Next Generation Ha Full-Disk Telescope for Innovative Space Weather Research
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A. Proposal Summary

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 monitor solar activity and its effects on the Sun-Earth system. We propose to build a Hα full-disk telescope, 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 full-disk telescope. We will use this instrument for our synoptic Hα full-disk observations. The new telescope will replace and extend the capabilities of the current Singer full-disk telescope, which can no longer be operated with the advent of the New Solar Telescope (NST) at BBSO in mid-2006. The NST is a 1.6 meter aperture telescope for high-resolution studies of the Sun. These instrumentation efforts – in the 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 of space weather forecasting, while beginning to provide the tools for the next generation of space weather forecasting.

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C. Project Description

The scientific productivity of BBSO has its foundation in a combination of high-spatial resolution and synoptic observations. More than 250 “Blue Books” have been released in the BBSO preprint series and the majority of them was published in peer-reviewed journals since NJIT took over the operation of BBSO on 1 July 1997. MC-SoFT will complement BBSO’s efforts in high-resolution studies of the Sun. The NST (Goode et al. 2003) will become operational in 2006 and the proposed MC-SoFT will leverage the investments in high-resolution observation and enable new scientific discoveries while ensuring the continuation of on-going synoptic research programs. MC-SoFT is an innovative suite of instruments that will greatly improve the synoptic observing program at BBSO. Without this instrument, the synoptic observing program at BBSO ceases to exist. MC-SoFT offers a variety of features exceeding the capabilities of the existing synoptic telescopes such as higher temporal and spatial resolution, spectral line scans, Hα dopplergrams, 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. MC-SoFT consists of three instrument components: the Hα full-disk telescope, the photometric full-disk telescope, and an option for observations of moderate spatial resolution with a $500'' \times 500''$ FOV.

C.1. Scientific Motivation

High-precision photometry has two branches at BBSO: One focuses on the evolution and dynamics of solar active regions with Hα observations, whereas the other is concerned with global changes of solar activity related to solar irradiance variability. Our proposed new instrument will emphasize the first part.

C.1.1. High-Resolution Hα Full-Disk Observations

Currently, BBSO is operating two full-disk telescopes. The 15 cm aperture Singer telescope takes high-cadence, high-resolution Hα images (Denker et al. 1998) and is part of the Global Hα Network (GHN, Steinegger et al. 2001a). 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.

The MC-SoFT 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 MC-SoFT 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 a rapidly evolving in solar physics, especially considering the large volume of data from synoptic and space-based facilities. 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 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. MC-SoFT 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. 2003) and ISOON have similar capabilities but they are not typically used in high-cadence mode and the seeing conditions favor BBSO. MC-SoFT a larger aperture and twice the spatial resolution compared to ISOON and SOLIS. It has a well established data pipeline and scientific support for feature recognition, the derivation of flow maps, and space weather forecasting capabilities. Without MC-SoFT, the GHN would experience a 8–10 hour data gap in its duty cycle. Space weather studies and forecast would severely impacted. Furthermore, in tandem with the NST, MC-Soft can uniquely exploit the synergies between high-resolution and synoptic solar observations.

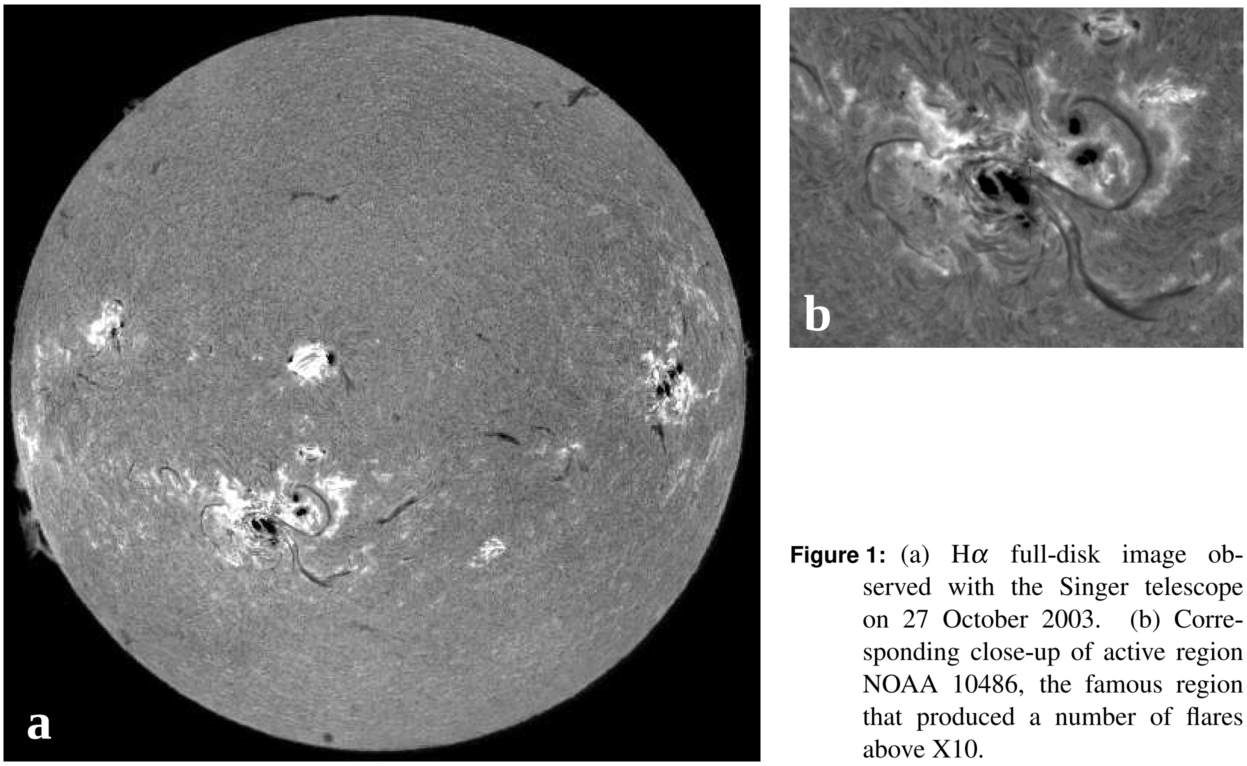

Figure 1: (a) Hα full-disk image observed with the Singer telescope on 27 October 2003. (b) Corresponding close-up of active region NOAA 10486, the famous region that produced a number of flares above X10.

One overarching topic in space weather studies is to find a comprehensive picture of the relation between 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 geoeffectiveness 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 MC-Soft, we will continue to combine Hα data with full-disk magnetograms from the Michelson Doppler Imager (MDI) and the Global Oscillation Network Group (GONG) 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 CME.

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.

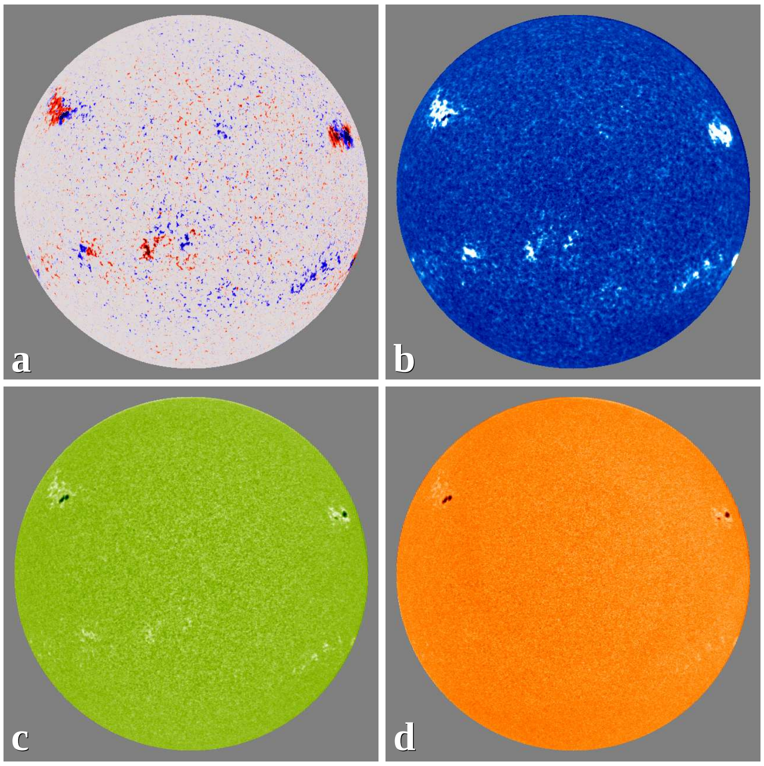

Figure 2: Full-disk observations on 27 May 1998. (a) Kitt Peak magnetogram, (b) BBSO Ca II K filtergram, (c) G-band filtergram, and (d) continuum image.

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.

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 summary, the MC-SoFT Hα full-disk telescope 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.

C.1.2. Photometric Full Disk Observations

Our current photometric full-disk telescope at BBSO is a 15 cm refractor and takes a set of Ca II K (393.3 nm) and broad-band continuum images (525 nm) once a day. The data processing for all full-disk data is the same (see Denker et al. 1998) and includes dark and flat-field correction. In addition, a two-dimensional limb darkening profile is computed and provides, after subtraction, a contrast enhanced image. The full-disk data is available from our anonymous FTP server (ftp://ftp.bbso.njit.edu/pub/archive/). Ca II K-line full-disk filtergrams have been obtained since 1981. However, the optical set-up and detector system has been continually improved since then (Johannesson et al. 1998). The latest system uses a Daystar filter with a FWHM of 0.15 nm and a blue-sensitive, Lumigen coated Kodak 1.4i MegaPlus CCD camera.

The synoptic Ca II K observations have been successfully used to reproduce the to reproduce the H I Lα irradiance variability observed with the Upper Atmosphere Research Satellite (UARS, Johannesson et al. 1995). Warren et al. (1996) used the Ca II K data to model the extreme ultraviolet (EUV) irradiance variability and Lean et al. (1998) used the Ca II K data to assess the component of bright magnetic features in the solar irradiance cycle. The Ca II K data has proven to be a valuable reference for space-based irradiance measurements, e.g., UARS, Solar Maximum Mission (SMM), Nimbus 7, and Earth Radiation Budget Satellite (ERBE). The Ca II data has also been used to calibrate ground-based data from the Precision Solar Photometric Telescope Project (PSPT) of the Radiative Inputs of the Sun to Earth (RISE) program. Since the Ca II K data set spans almost two decades, it provides an important record of solar irradiance variability.

The MC-SoFT photometric full-disk telescope observes the Sun in three distinct wavelength settings at Ca II K λ393.3 nm, the G-band λ430.6 nm, and the blue continuum λ450.7 nm. This combination of narrow-band ($\Delta\lambda = 0.3$ nm) filtergrams delivers a unique picture of solar irradiance variation (Lean 1997). Faculae are only visible near the limb in continuum images. However, G-band images show faculae across the entire disk. In addition, the chromospheric network and plages can be extracted from Ca II K images. In combination with full-disk magnetograms, e.g., GONG, SOLIS, and the Helioseismic and Magnetic Imager (HMI) onboard the Solar Dynamics Observatory (SDO), and newly developed feature identification algorithms, we can now assess the individual contributions of plages, faculae, pores, network and intranetwork brightenings to the solar irradiance variability. Figure 2 shows such a multi-wavelength data set obtained with BBSO's current photometric full-disk telescope. However, the proposed system doubles the spatial resolution and significantly increases the temporal resolution opening avenues for studies of active region dynamics.

G-band images have been predominantly used in the context of high-spatial resolution observations. However, their potential for moderate resolution observations has not yet been exploited. G-band brightenings are often used as proxies for small-scale magnetic fields. Even though individual G-Band bright-points would be unresolved, MC-SoFT could provide a global picture, where these small-scale magnetic fields are located, thus guiding the high-spatial resolution observations. However, the interesting question remains why are G-band bright points bright? Steiner et al. (2001) suggested that the enhanced contrast in the G-band is due to a reduction of CH molecules by dissociation (the ionization potential is only 3.5 eV) in deep photospheric layers, which are hotter (up to 800 K) than their surroundings. Sánchez Almeida et al. (2001) and Rutten et al. (2001) come to similar conclusions. The lower CH abundances lead to weaker CH lines allowing the underlying continuum radiation to "shine through the forest of G-band CH-lines".

Theoretical studies of G-bands bright-points were thus far limited to the physics of small-flux tubes. MC-SoFT data extends these studies to include their global distribution, their role in the evolution of active regions, and the solar cycle dependence. Since G-band bright-points are high-contrast features, they are ideally suited to measure proper motions in the upper photosphere using local correlation or feature tracking. Steiner et al. (2001) infer a line-core formation height of CH-lines in the G-band of about 140 km, which corresponds to $\tau_{500\mathrm{nm}} = 0.1$ of the quiet Sun. Steiner et al. (2001) also find a similar weakening of Fe I lines in the G-band contributing to the overall contrast enhancement. They concluded that this effect is present in all contrast measurements, which include many spectral lines of metallic neutrals. This contrast enhancement must be accounted for in realistic continuum photometry. Similar or even larger contrast enhancement is expected from CN band-head radiation at 388.3 nm (Chapman 1970, Steiner et al. 2001, Rutten et al. 2001), which could also be included as an option.

- 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).
- MC-SoFT 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, which usually occurs when the Sun heats the ground and produces convection in the air just above the ground. Turbulent motions in the air near the observatory are also reduced by the smooth flow of the wind across the lake 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.

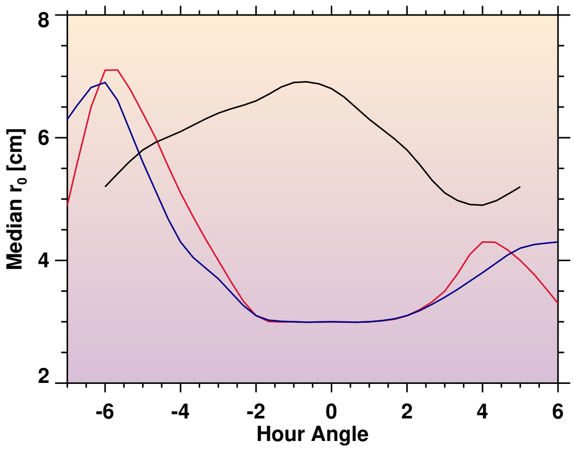

Figure 3: The median value of the r_0 measurements from the S-DIMM instrument at the three sites (**Big Bear**, **Haleakala**, and **La Palma**) as a function of hour angle (adapted from Figure 10.13 in Hill et al. 2004).

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. 2004). 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 consistent seeing conditions with extended periods of excellent seeing from sunrise to sunset (see Figure 3). 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. 2004).

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 MC-SoFT 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, MC-SoFT will routinely achieve $2''$ spatial resolution and $1''$ during extended period of excellent seeing conditions. Therefore, we will require a large-format, 4k $\times$ 4k pixel detector for the MC-Soft Hα channel. This is an essential upgrade from the current 2k by 2k system.

C.3. Multi-Channel Solar Full-Disk Telescope

MC-SoFT is a 20 cm effective aperture refractive telescope. A $f/12.5$ beam is required to match the size of the CCD detectors and the 30 mm aperture of the Lyot filter. The objective lens also serves as the entrance window of the telescope. The objective lens material blocks ultra-violet (UV) light and a special coating blocks infra-red (IR) radiation above 700 nm. The coating also protects the first surface of the objective lens, which is exposed to the elements. During rain or snow, the telescope control software will move the entrance window into a secure position. During extreme weather conditions, the whole turret will be enclosed in additional weatherproof material. The telescope is using a turret system, which allows a very compact instrument envelope. The turret is based on the GONG instrument and the GONG project has provided us with the detailed mechanical drawings so that we can scale the GONG turret to fit our 20 cm optics. MC-SoFT consists of three distinct instrument components: the Hα full-disk telescope, the photometric full-disk telescope, and an option for observations with high spatial resolution but smaller field-of-view (FOV) of about $500'' \times 500''$. The basic optical layout is shown in Figure 4.

The primary MC-SoFT science instrument is the Hα full-disk telescope. This instrument will have the broadest impacts on the NST utilization, the GHN, and the data requests from the solar physics and space science community. The photometric full-disk telescope and the moderate resolution option will help us to regain and extend most of the synoptic capabilities at BBSO. The relative importance of the three instrument components is also reflected in the budget. The photometric full-disk telescope only requires a new CCD camera and some interference filters and the moderate resolution option includes just a relatively cheap upgrade of a CCD camera system. Overall, the incremental cost should be justified by the versatility of MC-SoFT and its expected scientific output.

Simplicity is one of the MC-SoFT design goals. Many of the optical and mechanical components are readily available. Only the turret requires a new design, which is largely based on the GONG design. Thus, minimizing risk and redundant design efforts. Since the responsibilities of the BBSO observing staff will increase with the advent of the NST, care has to be taken in the MC-SoFT 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.

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 comprehensive NST thermal control system. Other information has to be recorded by the MC-SoFT 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 MC-SoFT 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.

C.3.1. Hα Full-Disk Telescope

MC-SoFT is based on the experience of the very successful Singer full-disk telescope (Denker et al. 1998). 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 is further improved by about 40% using a narrow band (0.3 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 lead the way towards 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.

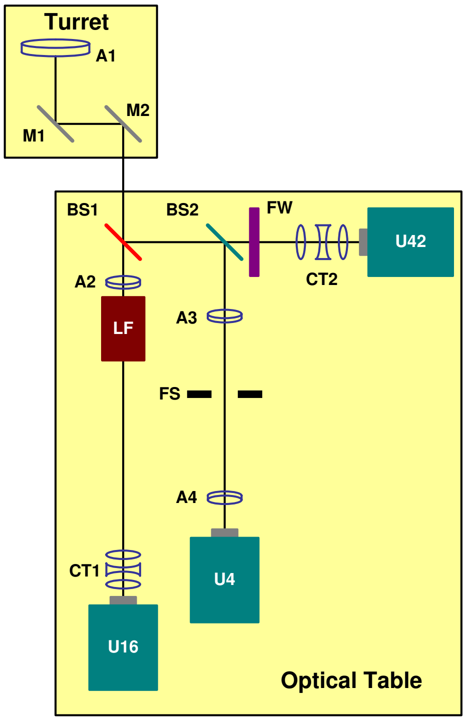

Figure 4: MC-SoFT optical layout. A1: telescope objective lens, M1 & M2: flat folding mirrors, BS1 & BS2: dichroic beamsplitters, A2: field lens, CT1 & CT2: Cooke triplets, LF: Zeiss Hα Lyot filter, A3 & A4: re-imaging optics, FS: field stop, FW: filter wheel with interference filters for Ca II K, G-band, and blue continuum, and U42, U16, & U4: Apogee Alta series CCD cameras.

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. Our preliminary optical design is almost diffraction-limited but we will try to improve this design during the design and development phase of the MC-SoFT project. However, it should be noted that the diffraction-limited resolution of the Hα telescope is smaller than the image scale for the 4k $\times$ 4k pixel detector. Although a diffraction-limited telescope is desirable, the performance of the telescope only has to be adapted to the image scale of the detector. The current design already achieves this requirement.

A field lens is inserted in front of the primary focal plane and the Lyot filter to avoid vignetting. We use a specially designed Cooke triplet, which is usually used to remove the seven basic or primary aberrations, i.e., first-order longitudinal and lateral color, and the five monochromatic third-order Seidel aberrations (Smith 1990). The chromatic abberations are not important for the Hα channel and the the corresponding degrees of freedom can be used to improve the lens design for the monochromatic abberations. The image scale requirements are about $0.5''$ pixel^{-1} in Hα (red channel) and $1.0''$ pixel^{-1} in Ca II K/G-band/blue continuum (blue channel).

C.3.2. Photometric Full-Disk Telescope

The photometric full-disk telescope observes three narrow-band (0.3 nm) wavelength regions of the solar spectrum: Ca II K λ393.3 nm, the G-band λ430.6 nm, and the blue continuum λ450.7 nm. The photometric accuracy of the measurements will be better than 1% with a goal of 0.1%. A dichroic beamsplitter is inserted in front of the field lens to split the light path into a red and blue/green channel. The wavelength cut-off is around 600 nm. The beamsplitter has to be over-dimensioned and moved away from the primary focal plane in order to avoid damage by the high light flux near the focal plane. An advantage of having the beamsplitter near but not to close to the focal plane are the lower requirements for the surface quality. Potential dust contamination and other inhomogeneities can be removed in the carefully designed flat-fielding procedure.

We use interference filters manufactured by Barr Associates (http://www.barrassociates.com), since this is the only company that uses ion assisted deposition to manufacture two-cavity narrow-band interference filters. The transmission usually exceeds 80% (despite the more conservative estimates in the price quotes and based on our experience with three previously ordered interference filters) and the filters are not prone to wavelength drifts due to aging as it is the case with conventional interference filters. The diameter of the filters is 50 mm. Thus, they can be directly inserted into the light beam ahead of the primary focal plane. The interference filters are mounted in a computer controlled filter wheel. One set of full-disk images will be acquired in each wavelength setting every minute.

All optical components are mounted on a 2.4 m $\times$ 1.5 m bread-board optical bench, which is supported by vibration isolators (http://www.newport.com). Due to space limitations of the access window located in the South-East corner of the observatory building (blue rhomboid in Figure 5)), the height of the optical bench above the observing floor is only about 40 cm and active vibration control cannot be used. However, the over-designed concrete observing floor is not very susceptible to vibrations. Air-conditioning equipment and other vibration sources will be relocated outside of the observatory building as part of the NST efforts and the observing staff is usually not on the observing floor. Therefore, we do not expect any problems with the stability of the equipment. This is also supported from our experience with the high-resolution instrumentation mounted on optical tables in the new optical laboratory on the second floor of the observatory building. An enclosure is mounted to the optical table to protect the instruments from dust contaminations and to provide a stable thermal environment. Besides sun-light, the thermo-electric cooling of the CCD cameras and the Lyot filters are heat sources that could heat the interior of the optical table enclosure. Therefore, MC-SoFT is tied into the NST/dome air-conditioning system and has a thermal control system keeping the temperature constant during operation.

C.3.3. Moderate Resolution Option

The Hα and photometric full-disk telescope replace the existing synoptic instruments at BBSO. In addition, we propose an option for observations with moderate spatial resolution ($0.5''$) and a FOV of $500'' \times 500''$. This instrument component would provide some of the capabilities of the current 25 cm refractor at BBSO. An additional beamsplitter or computer controlled flip mirror directs the light parallel to the Hα beam. A relay optics creates a secondary focal plane such that a field stops can be inserted to achieve the desired FOV. An achromatic re-imaging lens is used to create the appropriate image scale at the detector. Most of the optical components for this option are readily available at BBSO and will not be charged to the project. We only included an upgrade of the current Apogee KX CCD camera to an Alta U4 CCD camera to replace the obsolete ISA with a USB 2.0 interface. Several Lyot filters are available (e.g., Ca II K and He D_3) for dedicated observing runs of flare dynamics, active region evolution, and quiet Sun studies. The moderate resolution option also adds to the flexibility of the integrated MC-SoFT instrument suite and provides a "spare" light path for instrument development.

C.3.4. MC-SoFT Turret

The synoptic instrumentation at BBSO needed to find a new home with the advent of the NST, since it cannot any longer utilize the same equatorial mount as it was the case with the 65 cm vacuum refractor. In principle, two options could be considered: (1) a new telescope and new dome on the cause way or (2) a compact instrument located inside the existing observatory building. If we would use the existing Singer telescope and relocate it, we would have to build a new 4-meter dome on the causeway, extend the causeway, provide access to utilities, and build a new equatorial mount including telescope drive. Cost considerations prohibited us from pursuing this first option.

Turret telescopes are very cost effective systems with a small instrument footprint. They have been used in a variety of high-resolution and synoptic telescopes including Swedish Solar Telescope (SST, Scharmer et al. 2003) at the Observatorio del Roque de los Muchachos, La Palma, the Dunn Solar Telescope (DST) at the Sacramento Peak Observatory, New Mexico, the Improved Solar Optical Observations Network (ISOON), and GONG. The GONG project was very forthcoming in providing us with the mechanical drawings of the GONG turret, which we will use as the template for the MC-SoFT turret design. During the design and development phase, we will scale these AutoCad drawings to fit the 20 cm optics of MC-SoFT. About half of the equipment funds are allocated for mechanics and optics of the turret. The cost estimates are based on the original GONG costs prorated to 2005 and taking into account the larger optics. Other commercially available telescope are much cheaper, however, they cannot be used to feed the post-focus instrumentation satisfying image quality, stray-light, and FOV requirements. In addition, the turret design has to be reliable, since the instrument will be used every day for 8–10 hours.

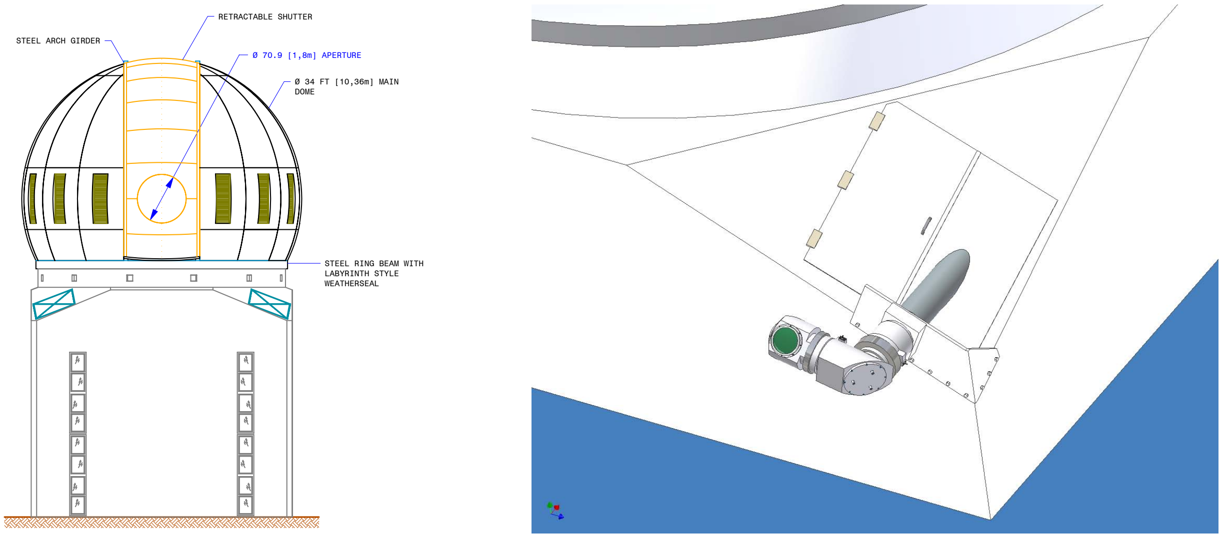

Figure 5: South view of BBSO with new 5/8 sphere dome. MC-SoFT will be located at the south-east corner of the building, where it will exit from an existing, 2 m × 2 m corner window at the top floor.

The stiffness of the turret system has to be evaluated in the MC-SoFT design and development phase. However, scaling the GONG turret to a 20 cm aperture system is not expected to pose any problems. Obviously, the bearing, gear, and transmission system has to replaced with a larger version and is a critical point in the overall system stiffness. This has to be evaluated int the design and development phase in order to minimize pointing errors induced by the wind flow across the lake. The resonance frequency has to be in a range that does not lead to vibrations due to the wind. A sturdy support system affixed to the southern exterior wall of the observatory building (see Figure 5) ensures the overall stiffness and allows for sufficient degrees of freedom to move the resonance frequency of the turret system in to a regime where it does not affect the system performance. The cross-section of the turret system is also relatively small so that wind shake should be negligible even though the turret has to extend about 1 m from the observatory to be freely exposed to the wind flow. The turret is located on the South-East corner of the observatory building (see Figure 5). Thus, we have full access to the eastern horizon in the morning. Only during the afternoon, the observatory building is blocking the westerly view. However, the shorter observing period in the afternoon is off-set by the automatic operation of MC-SoFT. Observations will commence shortly after sunrise, once all calibration data has been taken. The typical duty cycle for a day ranges from eight to ten hours depending on the observing season.

A platform is mounted to the exterior of the observatory building to provide access to the turret system. A catwalk starts from the "nose cone" of the observatory building, which housed a heliostat for a helioseismology experiment, and connects to the platform by a safety ladder. The building modification will be subcontracted to local companies in San Bernardino County, and will conform to California building and safety codes.

The folding mirrors of the turret are manufactured by Bernhard Halle GmbH (http://www.b-halle.de/). The mirror substrates are made of Zerodur and are precision polished to a surface flatness of $\lambda/20$. The diameter of the mirrors is 300 mm and their thickness is 40 mm. They have aluminium reflective coatings with quartz protective layers for the entire visible wavelength region. One disadvantage of a turret compared to an equatorial mount is the introduction of image rotation. However, since the moving parts, e.g., the two folding mirrors of the turret are far away from an image plane, flat-field correction of the images should not be affected. The images are de-rotated in the later stages of the image calibration process.

MC-SoFT Instrument Specifications:

- 20 cm effective aperture for high-cadence and large-format full-disk images.
- Instrument suite of Hα full-disk telescope, photometric full-disk telescope, and moderate resolution option.
- Small instrument envelope due to a compact turret design.
- The telescope is sufficiently flexible to allow future upgrades.
- Mc-SoFT is expected to maintain and expand a decade-long record of full-disk observations at BBSO.
- MC-SoFT 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.3.5. Data Acquisition, Calibration, and Archiving

The Alta U16 and U42 full frame CCD cameras manufactured by Apogee Instruments (http://www.ccd.com) are ideal for applications requiring large FOVs. About 1/3 of the equipment funds are allocated for the science-grade CCD cameras, since much of the proposed science relies on high-cadence and large-format detectors. The scientific output of MC-SoFT would be severely limited, if we would not use state-of-the-art CCD camera systems. The camera specifications are summarized in Table 2. The Alta U42 has a back-illuminated sensor with very high quantum efficiency. Both cameras have mechanical shutters and exposure times can be as short as 20 ms, which is sufficient to "freeze" wavefronts in the case of full-disk observations with moderate spatial resolution. The USB 2.0 interface allows to connect the camera directly to the host computer without any plug-in cards or external controllers. A dual stage thermo-electric Peltier cooling system with forced air reduces the read-out noise and the camera can be operate at 40 K below the ambient temperature. Various binning modes, sub-array readout, and fast sequencing modes are available for specialized observing sequences. The CCD camera runs from a single 12 V power supply with input voltage monitor. The camera is not a significant heat source due to the low power consumption. MaxIm DL/CCD software by Diffraction Limited (http://www.cyanogen.com) is included with every system and provides most of the functions for the daily operations of the synoptic observing program. We have worked with Apogee Instruments since 1996 and used their cameras in a variety of applications including the current Singer Hα full-disk telescope. Apogee has been in the scientific camera business for over a decade and their cameras have a solid reputation for reliability, performance, and ease of use. Based on our experience, especially considering the short system integration times, the Alta U16 and U42 CCD cameras are the ideal detectors for the MC-SoFT instrument suite. The existing 2k $\times$ 2k pixel KX4 camera will be upgraded to utilize a USB 2.0 interface and used in the moderate resolution channel.

MaxIm DL/CCD is compliant with ASCOM scripting (http://ascom-standards.org/), which allows astronomy software from a number of manufacturers to work together and thus it allows complete observatory integration. ASCOM establishes a set of interface standards for scriptable or programmable low level control of astronomical instruments and related devices, and promotes the use of these standard drivers from astronomy-related software applications. Our software development is based on freely available sets of instrument drivers that implement these standards. These drivers are usable apart from any particular application and are directly accessible from Windows Active Script languages and automation based tools. The drivers support any ActiveX-enabled scripting or programming language, including VBScript, JScript, Visual Basic, Visual C++, .NET, Java, etc. In the final telescope control software package, we will include image processing functions and scripted observing sequences for the CCD camera, software guider, filter wheels and other peripheral devices. MaxIm DL/CCD also provides comprehensive image processing tools including dozens of filter and processing options, full image preview, filter by brightness level. Image analysis tools include photometric analysis, line and area profiles, and statistics functions.

	Alta U16	**Alta U42**
Detector	Kodak KAF-16801E	E2V CCD42-40
Format	4096 × 4096 pixel	2048 × 2048 pixel
Pixel size	9.0 μm × 9.0 μm	13.5 μm × 13.5 μm
Detector size	36.9 mm × 36.9 mm	27.6 mm × 27.6 mm
Digitization rate	5 MHz @ 12-bit	2 MHz @ 12-bit
	1 MHz @ 16-bit	1 MHz @ 16-bit
Full well	100,000 e^-	100,000 e^-
Dynamic range	76.0 dB	81.7 dB
Quantum efficiency	62% @ 656.3 nm	$>$ 70% @ 390 nm – 740 nm
Noise	15 e^- @ 1 MHz	10 e^- @ 1 MHz

Table 2: CCD camera specifications.

We propose to acquire a dual CPU server computer for each of the full-disk telescope. Each computer has 2.4 TByte storage system, which is sufficient to store about three month of raw data assuming 30 GBytes per day. The data will be calibrated on-the-fly unless the telescope is operating in the high-cadence flare mode. In this case, the data will be processed after the fact. Higher order data products such as flare movies, synoptic charts, and flow maps are calculated between the observing periods. Date compression is also applied to the calibrated images during this time. Photometric data is preserved for flare periods only and for hourly data from the photometric full-disk telescope. At other times, lossy compression is applied to 16-bit integer data, which reduces the data volume by a factor of 10. Finally, the data (about 5 GBytes per day) will be copied to a TByte storage server, which provides on-line access the the last two years of BBSO data. This data server will ultimately provide access to all data obtained at BBSO since 1990. In addition, all data, e.g., raw data, flat-field calibrated data, limb-darkening subtracted data, and higher order data products, are archived on Super-DLT tapes with up to 300 GBytes storage capacity.

The user receives the data from a new WWW server with multiple CPUs and fast data I/O, which is currently implemented with support from NASA's Living With a Star (LWS) program. It provides access to a data bank and tools for data mining and visualization (Li et al. 1998). Since bandwidth limits the access to TByte data sets, care has to be taken in the design of the data services. Quick look images, well-defined data queries, and comprehensive high-order data products that serve the needs of the typical user will minimize the download of unwanted quantities of data and thus preserve bandwidth. All data have an extended SoHO-style filename and header information, which reflect the BBSO instrument specific characteristics, e.g., high cadence data, calibration level, spectral scans, etc. Flat-field corrected data is stored in JPEG format for quick look analysis and the corresponding FITS data (raw data and higher level data products) can be retrieved through WWW interfaces or simple scripts. All data analysis software is readily available. In the future, we intend to make higher level data products available such as MPEG movies of user selected regions of interest in the Hα full-disk images, daily differential rotation maps in Hα and residual flow maps, and high-spatial resolution MPEG movies and corresponding horizontal flow maps.

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 MC-SoFT 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 2001). 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 MC-SoFT 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.

In summary, we expect that the streamlined MC-SoFT 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 MC-SoFT project.

MC-SoFT Standard Data Products:

- ❖ 4k × 4k pixel Hα full-disk images with a cadence of one minute.
- ❖ 4k × 4k pixel Hα full-disk dopplergrams and line scans with a cadence of 30 minutes. This data are especially important to predict filament eruptions.
- ❖ High-cadence (once every 10 s), 4k × 4k 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 MC-SoFT control system
- ❖ 2k × 2k pixel Ca II K/G-band/blue continuum images with a cadence of one minute for solar irradiance studies.
- ❖ 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.4. 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 schools: 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 CSTR. Most of them are supported by NSF research grants and NSF Research Experience for Undergraduates (REU) stipends. We would like to include an undergraduate student in this project, since working with the MC-SoFT 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 almost all aspects of its development. The major contribution of the graduate student to the MC-SoFT 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 MC-SoFT 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.

Even though the graduate student plays an important role in the MC-SoFT development, the overall responsibility for the success of the project resides with the PI and the Co-PIs, who make use of and integrate the extended expertise of MC-SoFT 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 this integrated instrumentation and education program.

C.5. Management Plan and Project Milestones

The overall project responsibility rests with PI Denker who benefits from advice from Co-PIs Wang and Ren. 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 MC-SoFT project is well defined, low-risk, competitive with similar projects, and has a realistic two-year time-horizon.

The project is located both at NJIT/CSTR and BBSO. The work efforts at NJIT/CSTR are directly supervised by 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 monthly basis to foster the collaboration between team members at both locations and keep everyone up-to-date on the progression of the project. All MC-SoFT 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. William Marquette, the BBSO site-director, schedules the local contractors and makes sure that the building modifications are done on-time and according to local building codes. Marquette, will also direct Jeff Nenow, mechanical engineer at BBSO, who leads the system integration efforts of the mechanical components at BBSO.

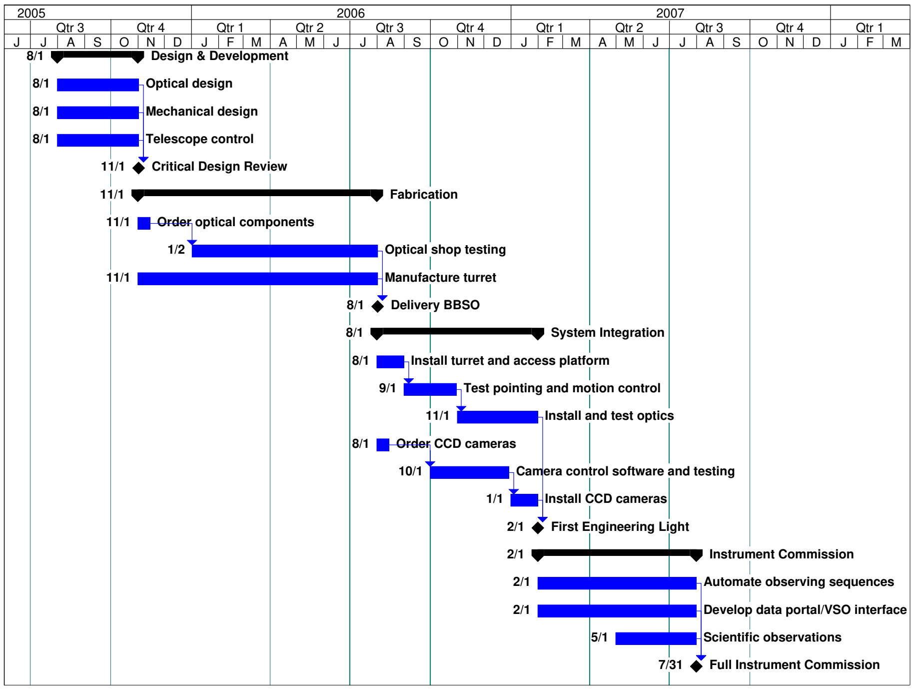

Figure 6: MC-SoFT Gantt chart summarizing time lines, milestones, instrument phases, and task schedules.

Technical oversight for the optical systems design and implementation will be provided by Co-PIs Ren and Wang. At the time of the Critical Design Review will seek advise from members of our scientific advisory board and other experts in solar instrumentation. The Gantt chart provided in Figure 6 summarizes the MC-SoFT development and implementation time lines, milestones, project phases, and task schedules.

Even though MC-SoFT 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 included a full-time graduate student in the project who will be involved in all aspects of the instruments development, fabrication, and deployment. PI Denker will be the graduate student's Ph. D. advisor supported by Co-PI Wang who will serve as the co-advisor. We will identify additional funds at the conclusion of this project to finance the scientific research component of the graduate student's Ph. D. thesis. The graduate student resides in New Jersey during the first year of the project and in California during the second year. John Varsik, senior researcher and system administrator at BBSO, will support the student in all issues concerning computers and control software. Joe Molnar of the Manufacturing Center is in charge of the turret fabrication and will introduce the student to the work in a factory-style machine shop. Finally, Co-PI Ren will guide the student in optical design.

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E. Biographical Sketches

E.1. 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
1989–1994:	Teaching Assistant at the Universitäts-Sternwarte Göttingen, Germany

Affiliations

2000–2004:	Advanced Technology Solar Telescope (ATST) Site Survey Working Group
1999–present:	American Astronomical Society
1999–present:	Solar Physics Division of the American Astronomical Society

Collaborations

Jongchul Chae (Seoul National University, Korea), Chris St. Cyr (Computational Physics, Incorporated, Naval Research Laboratory), Ming Ding (Department of Astronomy, Nanjing University China), Peter Gallagher (L-3 Government Services), Joseph Gurman (NASA Goddard Space Flight Center), Arnold Hanslmeier (Kanzelhöhe Solar Observatory, Austria), Frank Hill (National Solar Observatory), Christoph Keller (National Solar Observatory), Jeff Kuhn (Institute for Astronomy, University of Hawaii), Alexander Kosovichev (W. Hansen Experimental Physics Laboratory, Stanford University), Sara Martin (Helio Research), Alan McAllister (Helio Research), Nariaki Nitta (Lockheed Martin Solar and Astrophysics Laboratory), Thomas Rimmele (National Solar Observatory), Jun Sato (National Research Council), and Jingxiu Wang (Beijing Astronomical Observatory, National Astronomical Observatories, Chinese Academy of Sciences)

Selected Publications

Denker, C., Mascarinas, D., Xu, Y., Cao, W., Yang, G., Wang, H., Goode, P. R., Rimmele, T. R., 2004: *High-Spatial Resolution Imaging Combining Frame Selection, High-Order Adaptive Optics, and Speckle Masking Technique.* Solar Physics, in press

Denker, C., Tritschler, A., Löfdahl, M., 2004: *Image Restoration.* in: Encyclopedia of Optical Engineering, R. B. Johnson and R. G. Driggers (eds.), Marcel Dekker, New York, in press

Denker, C., Ma, J., Wang, J., Didkovsky, L. V., Varsik, J. R., Wang, H., Goode, P. R., 2003: *IRIM: An Imaging Magnetograph for High-Resolution Solar Observations in the Near-Infrared.* in: Innovative Telescopes and Instrumentation for Solar Astrophysics, S. L. Keil and S. V. Avakyan (eds.), Proceedings of the SPIE **4853**, 223-234

Denker, C., Yang, G., Wang, H., 2001, *Near Real-Time Image Reconstruction.* Solar Physics **202**, 63-70

Denker, C., 1998, *Speckle Masking Imaging of Sunspots and Pores.* Solar Physics **180**, 81-108

Denker, C., Johannesson, A., Goode, P. R., Marquette, W., Wang, H., Zirin, H., 1998: *Synoptic Hα Full Disk Observations from the Big Bear Solar Observatory. I. Instrumentation, Image Processing, Data Products, and First Results.* Solar Physics **184**, 87-102

Denker, C., 1997, *Two-Dimensional Speckle Spectroscopy of the Moustache Phenomenon on the Sun.* Astronomy Astrophysics **323**, 599-605

Rimmele, T. R., Richards, K., Hegwer, S., Fletcher, S., Gregory, S., Moretto, G., Didkovsky, L. V., Denker, C., Dolgushin, A., Goode, P. R., Langlois, M., Marino, J., Marquette, W. H., 2004: *First Results from the NSO/NJIT Solar Adaptive Optics System.* in: Telescopes and Instrumentation for Solar Astrophysics, S. Fineschi and M. A. Gummin (eds.), Proceedings of the SPIE **5171**, 179-186

Wang, H., Denker, C., Spirock, T., Goode, P. R., Yang, S., Marquette, W., Varsik, J., Fear, R. J., Nenow, J., Dingley, D. D., 1998, *New Digital Magnetograph System at Big Bear Solar Observatory.* Solar Physics **183**, 1-13

Wang, J., Wang, H., Spirock, T. J., Lee, C. Y., Ravindra, N. M., Ma, J., Goode, P. R., Denker, C., 2000: *Optical Design of a Near-Infrared Birefringent Filter System and Measurement of Birefringence Index of Calcite.* Optical Engineering **40/6**, 1016-1023

E.2. Deqing Ren

Education

2001:	Ph. D. in Physics/Astronomy, University of Durham, Great Britain
1988:	M. Sc. in Mechanical Engineering, Nanjing University of Science and Technology, China
1985:	B. Sc. in Mechanical Engineering, Nanjing University of Science and Technology, China

Professional Experience

2004–present:	Research Scientist, Center for Solar-Terrestrial Research, New Jersey Institute of Technology, Newark, New Jersey
2003–2004:	Research Associate, Princeton University, New Jersey
2002–2003:	Research Associate, Penn State University, Pennsylvania
2001–2002:	Optical Engineer, National Solar Observatory, Sacramento Peak, New Mexico
2000–2001:	Senior Post-Doctoral Research Assistant, University of Durham, Great Britain
1988–1996:	Engineer, Kunming Institute of Physics, China

Synergistic Activities

2002–2003:	Constructed an Advanced Image Slicer Integral Field Unit (IFU) for 3-D spectroscopy in the first time in the USA
2001–2002:	Invented a single-mode fiber interferometer for AO wave-front calibration and test
2001–2002:	Leading the optical design of a high-order Adaptive Optics (AO) for Dunn Solar Telescope (DST), National Solar Observatory, Sacramento Peak, New Mexico
2001–2002:	Involved in the optical design for the ATST 4-m solar telescope and its AO optical design
1997–2000:	Pioneered a fiber bundle connector for fiber multiple spectrographs; constructed a prototype multiple IFUs for an 8-meter telescope; involved in the construction of the GMOS IFU for the 8-meter Gemini telescope

Collaborations

Recent Collaborators: Gary J. Hill (MacDonald Observatory, University of Texas), Christoph Keller (National Solar Observatory, Tucson, Arizona), Thomas Rimmele, (National Solar Observatory, Sacramento Peak, New Mexico), and Ray Sharples (University of Durham, Great Britain)

Graduate and Postdoctoral Advisors: Jeremy Allington-Smith (University of Durham, Great Britain), Jian Ge (Penn State University, Pennsylvania), Steve Hegwer (National Solar Observatory, Sacramento Peak, New Mexico), and Jeremy Kasdin (Princeton University, New Jersey)

Selected Publications

Allington-Smith, J. R., Content, R., Ren, D., 2000, *Integral Field Spectroscopy with the Gemini Multi-Object Spectrograph.* Proceedings of the SPIE **4008**, 1172-1180

Lee, D., Haynes, R., Ren, D., Allington-Smith, J. R., 2001, *Characterization of Lenslet Arrays for Astronomical Spectroscopy.* Publications of the Astronomical Society of the Pacific **113**, 1406-1419

Ren, D., 2004, *Lens Design.* in: Encyclopedia of Optical Engineering, R. B. Johnson and R. G. Driggers (eds.), Marcel Dekker, New York, in press

Ren, D., Hegwer, S., 2003, *Image Slicer Integral Field Unit for Solar Telescopes.* Proceedings of the SPIE **4853**, 551-557

Ren, D., Allington-Smith, J. R., Sharples, R. M., Dodsworth, G. N., 2003, *The Design and Construction of a Multiple-Integral-Field-Unit for 8-Meter Telescopes.* Proceedings of the SPIE **4842**, 384-391

Ren, D., Hegwer, S., Rimmele, T. R., 2003, *The Optical Design of a High-Order Adaptive Optics for the NSO Dunn Solar Telescope and the Big Bear Solar Observatory.* Proceedings of the SPIE **4853**, 593-599

Ren, D., Rimmele, T., Hegwer, S., Murray, L., 2003, *A Single-Mode Fiber Interferometer for AO Wavefront Tests.* Publications of the Astronomical Society of the Pacific **115**, 355-361

Ren, D., Allington-Smith, J. R., 2002, *On the Application of IFU Design Theory for Imaging Spectroscopy.* Publications of the Astronomical Society of the Pacific **114**, 866-878

Ren, D., Sharples, R., Allington-Smith, J. R., Dodsworth, G. N., Robertson, D. J., Dalton, G., 2001, *Design and Construction of a Fibre Bundle Connector using Microlenses.* Optical Engineering **40/12**, 2709-2717

Ren, D., Allington-Smith, J. R., 1999, *Apochromatic Lenses for Near-Infrared Astronomical Instruments.* Optical Engineering **38/3**, 537-542

E.3. Haimin Wang

Education

1982:	B. S. in Astronomy, Nanjing University, China
1988:	Ph. D. in Astrophysics, California Institute of Technology, Pasadena, California

Professional Experience

1997–present:	Associate Director, Big Bear Solar Observatory, New Jersey Institute of Technology, Newark, New Jersey
2004–present:	Distinguished Professor of Physics, Physics Department, New Jersey Institute of Technology, Newark, New Jersey
2000–2004:	Professor of Physics, Physics Department, New Jersey Institute of Technology, Newark, New Jersey
1997–2000:	Associate Professor of Physics, Physics Department, New Jersey Institute of Technology, Newark, New Jersey
1995–1997:	Assistant Professor of Physics, Physics Department, New Jersey Institute of Technology, Newark, New Jersey
1994–1995:	Senior Research Fellow, California Institute of Technology, Pasadena, California
1992–1994:	NASA Compton Research Fellow, California Institute of Technology, Pasadena, California
1988–1992:	Research Scientist in Astronomy, California Institute of Technology, Pasadena, California

Ph. D. and Post-Doctoral Advisor

Harold Zirin (California Institute of Technology)

Collaborations

David Falconer (Marshall Space Flight Center), Jongchul Chae (Seoul National University, Korea), James Chen (Naval Research Laboratory), Yuangyong Deng (Beijing Astronomical Observatory, Chinese Academy of Sciences), Haisheng Ji (Purple Mountain Observatory, China), Yunchun Jiang (National Astronomical Observatory/Yunnan Observatory, Chinese Academy of Sciences), Christoph Keller (National Solar Observatory), Mats Löfdahl (Royal Swedish Academy of Sciences), Sara Martin (Helio Research), Yong-Jai Moon (Korea Astronomy Observatory), Ron Moore (Marshall Space Flight Center), Thomas Rimmele (National Solar Observatory), Nathan Schwadron (Southwest Research Institute), Aihua Wang (University of Alabama), S. T. Wu (University of Alabama), and Hong-Qi Zhang (National Astronomical Observatories, Chinese Academy of Sciences)

Selected Publications

Liu, C., Qiu, J., Gary, D. E., Krucker, S., Wang, H., 2004, *Studies of Microflares with RHESSI Hard X-Ray, BBSO Hα and MDI Magnetograms.* Astrophysical Journal **604**, 442-448

Jing, J., Lee, J., Spirock, T. J., Xu, Y., Wang, H., Choe, G. S., 2003, *Periodic Motion Along a Solar Filament Initiated by a Subflare.* Astrophysical Journal Letters **584**, L103-L106

Qiu, J., Liu, C., Gary, D. E., Nita, G. M., Wang, H., 2004, *Hard X-Ray and Microwave Observations of Microflares.* Astrophysical Journal **612**, 530-545

Wang, H., Liu, C., Qiu, J., Deng, N., Goode, P. R., Denker, C., 2004, *Rapid Penumbral Decay Following Three X-Class Flares.* Astrophysical Journal Letters **601**, L195-L198

Wang, H., Qiu, J., Jing, J., Zhang, H., 2003, *Study of Ribbon Separation of a Flare Associated with a Quiescent Filament Eruption.* Astrophysical Journal **593**, 564-570

Wang, H., Gallagher, P., Yurchyshyn, V., Yang, G., Goode, P. R., 2002, *Core and Large-Scale Structure of the 2000 November 24 X-Class Flare and Coronal Mass Ejection.* Astrophysical Journal **569**, 1026-1031

Wang, H., Ji, H., Schmahl, E. J., Qiu, J., Liu, C., Deng, N., 2002, *Sudden Disappearance of a Small Sunspot Associated with the 2002 February 20 M2.4 Flare.* Astrophysical Journal Letters **580**, L177-L180

Wang, H., Spirock, J., Qiu, J., Ji., H., Yurchyshyn, V., Moon, Y., Denker, C., Goode P. R., 2002, *Rapid Changes of Magnetic Fields Associated with Six X-Class Flares.* Astrophysical Journal **576**, 497-504

Yurchyshyn, V., Wang, H., Goode, P. R., Deng, Y., 2001, *Orientation of the Magnetic Fields in Interplanetary Flux Ropes and Solar Filaments.* Astrophysical Journal **563**, 381-388

F. Summary Proposal Budget

The instrument budget is summarized in the following spreadsheet. The prices are either based on vendor price quotes provided as supplementary documents to this proposal 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. They are a line item in the equipment <$2,500 category in the summary proposal budget spreadsheet. Equipment items to be purchased in Year 1 and Year 2 of the proposal are indicated in **blue** and **red**, respectively.

Product	Vendor	Item Price	Quantity	Total
Objective lens, D = 200 mm	Nu-Tek Precision Optical Corporation	$15,000.00	1	$15,000.00
Dicroic beamsplitter, D = 100 mm	Nu-Tek Precision Optical Corporation	$7,500.00	1	$7,500.00
Relay lenses, D = 63 mm	Nu-Tek Precision Optical Corporation	$4,000.00	6	$24,000.00
Plane mirror substrate, Zerodur, D = 300 mm	Bernhard Halle Nachfl. GmbH	$4,300.00	2	$8,600.00
Protective aluminium coating	Bernhard Halle Nachfl. GmbH	$650.00	2	$1,300.00
Optical table, 5 ft. x 8 ft., M-RS2000-58-8	Newport	$5,913.00	1	$5,913.00
Optical Mounts, 3 in., U300-A3K	Newport	$210.00	6	$1,260.00
LTA Series Precision Motorized Actuators, LTA-HS	Newport	$1,280.00	2	$2,560.00
Linear Stages, 426	Newport	$363.00	6	$2,178.00
Micrometer, SM-25	Newport	$89.00	4	$356.00
Panels for optical bench enclsure	McMaster Carr	$1,280.00	1	$1,280.00
Structural rail system for optical bench enclosure	McMaster Carr	$520.00	1	$520.00
Interference filter CaII K	Barr Associates	$6,270.00	1	$6,270.00
Interference filter G-band	Barr Associates	$5,675.00	1	$5,675.00
Interference filter continuum	Barr Associates	$5,875.00	1	$5,875.00
Interference filter H-alpha	Barr Associates	$9,745.00	1	$9,745.00
Turret and other mechanical components	NJIT Center for Manufacturing Systems	$120,000.00	1	$120,000.00
Catwalk, steel ladder with welded-on cage, access door	Richard Zaharias (local contractor)	$22,538.00	1	$22,538.00
Alta U16 CCD camera incl. MaxIm/DL software	Apogee Instruments	$38,495.00	1	$38,495.00
Alta U42 CCD camera incl. MaxIm/DL software	Apogee Instruments	$40,995.00	1	$40,995.00
Upgrade KX4 to U4	Apogee Instruments	$5,000.00	1	$5,000.00
Stonehaven A261T 2U Rack Server	Aberdeen	$7,836.00	2	$15,672.00
Quantum SDLT 320 Tape Drive	CDW	$3,350.00	1	$3,350.00
Year 1				**$238,770.00**
Year 2				**$105,312.00**
Total				**$344,082.00**

The following spreadsheet lists all expenses separately for both NSF and NJIT including fringe benefits and facilities and administrative costs (F&A) for each year during the two-year duration of the project. PI Denker and Co-PI Wang contributions are covered as part of their basic research. One month/year salary is requested for Co-PI Ren. In addition, one month/year is required for BBSO staff members William Marquette, Jeff Nenow, and John Varsik to cover their contributions to the MC-SoFT project. The budget includes NSF support including tuition for one Ph. D. student for two years. Once the project is concluded, the Ph. D. student will use MC-SoFT to collect science data for the research part of the Ph. D. thesis. The funding for this part of the Ph. D. student's work will come from a different research grant. The NSF budget also includes the following smaller items: \$5,000/year supply funds for laboratory maintenance and materials of the BBSO machine shop, and \$2,000/year for publications in refereed journals and conference proceedings. In addition to our scientific publication, CSTR/BBSO has continuously published its instrument development efforts in journals and proceedings such as Solar Physics, Optical Engineering, Encyclopedia of Optical Engineering, Proceedings of the SPIE, and Astronomical Society of the Pacific Conference Series. Travel funds in the amount of \$5000/year are requested for attending one domestic conference (Solar Physics Divsion/American Astronomical Society or SPIE International Symposium – Astronomical Telescopes and Instrumentation) and for project-related travel from CSTR to BBSO. Typical air fares are \$300 (Newark–Ontario or Newark–Santa Ana), two-week car rental is about \$250, and BBSO provides housing. We anticipate two or three two-week stays at BBSO per year during the instrument development and commission. The budget also includes 10-week salary at \$10/hour for an undergraduate student, who will work as a summer research assistant at BBSO. We expect to recruit a Junior from the ADHC, who is expected to return for the second year. The top 10% of the NJIT students are enrolled in the ADHC and our close collaboration with the ADHC has allowed us in the past to find extremely motivated and smart students for projects at CSTR and BBSO.

		Yr - 1	Yr - 2	Yr - 1	Yr - 2	Total		
Categories		**Sponsor**	**Sponsor**	**NJIT**	**NJIT**	**Sponsor**	**NJIT**	**Grand**
Faculty AY	**1000**							
Denker	1007	0	0		0	0	0	0
Wang	1007	0	0		0	0	0	0
		0	0		0	0	0	0
		0	0		0	0	0	0
Sub-Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**
Faculty Summer								
	1024	0	0		0	0	0	0
		0	0		0	0	0	0
Sub-Total		**0**	**0**	**0**	**0**	**0**	**0**	**0**
Professional Staff	**1100**							
Marquette, Wm 1 mos	1101	5,125	5,304		0	10,429	0	10,429
Nenow, J 1 mos		4,167	4,313		0	8,480	0	8,480
Ren, D. 1 mos		4,167	4,313		0	8,480	0	8,480
Varsik, J 1 mos		4,375	4,528		0	8,903	0	8,903
Sub-Total		**17,834**	**18,458**	**0**	**0**	**36,292**	**0**	**36,292**
Students	**1300**							
Graduate Stipend	1304	20,500	21,218		0	41,718	0	41,718
Undergraduates, hourly	1313	4,000	4,140		0	8,140	0	8,140
Other Students		0	0		0	0	0	0
Sub-Total		**24,500**	**25,358**	**0**	**0**	**49,858**	**0**	**49,858**
Total Personnel Costs:		**42,334**	**43,816**	**0**	**0**	**86,150**	**0**	**86,150**
Fringe Benefits	**2000**							
Fringe Benefits, 25.9% AY	2050	4,619	4,781	0	0	9,400	0	9,400
Fringe Benefits, 6.9%, Summer	2060	0	0	0	0	0	0	0
Fringe Benefits, 9% Graduates	2070	2,205	2,282	0	0	4,487	0	4,487
Total Fringe Benefits:		**6,824**	**7,063**	**0**	**0**	**13,887**	**0**	**13,887**
Travel	**5000**							
Domestic	5000	5,000	5,000			10,000	0	10,000
International	5110					0	0	0
Total Travel Costs:		**5,000**	**5,000**	**0**	**0**	**10,000**	**0**	**10,000**
Equipment:	**3000**							
Equipment < 2500	3111	5000	3000			8,000	0	8,000
Equipment > 2499	3001	238,770	105,312			344,082	0	344,082
Total Equipment Costs:		**243,770**	**108,312**	**0**	**0**	**352,082**	**0**	**352,082**
Supplies:	**4000**							
Supplies		5,000	5,000			10,000	0	10,000
						0	0	0
Total Supply Costs:		**5,000**	**5,000**	**0**	**0**	**10,000**	**0**	**10,000**
Other:	**6000**							
		0	0			0	0	0
Publications		2,000	2,000			4,000	0	4,000
Total Other Costs:		**2,000**	**2,000**	**0**	**0**	**4,000**	**0**	**4,000**
Subcontracts/Agreements:								
< $25,001	6110					0	0	0
> $25,000	6111					0	0	0
Total Subcontracts/Agreements:		**0**	**0**	**0**	**0**	**0**	**0**	**0**
Other:	**8000**							
Tuition	8003	15,647	16,742		0	32,389	0	32,389
						0	0	0
Total Other charges:		**15,647**	**16,742**	**0**	**0**	**32,389**	**0**	**32,389**
Total Direct Costs:		**320,575**	**187,933**	**0**	**0**	**508,508**	**0**	**508,508**
Total MTDC:		**66,158**	**65,879**	**0**	**0**	**132,037**	**0**	**124,037**
F&A: 51;52% of MDTC		**33,741**	**34,257**	**0**	**0**	**67,997**	**0**	**67,997**
TOTAL PROJECT COSTS:		**354,316**	**222,190**	**0**	**0**	**576,505**	**0**	**576,505**

G. Facilities, Equipment, and Other Resources

The NJIT's Center for Solar-Terrestrial Research (CSTR) operates two major solar facilities: BBSO and the Owen's Valley Solar Array (OVSA). The Center also operates the five-station GHN to continuously monitor solar activity. CSTR is currently expanding its office complex on the Newark campus to accommodate the increasing number of graduate students and researchers. The new parts of the office complex will become available in early 2005. Two new optical laboratories (one at CSTR and one at BBSO) are available for the design, development, and testing of new instruments. In addition, CSTR has direct access to several parallel and distributed computer architectures, which are part of the real-time image reconstruction system and the Information Technology Research (ITR) project.

Since instrument development is a corner stone of this proposal, the Center for Manufacturing Systems (CMS) at NJIT, which is an Advanced Technology Center of the New Jersey Commission on Science and Technology, would is an ideal partner for the MC-SoFT development. CMS is specialized in equipment and product design and prototype development. In recent years CSTR and CMS collaborated in various projects, which included mechanical, electrical and electronic designs using a variety of advanced Computer Aided Design (CAD) systems. Many parts of the NST are manufactured at CMS and we have established a highly efficient "pipeline" between the instrument designers at CSTR/BBSO and the manufacturing center. CMS offers a 7,000 square foot, two story, high-bay factory floor, which houses a full complement of advanced machine tools and a production scale, multi-layer extrusion line. Machines are connected by a high-speed computer network, and served by industrial robots. CSTR has full access to CMS and Joseph Molnar, the manufacturing manager at CMS, has always been understanding and helpful in educating our graduate students.