm	856	389	313
2-hr blocks $r_0 > 7$ cm per year	62	15	14
CTF ATST	0.712	0.619	0.639
Annual clear hours	3120	2710	2800
CTF GONG (Teide for La Palma)	0.714	0.647	0.708
Median wind speed [m/s]	4.7	4.5	3.6

Table 1: Seeing characteristics at BBSO, Haleakala, and La Palma (see Tables 1 and 2 in Hill et al. 2004a).

In night-time astronomy DIMMs have been the standard tool to measure the Fried-parameter r_0 for over a decade. Two apertures are placed in front of telescope and r_0 is derived from the differential motion between two images of the same star. Since the Sun is an extended object, a slit is placed across the solar limb, which limits the differential motion measurement of S-DIMM to one dimension. Otherwise, the basic principles are the same and well understood. S-DIMM measures the total value of r_0 integrated from the observing height at eight meters to the top of the atmosphere with no height weighting of the structure constant of the index of refraction fluctuations $C_n^2(h)$. In a more applied sense, the Fried-parameter corresponds to the largest aperture of a telescope that would just be diffraction limited. In solar physics, seeing conditions with a Fried-parameter $r_0 > 7.0$ cm are considered excellent. The aperture of SAM will be placed at about the same height as S-DIMM. Therefore, the S-DIMM measurements are directly applicable without any height extrapolation of the seeing measurements.

Based on the median seeing of $r_0 \approx 6$ cm, SAM will routinely achieve $2''$ spatial resolution and $1''$ during extended period of excellent seeing conditions. Therefore, we will ultimately require a large-format, 4k $\times$ 4k pixel detector for the SAM Hα channel.

C.3 The Solar Activity Monitor Telescope

The SAM is a 25 cm telescope with an unobscured aperture based on the SST design (see Scharmer et al. 2002 for a detailed description of the SST design) and will be manufactured by Stockholms Digitalmekanik in Sweden, who also manufactured the original 0.97-meter SST. The first optical element of the SAM is a doublet lens, which also acts a vacuum window. The lens material is fused silica or lead doped materials to minimize the stress birefringence, which is no longer negligible for such large and thick optical elements. Thus, enabling more precise polarimetry. Most of the optical elements are enclosed in a vacuum tank to avoid instrument seeing. Two optical systems follow the doublet lens. A field lens has to be introduced to provide good performance in the primary focal plane, if the entire visible range should be observed. However, the optical design in Figure 4 has been carried out only for the design wavelength 610.3 nm and

656.3 nm. In this case, the optimized doublet already produces a diffraction limited image. This proof-of-concept design will further be improved, if the project is funded. Another achromat provides a pupil plane with the primary focal plane at infinity. This design allows the integration of a correlation tracker (tip-tilt correction) and an Adaptive Optics (AO) system at a later stage of the project. The pupil and primary image planes are easily accessible in this optical design. Filter wheels with pupil mask, field stops, pinholes, target plates, and other calibration devices could be inserted increasing the versatility of the instrument. What would be the active and adaptive mirrors are now the fold mirrors of the system bending the vertical light path coming from the turret to a horizontal path into the instrumentation shelter. In Figure 3, we show schematic sketches of the turret design including the singlet lens and the two flat folding mirrors. We are currently discussing with Stockholms Digitalmekanik the best choice for the optical design. The design challenges are related to the angle of incidence of the Lyot filters and the diffraction limited performance across the full FOV. However, when we upgrade to active/adaptive optics, it should be noted that even for 4k $\times$ 4k pixel detector for full-disk observations, we would undersample the spatial resolution by a factor of two at the diffraction limit. It should be noted that the SAM telescope does not have any obscuration of the pupil, i.e., straylight is minimized, which could be further improved by a Lyot-stop in the pupil plane. In this configuration, the SAM would be an ideal for Earthshine observations (Pallé et al. 2004), which are routinely carried out at BBSO.

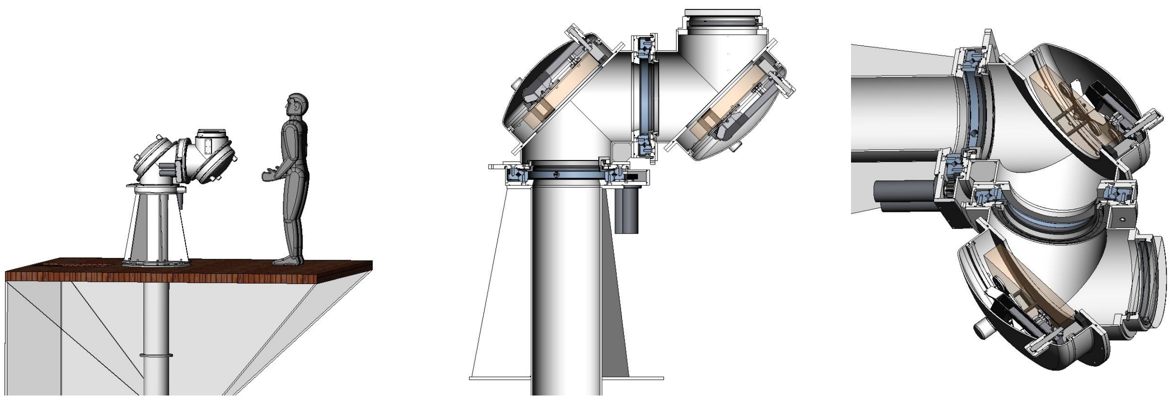

Figure 3: Schematic diagrams of the SAM turret design.

The current synoptic telescopes were attached to the same equatorial mount as the 65 cm vacuum reflector. At the end of the design study for the NST, it became clear that such an approach would not be feasible. Another approach of mounting a turret to the southern exterior wall of the observatory building was also rejected due mechanical difficulties and relatively high costs. The most cost effective solution is the relocation of the instrument onto the causeway that connects the observatory island with the north shore of Big Bear Lake. We selected the previous site of the Taiwan Oscillation Network (TON) shown in Figure 5. We can make use of the TON foundation to erect the 5-meter high telescope support stand build from two segments of prefabricated reinforced concrete drainage pipe with a 2-meter diameter. The concrete segments are attached to the foundation by a framework of steel I-beams. The turret adds another meter to the height of the telescope aperture, which will be sufficiently high to see the Sun at noon above the observatory building even in the winter months. Thus, unobscured observations are enabled from sunrise to sunset. The optical instruments will be located in a modified 20 ft $\times$ 8 ft cargo container (for the location see area outlined by the yellow caution tape in Figure 5). This is the same type of instrument enclosure that has bee successfully used for the GONG telescopes. The cargo containers will be painted with TiO_2 paint to minimize the heat load in the summer months. The walls are insulated and a heating and air conditioning system will keep the instrument environment at a constant 20° C. All optical elements will be mounted on an optical bread-board table with its own foundation to minimize effects of vibrations.

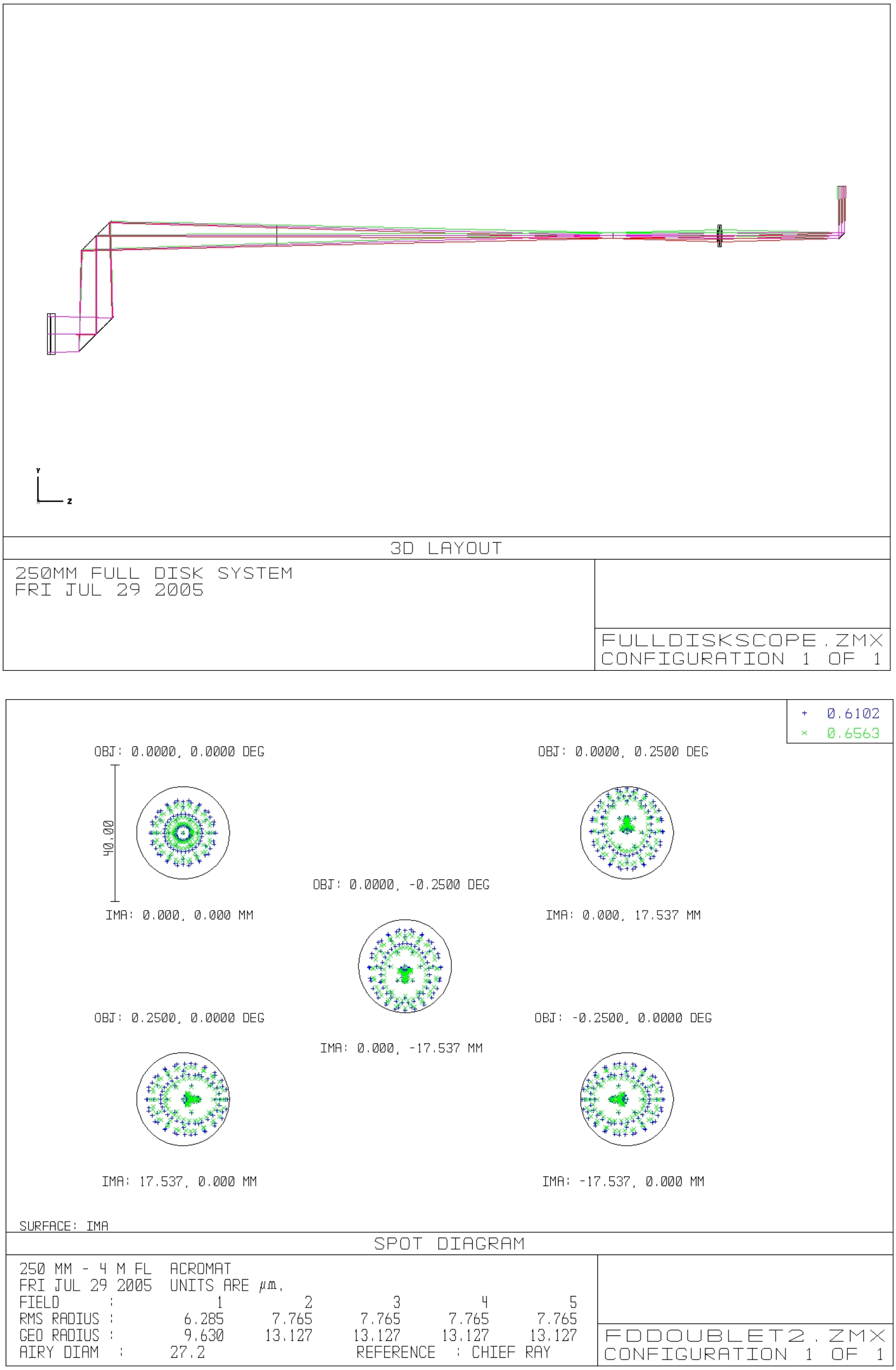

Figure 4: Zeemax sketches of the SAM optical layout and spot diagram.

During rain or snow, the telescope control software will move the entrance window into a secure position. The telescope is using a turret system, which allows for a very compact instrument envelope. Simplicity is one of the SAM design goals. Many of the optical and mechanical components are readily available. Since the responsibilities of the BBSO observing staff will increase with the advent of the NST, care has to be taken in the SAM design to keep the operational efforts and maintenance costs low. In addition, we will benefit from the development of the NST telescope control system, which will provide many modules that can be adapted to automatically control the synoptic instrument suite. Much of the hardware and software is based on industry standards, which makes system migration simple, adds reliability, and provides future upgrade paths to stay in sync with technological advances.

Figure 5: Proposed location of the Solar Activity Monitor (SAM) on the causeway to the north of the observatory building. The yellow caution tape outlines a 20 ft $\times$ 8 ft rectangle corresponding to the size of a small cargo container that will house the optical instruments.

An automated telescope has to keep track of a variety of instrumental and local parameters such as voltages and currents of drive motors, inside and outside temperature, wind speed and direction, etc. Some of the information can be gathered from the comprehensive NST thermal control system. Other information has to be recorded by the SAM control system. Again, we will make use of the NST design efforts to track telescope parameters and performance. All instrumental and local parameters are collected in a data base to optimize instrument performance and debug potential operational problems. In addition, the telescope control software includes provisions for event-triggered operation, remote-control, and autonomous operation, which will enhance our capabilities in campaign-style observations with multiple ground- and space-based observatories.

In the following sections, we discuss the performance of the SAM and discuss a variety of instrument specifications including photometric accuracy – spatial, temporal, and spectral resolving power – reliability and stability of the instrument – data acquisition rates – expected data volume – flexibility of operation – science applications – user-friendliness and data access – and cost of acquisition, operation, and maintenance.

SAM Specifications:

- ❖ 25 cm effective aperture for high-cadence and large-format full-disk images and full-disk vector magnetograms.
- ❖ Small instrument envelope due to a compact turret design.
- ❖ The telescope is sufficiently flexible to allow future upgrades.
- ❖ The SAM will maintain and expand a decade-long record of full-disk observations at BBSO.
- ❖ Vector magnetograms with spatial resolution (before AO and camera upgrades) of $2.0''$ to complement the Hα (and other) full-disk observations and provide a comprehensive data set for space weather research and forecasting.
- ❖ The SAM will serve a large user community in solar physics and space science, and we will increase and simplify the access to the scientific data products.

C.4 Hα Full-Disk Imager

The first building block of the SAM is an Hα full-disk imager based on the experience of the very successful Singer full-disk telescope (Denker et al. 1998). The SAM telescope will deliver a well-defined focal plane and pupil image, which are the staring points for any subsequent scientific instrument. Thus, allowing for flexibility in the optical set-ups and providing an easy upgrade path for the life-time of the instrument.

The Hα Lyot filter that is currently being used will be replaced with a Zeiss Lyot filter that has been thus far reserved for high-spatial resolution observations on the 65 cm vacuum reflector. This Zeiss filter is computer controlled and enables automated spectral line scans. A bandpass of 0.05 nm or 0.025 nm can be selected depending on the research program. This leads to a moderate spectral resolution of about $\Delta\lambda/\lambda \approx 25,000$. The transmission Zeiss Lyot filter is about 30% higher compared to the old system. The transmission will be further improved by about 40% using a narrow band (0.5 nm) ion-assisted deposition interference filter manufactured by Barr Associates as the prefilter for the birefringent filter. The bandpass of the prefilter is sufficiently narrow to suppress false light but wide enough to permit line wing measurements.

The improved transmission characteristics of the filter system, the larger aperture of the telescope, and a better quantum efficiency of the CCD camera system ultimately will lead the way toward a large-format, 4k $\times$ 4k pixel detector. The exposure times will be similar to the existing system corresponding to about 40 ms at Hα line center. High-cadence full-disk observations with a $1''$ spatial resolution will be the corner stone of BBSO's new synoptic observing program. Since the expected cadence for the synoptic observations is about one image every minute or one image every 10 seconds for flare studies, a data acquisition rate of one frame per second is adequate. This eliminates the search for fast frame rate CCD cameras and allows us to choose science-grade, large format CCD camera systems marketed for the high-end amateur astronomy market. These camera systems are extremely cost-effective and have a variety of characteristics that makes them ideally suited for synoptic solar observations. These detectors are commercially available for about $40,000 (see the Alta U16 system from Apogee, http://www.ccd.com). However, at this time we will use our existing 2k $\times$ 2k pixel CCD camera system to keep the cost of the project reasonable without sacrificing substantial parts of our science program.

The most challenging design problem is the small entrance aperture (30 mm) of the Zeiss Hα Lyot filter, since we want to image a relatively large FOV of $0.6^\circ \times 0.6^\circ$ encompassing the whole Sun with good image quality. However, it should be noted that the diffraction-limited resolution of the Hα telescope is somewhat smaller than the image scale for the 4k $\times$ 4k pixel detector. Nonetheless, the SAM is a diffraction-limited telescope, and full advantage of this would come from adaptive optics and larger format cameras. To carefully consider the other possible problems arising from the Zeiss filter, we note that there is another problem resulting from the variation of the passband with the angle of incidence across the filter. The beam has to be slow enough so that the change in retardation compared to normally incidence rays will not affect the 0.025 nm passband of the Lyot filter. Some of these problems can be mitigated by a field lens, which is inserted in front of the focal plane of the Zeiss filter in a telecentric configuration. A specially designed Cooke triplet can then be used to remove the remaining abberations, i.e., first-order longitudinal and lateral color, and the five monochromatic third-order Seidel aberrations (Smith 1990). The chromatic abberations are not that important for the Hα channel and the the corresponding degrees of freedom can be used to improve the lens design for the monochromatic abberations. Another option would be an intermediate pupil stop, since retardation varies across the filter with the square of the incidence angle. Either way the problems of the small entrance aperture of, and beam incidence to the Zeiss filter are straightforwardly soluble.

Hα Imager Data Products:

- ❖ 2k $\times$ 2k pixel Hα full-disk images with a cadence of one minute.
- ❖ 2k $\times$ 2k pixel Hα full-disk dopplergrams and line scans with a cadence of 30 minutes. These data are especially important in the prediction of filament eruptions.
- ❖ High-cadence (once every 10 s), 2k $\times$ 2k pixel Hα full-disk images for flare studies. An automated flare detection algorithm has been developed with support of an NSF ITR grant that will be implemented in the SAM control system.
- ❖ All data will be carefully calibrated including limb darkening subtraction to enhance image contrast. The full-disk data are compiled into daily, low-resolution quick-look movies and full-resolution movies featuring flares, Moreton waves, filament eruptions, and other energetic events.
- ❖ Daily maps of flow fields are computed providing information on differential rotation, meridional flows, and proper motions in active regions.
- ❖ Since many science objective do not require high-precision photometry, data compression is used for the bulk of images.

C.5 Digital Vector Magnetograph

The Digital Vector Magnetograph (DVMG) system has been one of the BBSO "workhorses". Its design is presented in Spirock et al. (2001). Thomas Spirock developed this instrument supported by the AFOSR Graduate Fellowship Program. He recently graduated and received his Ph. D. in Electrical and Computer Engineering. Thomas is continuing his work at BBSO as a post-doctoral researcher at BBSO, where he is leading instrumentation efforts for the NST.

The DVMG analyzes the polarization state of light, i.e., its intensity (Stokes-I), the circular polarization (Stokes-V), and the linear polarization (Stokes-Q and -U). Two types of magnetograms are provided by BBSO: longitudinal (line-of-sight) magnetograms and vector magnetograms of the full Stokes-vector including the transverse component of the magnetic field. The FOV of the current system is about $300'' \times 300''$ with an image scale of $0.6''$ per pixel. The typical cadence is one minute. A schematic diagram of the DVMG system is presented in Figure 6.

Much of this design can be carried over to the SAM telescope. Again, since we use a Zeiss filter in the Ca I 610.3 nm line, the same optical considerations and limitations apply as in the case of the Hα full-disk imager. The light would be fed directly from the telescope to the magnetograph and we insert a computer controlled flip mirror to direct the light to the Hα imager. In principle, a dichroic beamsplitter could be used, which would however introduce strong astigmatism. Time-sharing seems to be the better choice in this case. The polarization optics consisting of a ferro-electric and two nematic liquid crystals can be used without modification. Thus, minimizing system migration and integration time. The only design effort is related to an appropriate re-imaging optics.

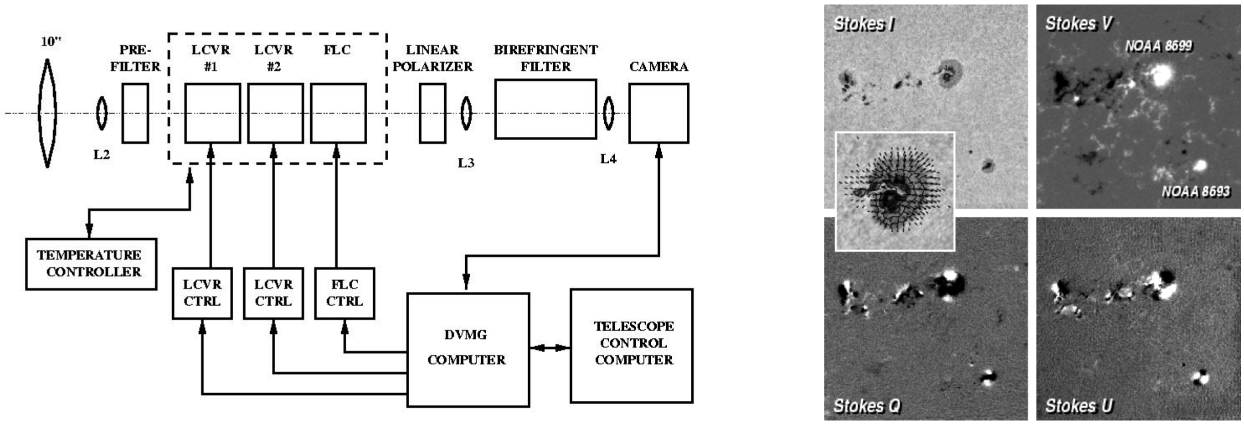

Figure 6: Schematic diagram of the Digital Vector Magnetograph (DVMG) and a typical DVMG data set showing the full Stokes vector (I, V, Q, and U) and an insert with the vector field (the longitudinal component is shown as contours).

The major change of the DVMG system involves its detector system. We purchased a Cooke PCO.2000 CCD camera. This 2048×2048 pixel CCD camera has a peak quantum efficiency of 55%, which is more than three times as large as the current system. In addition, it has 14-bit digitization, an improved signal-to-noise ratio, thermo-electric cooling, and a data acquisition rate of 10 frames per second. Integrating this camera into the DVMG system allows an upgrade to full-disk imaging with an image scale of $1''$ per pixel.

DVMG Data Products:

❖ 2k $\times$ 2k pixel full-disk longitudinal magnetograms with a cadence of one minute.
❖ 2k $\times$ 2k pixel full-disk vector magnetograms with a cadence of four minutes.
❖ 2k $\times$ 2k pixel full-disk continuum filtergrams with a cadence of one minute.
❖ Note: Adaptation of the DVMG only requires modest optical design efforts and the upgrade to a full-disk system is based on an already purchased large-format CCD camera.

C.6 Active and Adaptive Optics Upgrade

The diffraction limit of a 25 cm at 600 nm is about $0.5''$. Adaptive optics or at least active optics is required to obtain data that approaches diffraction-limited resolution. Keller et al. (2003b) build a low-cost ($25,000 for a 37-actuator system) solar adaptive optics for the infrared wavelength region, which has been successfully implemented at NSO's 1.5-meter McMath-Pierce solar telescope at the Kitt Peak Observatory in Arizona. The system is based on fast (1 KHz) commercial CCD cameras and imaging boards attached to an industrial PC with Linux as operating system. The software developed by Keller et al. make extensive use of the multi-media instructions of the chipset, which allows parallel processing of 8×8 pixel tiles providing a bandwidth of 250 Hz. During the development of the NSO/BBSO high-order adaptive optics system (Rimmele et al. 2004), we acquired several Dalsa CCD cameras that could be used in such a system. Thus, minimizing substantially minimizing the cost. We also have the parts for a correlation tracker (tip-tilt mirror of an obsolete spot tracker). Even with just these parts and without a wavefront sensor, three observing modes could be implemented: (1) a digital quad cell for sunspots or full-disk guider, (2) a digital limb tracker, and (3) a correlation tracker. The ultimate upgrade to fully adaptive optics would only require the optical and mechanical parts for the wavefront sensor and deformable mirror. The cost estimate for the remaining parts is less than $15,000.

C.7 Data Handling and Data Management

Supported by the NSF ITR grant, we will develop WWW based software tools to process data, events, and solar activity forecasts in real-time, which will be integrated into the current solar activity and space weather prediction WWW pages at BBSO (http://www.bbso.njit.edu/), e.g., the Solar Active Region Monitor, the Global Hα Network, and the Solar Activity Report. The ITR activities will leverage investments in the SAM instrument. The data mining and visualization services will also be a part of the Virtual Solar Observatory (VSO) being developed by the solar physics community under the stewardship of the National Solar Observatory (NSO). The VSO is a community effort, which attempts to distribute ground-based and space data to users uniformly and efficiently (Hill et al. 2004b). We will actively collaborate with the NSO group to include our real-time data and forecasting as a part of VSO.

Open-source software tools will be used for the development of the WWW based user interface and for the access to raw and to processed SAM data. A Linux based Apache WWW server will be utilized. Web-based forms in HTML will be processed by Perl scripts and if needed C programs to generate and return the required responses by accessing a MySQL database server/engine. Of particular relevance to the proposed data bank system is SolarSPIRE (Hill et al. 2002) based on SPIRE (Bergman et al. 2000), a digital library system for content-based search and retrieval in scientific image databases (Li et al. 1998).

In summary, we expect that the streamlined SAM data pipeline will significantly improve the accessibility of data relevant to solar physics, space weather research, and space science. In addition, other sources of funding, especially the NSF ITR grant, will provide the necessary resources to implement advanced data mining and visualization capabilities that will leverage the hardware investments of the SAM project.

Data Handling and Data Management:

- ❖ BBSO has strong support through the NSF ITR program to develop tools and techniques for space weather forecasting. This support will leverage the investments in the SAM.
- ❖ The current Hα full-disk data are already part of the VSO and ARM. The implementation of a data pipeline for the SAM data products is straightforward.
- ❖ Supported through the NASA Living with a Star program, BBSO has made substantial investments in the data handling and data management environment featuring a WWW/FTP server with 1 TByte SCSI disk storage capacity and a dual-CPU data analysis and storage serve with 6 TByte capacity. The dome shore link has also been improved to a multi-mode fiber optics GigaBit link.

C.8 Education

NJIT is New Jersey's public technological research university (http://www.njit.edu/). NJIT is a comprehensive public university, and is one of the nation's most computing-intensive universities. It offers 100 undergraduate and graduate degree programs in six colleges: engineering, science and liberal arts, computer science, architecture, management, and the Albert Dorman Honors College (ADHC). More than 8,000 students (about 5,700 undergraduates and 3,100 graduates) are enrolled on the university's urban campus in the University Heights section of Newark, New Jersey. NJIT's student body is very diverse, with a strong minority population and many first generation college students.

The Physics Department currently comprises 17 professorial faculty working in areas of solar physics, optics (including IR and THz), biophysics, material science, and computational physics. The undergraduate curriculum includes the standard physics lecture and laboratory courses, astronomy and astrophysics, optical science and engineering, and material science. A new biophysics undergraduate program is now being developed. An important part of undergraduate education within the department is the research opportunities that are provided by the research groups. At the graduate level, the physics course work related to solar and space physics currently includes courses in solar physics, plasma physics, and radio astronomy.

At the undergraduate level, we have three to five students every year working as research assistants at NJIT's Center for Solar-Terrestrial Research (CSTR), which operates BBSO as well as the Owens Valley Solar Array of radio telescopes. These are the two major facilities CSTR operates, which give CSTR unique data from which to study the Sun. Most of the CSTR undergraduates are supported by NSF research grants and NSF Research Experience for Undergraduates (REU) stipends. We plan to include an REU undergraduate student in this project, since working with the SAM team members will provide the student with an excellent opportunity to gain first-hand knowledge of the dynamics and requirements of a challenging research project. Thus, the student will be prepared for a future career in science or technology-related professions. Undergraduate research can also be instrumental in the decision making process, if the student is interested to pursue an academic career, i.e., to continue as a Ph. D. student at CSTR or another university.

At the graduate level, a Ph. D. will take an important role in this instrumentation project. CSTR/BBSO highly prizes its special role in the education of the next generation of scientists who build instruments. 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 so that one graduate student can handle essentially all aspects of its development. The major contribution of the graduate student we plan to use in the SAM project would be the development of the telescope control software, which includes automatic and remote operation, event-triggered observing sequences, and data sharing with other instruments. E.g., some of the newly developed flare and filament detection algorithms will be applied to the data in real-time and can autonomously start or change an observing sequence when a flare or filament eruption is detected. The integration of real-time feature recognition into a telescope control system is a challenging computer science and engineering problem, which could be the technical part of the student's Ph. D. thesis. Our students receive Ph. D.'s in Applied Physics, Electrical and Computer Engineering or Computer Science. This training prepares them scientific careers, while ensuring broader career opportunities. Past experience has shown that this approach to graduate education can be highly successful. Examples of instrumentation projects include a birefringent filter for NIR observations, NIR achromatic wave plates, two imaging magnetograph systems, a real-time image reconstruction system, and the thermal and telescope control systems for the NST. At the completion of the SAM project, the graduate has access to one of the most advanced Hα and photometric full-disk telescopes. The full-disk data provides the foundation for the subsequent science part of the student's Ph. D. thesis. This research will be separately funded. The graduate student, Garrett Smith, has been accepted to the NJIT Ph. D. program for the Fall 2005 semester and will receive financial support as a teaching assistant in the Physics Department for two years covering the entire period of this instrumentation proposal. Garrett Smith is a U. S. citizen and has been working at CSTR as an undergraduate research assistant for over three years. He also stayed at BBSO as a summer research student in 2004 and 2005 for 10 weeks each. He has been working on chromospheric differential rotation based on Hα full-disk data and possesses intimate knowledge of the Hα full-disk system. Garrett's work will also benefit from CSTR optical laboratories in BBSO and on-campus at NJIT.

Even though the graduate student plays an important role in the SAM development, the overall responsibility for the success of the project resides with the PI and the Co-PI, who make use of and integrate the extended expertise of SAM team members. The primary educational objective of the Physics Department faculty in the CSTR is to provide students the opportunity to participate in state-of-the-art research and instrumentation projects within an environment that stimulates their interest in the discovery process, fosters creativity, and prepares them for a wide range of leadership positions at the onset of the 21st century. Educating the next generation of astronomers, astrophysicists, solar physicists and instrument builders is at the core of our integrated instrumentation and education program.

C.9 Management Plan and Project Milestones

The overall project responsibility rests with PI Goode who benefits from advice from Co-PI Denker. We have assembled an experienced team of researchers, computer experts, and mechanical and optical engineers who have been intimately involved with various instrumentation projects over the years. The SAM project is well defined, low-risk, and has a realistic one-year time-horizon.

The project is located both at NJIT/CSTR and BBSO. The work efforts at NJIT/CSTR will be directly supervised by Co-PI Denker. Frequent visits to BBSO are planned to coordinate the work at both project locations. Both NJIT and BBSO have video-conference facilities, which will be used on a bi-weekly basis to foster the collaboration between team members at both locations and keep everyone up-to-date on the progression of the project. All SAM activities are carefully coordinated with Roy Coulter, the NST project director at BBSO, to avoid scheduling conflicts or over-lapping work schedules of staff members. Co-PI Denker schedules the local contractors and makes sure that the building modifications are done on-time and according to local building codes. Jeff Nenow, mechanical engineer at BBSO, will lead the system integration efforts of the mechanical components at BBSO. At the time of the Critical Design Review, we will seek advise from members of our scientific advisory board and other experts in solar instrumentation.

Even though the SAM is a challenging instrumentation project, a graduate student can play a crucial role in the instrument development. Many CSTR graduate students and alumni have developed substantial parts of instruments and subsequently used these instruments for scientific projects. We intend to follow this successful path and a full-time graduate student, Garrett Smith, will be involved in all aspects of the instruments development, fabrication, and deployment. Co-PI Denker will be the graduate student's Ph. D. advisor supported by Prof. Haimin Wang who will serve as his co-advisor. We will identify additional funds to support the scientific research component of the graduate student's Ph. D. thesis.

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E Biographical Sketches

E.1 Philip R. Goode

Education

1964:	A. B. in Physics, University of California, Berkeley
1969:	Ph. D. in Physics, Rutgers, The State University, New Jersey

Current Positions

1997–present:	Director of the Big Bear Solar Observatory, New Jersey Institute of Technology, Big Bear City, California
1997–present:	Director of the Center for Solar-Terrestrial Research, New Jersey Institute of Technology, Newark, New Jersey
1994–present:	Distinguished Professor of Physics and Mathematics, New Jersey Institute of Technology, Newark, New Jersey
1996–present:	Visiting Associate, Physics, California Institute of Technology, Pasadena, California

Research Interests and Experience

Sun's interior and atmosphere; magnetic fields; helioseismology; climate studies. Over 200 publications. Director of BBSO, which has more than 10 Ph.D. students. Among 24 current and past students and post-docs, 8 have moved on to faculty/national center tenure track postions.
Long experience in helioseismology and studies of magnetic fields, especially in combining BBSO ground-based data with satellite data to determine dynamic properties of the solar magnetic fields, place a lower limit on solar irradiance and to probe the solar interior. Several years experience in measuring the Earth's large-scale reflectance using the earthshine and modeling the Earth's reflectivity using satellite cloud cover finding appreciable decadal variation of reflectance due to cloud changes. Building global network to measure the Earth's global reflectance and spectrum. Leading project to build BBSO's 1.6 m clear aperture, off-axis solar telescope (world's largest aperture) that will have its first light in 2006. Its light will feed our high order adaptive optics system, which in turn will feed our next generation, Fabry-Perot based, visible light and near infrared polarimeters. BBSO also has a fully operational Beowulf cluster doing real time image reconstruction.

Selected Publications

Wang, H., Qiu, J., Jing, J., Spirock, T. J., Yurchyshyn, V., Abramenko, V., Ji, H., Goode, P. R., 2004: *Evidence of Rapid Flux Emergence Associated with the M8.7 Flare on 2002 July 26.* Astrophysical Journal **605**, 931-937

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E.2 Carsten Denker

Education

1985–1996:	Georg-August Universität Göttingen, Germany
1991:	Awarded Diploma in Physics (equivalent to M. Sc.), Thesis Title: *The Magnetic Field of Penumbral Fine-Structures*, Thesis Advisor: Prof. Franz Kneer
1993:	Diploma in Social Science, Thesis Title: *The Enquête-Commission for 'Technology Assessment' of the German Parliament — On the Relation Between Politics, Science and Public Opinion*, Thesis Advisor: Prof. H. G. Martens
1996:	Awarded Ph. D. in Physics, Thesis Title: *The Investigation of Sunspot Fine-Structure by Means of Speckle Interferometry*, Thesis Advisor: Prof. Franz Kneer

Professional Experience

2001–present:	Assistant Professor of Physics at the New Jersey Institute of Technology, Newark, New Jersey
1999–2001:	Assistant Research Professor at the Big Bear Solar Observatory/New Jersey Institute of Technology, Big Bear City, California
1997–1999	Postdoctoral Research Associate at the Big Bear Solar Observatory/New Jersey Institute of Technology (with Prof. Philip R. Goode), Big Bear City, California
1996–1997:	Postdoctoral Scholar in Solar Astrophysics at the California Institute of Technology (with Prof. Harold Zirin), Pasadena, California
1994–1996:	Research Assistant at the Universitäts-Sternwarte Göttingen, Germany
1992:	Summer Research Assistant at the National Solar Observatory, Sacramento Peak, Sunspot, New Mexico
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