

B. Project Description

B.1 Overview

The 1.6 m clear aperture solar telescope in Big Bear has been operating for more than four years. This telescope is the highest resolution solar telescope in the world. The telescope is the first facility-class solar telescope built in U.S. in a generation. New adaptive optics systems are in regular operation, and several new post-focus instruments are now on-line. Further, we have an automated system that allows anyone to remotely examine and choose desired datasets that are automatically placed in an anonymous ftp site after the request. However, with the coming torrent of NST data, we need a petabyte scale server to store and provide data to the community. **Here we propose for a petabyte scale data server to keep data in Big Bear and provide it the community. The server costs \$220 K.** We are grateful for the support that AFOSR has provided us over the years, and look forward to

It is the Sun's magnetic field that makes it a dynamic, eruptive star. The coupling of that field and convective motion in the solar atmosphere drive a variety of dynamic phenomena, from small-scale bright points in the photosphere, to extensive explosive flares and coronal mass ejections (CMEs) from the chromosphere. Thus far, however, we only have a coarse framework of how mass and energy are stored, transported and released in solar atmosphere.

There are several hurdles hindering us from moving forward. First, the magneto-convection rooted at the base of the photosphere has an intrinsic scale ~ 100 km that must be probed, which requires a telescope of aperture ~ 1.5 m to resolve such scales. Thus, studies of the dynamics of these fine structures require solar astronomy to graduate to larger than meter-class optical solar telescopes. Second, to obtain diffraction limited imaging with large aperture telescopes, especially critical technologies and sophisticated hardware, such as adaptive optics, have to be deployed to correct for atmospheric distortion. Third, the ideal solar instrumentation should be characterized by high spatial resolution, high temporal cadence, large spectral power, wide field-of-view (FOV) and broad wavelength coverage. A majority of the focal plane instrumentation operating at major solar telescopes have to make a painful trade-off among these qualities. Spectrometers based on dual or triple Fabry-Pérot Interferometers (FPIs) offer an excellent solution. Yet such spectrometers are only available in a narrow visible wavelength range. Fourth, despite the great effort that has been made in solar magnetic field measurements, diffraction limited polarimetric observations are rare with high sensitivity and precision. Moreover, most of these measurements concentrate on the photosphere. There are almost no reliable measurements of the magnetic vector field in the chromosphere and at the base of corona, which particularly serves as an important boundary condition in building self-consistent coronal models.

With all of the aforementioned criteria in mind and after several years of effort, an off-axis, 1.6 m clear aperture New Solar Telescope (NST) has been built and put into operation at the Big Bear Solar Observatory (BBSO). The NST is the largest aperture, highest resolution solar telescope in the world and will dominate U.S. ground-based solar observations at least until the end of this decade before the 4 m Advanced Technology Solar Telescope (ATST) comes online. Since an adaptive optics (AO) system was implemented on the NST in the Summer of 2010, diffraction limited observations have regularly been obtained. Figure 1 shows two typical diffraction limited images of the photosphere and chromosphere taken in TiO 705.7 nm and H α 656.3 nm, respectively. These were taken with the old AO system, Nonetheless, the left image in Figure 1 was called the most precise image of the

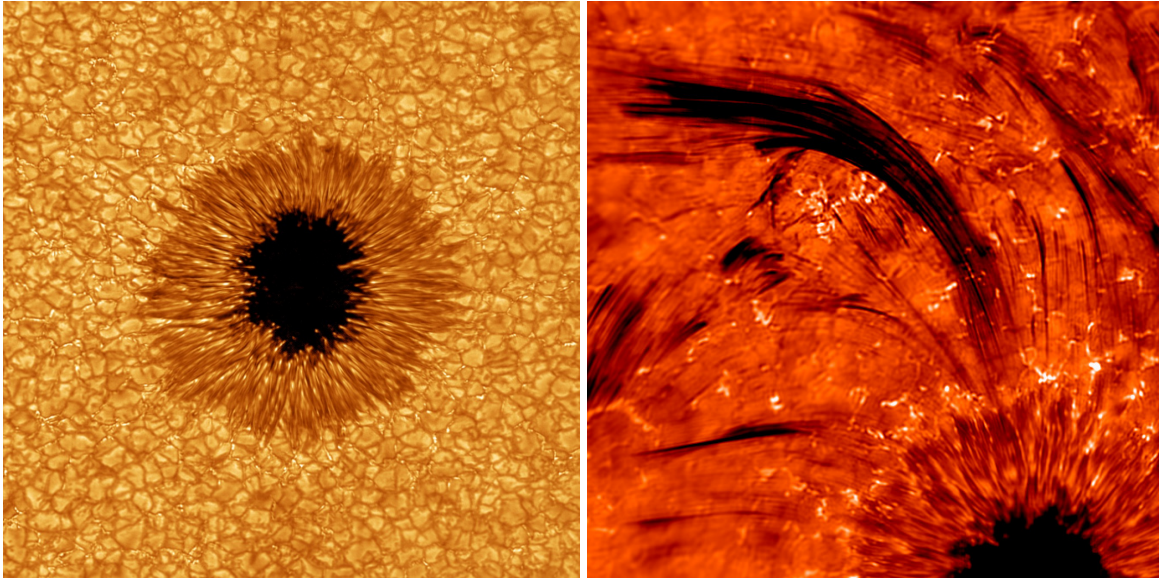


Figure 1: Left: A small sunspot observed on 2 July 2010. Right: H_{α} image of the same sunspot revealing the dynamical layer overlying the surface region shown in the full sunspot image. Most apparent are the long dark streaks, so-called “jets” arising from the bright magnetic regions on the edge of the penumbra. Both images used adaptive optics enabling real-time correction for atmospheric distortion.

Sun’s surface ever taken¹ and was chosen by the science editors of National Geographic as one of the top ten space images of 2010. This first generation adaptive optics system featured a 97 actuator deformable mirror. After three years of considerable effort there is a new AO system on the NST having 357 actuators enabling a fuller correction of atmospheric distortion. Figure 2 shows a sunspot image from 2013, after the new AO system came into regular operation. Figure 1 and Figure 2 are sunspots from comparable seeing days, the image from 2010 (with 97 actuator DM) and Summer 2013 sunspot image (with 357 actuator DM) were both taken in TiO (710 nm). The differences between the two images are stark. The 2013 image shows a much sharper central region. What is apparent in the center of the Summer 2013 image is the fine structures, which are absent in the 2010 image. For instance, in the 2013 data sequence, one can see dark centers in some umbral dots something that has been predicted, but has never been seen before. Basically, the higher order AO corrects sufficiently to enable us to exploit the NST’s large aperture. Thus, for a sunspot, like that in Figure 2, we resolve <0.1 dark centers in umbral dots. Such image quality enables us to probe the origins of space weather on much finer spatial scales than ever before. Also, in a movie of Figure 2, one can see a clear twisting motion in the light bridge. Further, the NST’s success opens a door to unprecedented high resolution observations. Its 2.0 m^2 area of the primary mirror also provides a huge “light-bucket” to accumulate sufficient photons for high temporal cadence observations in the visible and NIR. A schematic of the NST and its instrumentation is shown in Figure 3.

In typical operation, AO corrected light is fed to the spectro-polarimeters, which can generate about 5 TB per day of raw data. Currently, we process these data via speckle reconstruction, which utilizes bursts of about 100 images and reconstructs each burst into a single image. The reconstructed images are then strung together to make a movie with a time cadence of several seconds. However, 90% of the data are lost for lack of storage, which precludes re-visiting the data later if one thinks of another use for the raw data. Further, this limits the capabilities of any user who downloads the

¹<http://www.cieletespace.fr/node/5752>

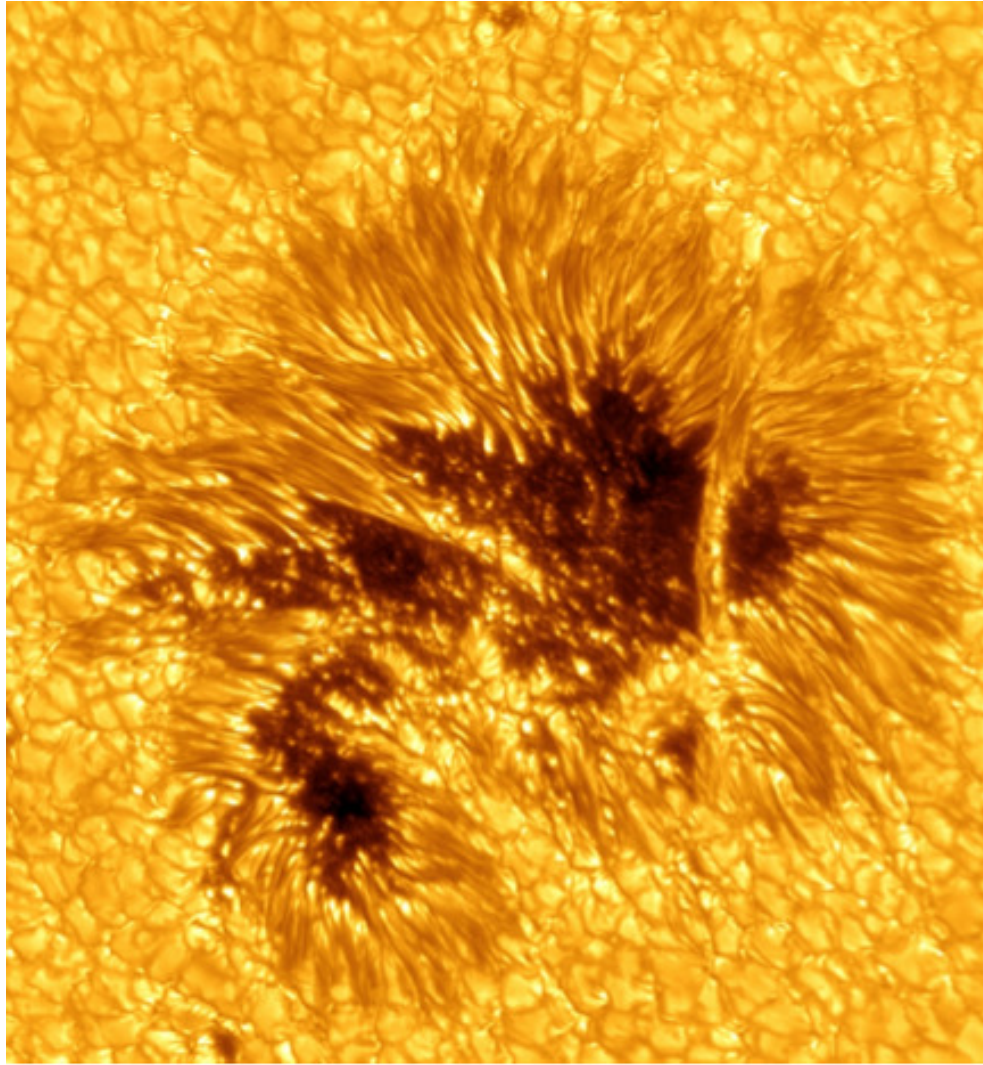


Figure 2: A sunspot image on DATE??? was near disk center. Improving spatial resolution from AO-308 within the isoplanatic patch reveals a much more complex and fine structure to the magnetic field compared to Figure 1.

data. We have an automated data retrieval system in place, which could be easily modified to allow retrieval of raw data.

The retrieval is straightforward. An interested user can go (MAKE THE WWW.'S VISIBLE???)

The power of the NST is illustrated in Figure 5, which illustrates our discovery of cold loops in He I 10830 Å light. The loops originate from magnetic bright point shuffling in the intergranular lanes. Impulsive events feed the loops which are ten times cooler and ten time narrower than any seen before. They reach up to the base of the corona and somehow light up the million degree corona. Continuous impulsive events have been tracked from their origin in the photosphere on through to their brightening of the local corona. We achieve this by combining high resolution ground-based data from the NST with AIA/SDO satellite data. The NST observations in a narrow band absorption line, Helium I 10830 Å reveal unexpected complexes of ultrafine, hot magnetic loops seen to be reaching from the photosphere to the base of the corona. Most of these ultrafine loops are characterized by an apparently constant, but surprisingly narrow diameter of about 100 km all along each loop, and the loops originate on the solar surface from intense, small-scale magnetic field elements. The NST observations detect upward injections of hot plasma that drives the ultrafine loops from the photosphere to the base of the corona. The ejecta have their individual footpoints in the intergranular lanes between the sun's ubiquitous, convectively driven granules. We note that

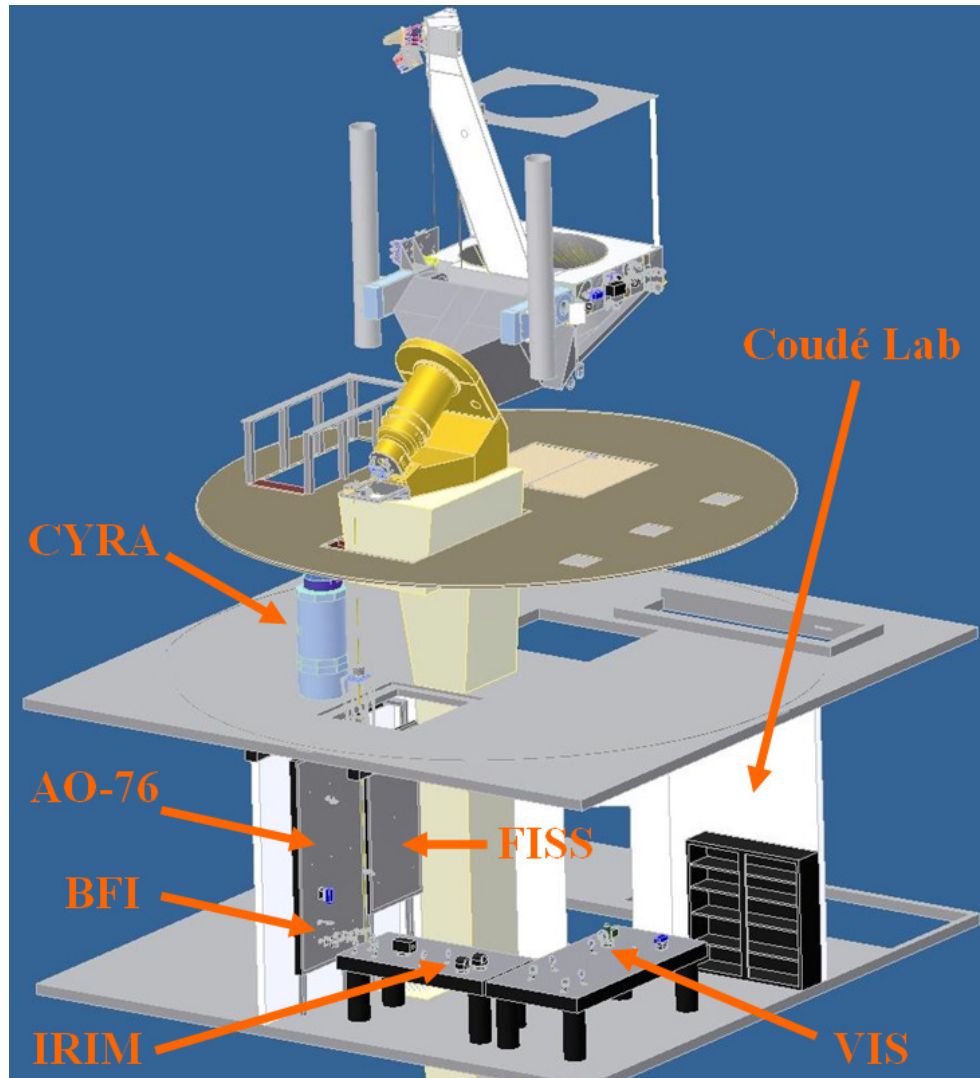


Figure 3: A schematic of the off-axis NST with its secondary mirror at the highest point. NST light is fed from the top floor to either the Coudé Lab or CYRA (CrYogenic solar spectroGRAph). In the Coudé Lab, all light is first corrected by AO, then the beam is split into IR and visible light components, which are fed to one or more of the BFIs (Broadband Filter Imagers), like TiO (G-band), H α or 10830 Å, or to FISS (Fast Imaging Solar Spectrograph), as well as to NIRIS (Near InfraRed Imaging Spectro-polarimeter). VIS (Visible Imaging Spectro-polarimeter) awaits AO-308. CYRA will be fed by a tip-tilt correction. NEED UPDATED VERSION OF THIS SHOWING CORRECT CYRA AND REPLACING IRIM BY NIRIS???

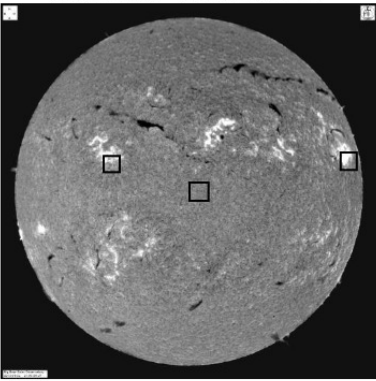
segments of some of the more intense upward injections are seen as rapid blue-shifted events in simultaneous H α blue wing images observed at BBSO. In sum, the observations showed impulsive coronal heating events from upward energy flows originating from intergranular lanes on the solar surface accompanied by co-spatial mass flows.

B.2 NST Instruments

Adaptive Optics: The currently operational AO, - called “AO-308” was installed on the NST in 2013. AO-308 incorporates a 357 actuator deformable mirror (DM), a Shack-Hartmann wave front sensor with 308 subapertures, and a digital signal processor system. AO corrected light is fed to all instruments in the Coudé Lab. There diffraction limited resolution is attained in the visible after speckle reconstruction. Without speckle reconstruction, and under good atmospheric conditions, the resolution is sufficient to perform diffraction limited photometry and polarimetry over the isopla-

[Previous Day](#)[BBSO Archive and Observing Log](#)[Next Day](#)

NST Data Coverage
16:04:45.2 - 22:25:15.6 UT



Data Samples

bbso_tio_pcosr_20120524_160445.fts	thumb	header
bbso_tio_pcosr_20120524_165453.fts	thumb	header
bbso_tio_pcosr_20120524_175049.fts	thumb	header
bbso_tio_pcosr_20120524_184107.fts	thumb	header
bbso_tio_pcosr_20120524_185932.fts	thumb	header
bbso_tio_pcosr_20120524_193200.fts	thumb	header
bbso_tio_pcosr_20120524_193349.fts	thumb	header
bbso_tio_pcosr_20120524_202446.fts	thumb	header
bbso_tio_pcosr_20120524_211514.fts	thumb	header
bbso_tio_pcosr_20120524_214714.fts	thumb	header
bbso_tio_pcosr_20120524_220415.fts	thumb	header

[Top](#)

DATE: 2012/05/24
FILTER: TIO; Ha-0.75A
OBS TIME: 16:04 - 22:25 UT
TARGET: NOAA 11484
SEEING, DATA QUALITY: fair, not stable
OBSERVER: CP,Cao
OBS COMMENTS: Region center. Nearing west limb. HeI 10830A run
OBS COMMENTS: Run by vayur; Used 70 best images

Comments by Scientist:
See [Obs Logs](#) for more info...

After Reconstruction Info:
Quick Look Low Resolution [TIO](#) and [Ha](#) Movies

Reconstructed Images Samples:

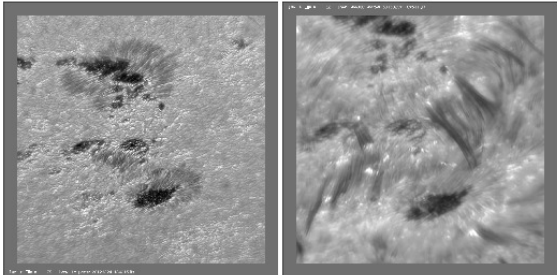


Figure 4: On a typical observing day, the NST collects about 5 TB of raw data. And data are post-processed to about 500 GB for ease of use. All data taken during 2010-2012 are now released to public through an automatic data request system. You can click this link and use the catalog to get a quick look at the data. Then, if you would like to download data, click this link and fill out the data request form and submit it. You will receive an email directing you to an anonymous ftp site where you can collect the data. For the raw data, there will be much more data and so the location of the stored data will be within the new server. This change would be transparent to the requestor.

natic patch at all visible (and IR) wavelengths on the NST under nominal BBSO seeing conditions. Traditional AO systems, such as AO-308 yield diffraction limited observations confined to the isoplanatic patch ($\sim 7''$ - $8''$ at 500 nm on average in summer) with a gradual roll-off away from the patch. The next generation multi-conjugate AO (MCAO) is being developed at BBSO, which will enable diffraction limited observations over an extended field. MCAO will employ three DMs to correct the turbulence in the ground layer (< 500 m), and the boundary layer (3-6 km) respectively. First light of the NST MCAO system is expected in Fall 2013 with regular operation in Summer 2014. Since MCAO corrects a much larger field, perhaps even the entire field, the temporal cadence of the observations will be much higher, which is another reason a petabyte scale data server is required.

NIRIS - Near InfraRed Imaging Spectro-polarimeter

The Near InfraRed Imaging Spectropolarimeter (NIRIS) is the direct successor to our earlier IR spectro-polarimeters. NIRIS will utilize dual Fabry-Pérot etalons that provide a larger, 85 arcsec, field of view and 6 times greater throughput resulting in a faster scan cadence of 1 sec for spectroscopic and 10 sec for full Stokes polarimetric measurements. The dual-beam optical design will image two simultaneous polarization states onto a 2024x2048 HgCdTe closed-cycle He cooled IR array, partially purchased under a previous DURIP. The primary lines of interests for NIRIS are the Fe I 1565 nm doublet which is the most Zeeman sensitive probe of the magnetic field in the deepest photosphere and the He I 1083 nm multiplet that is the best currently available diagnostics of upper chromospheric magnetic fields.

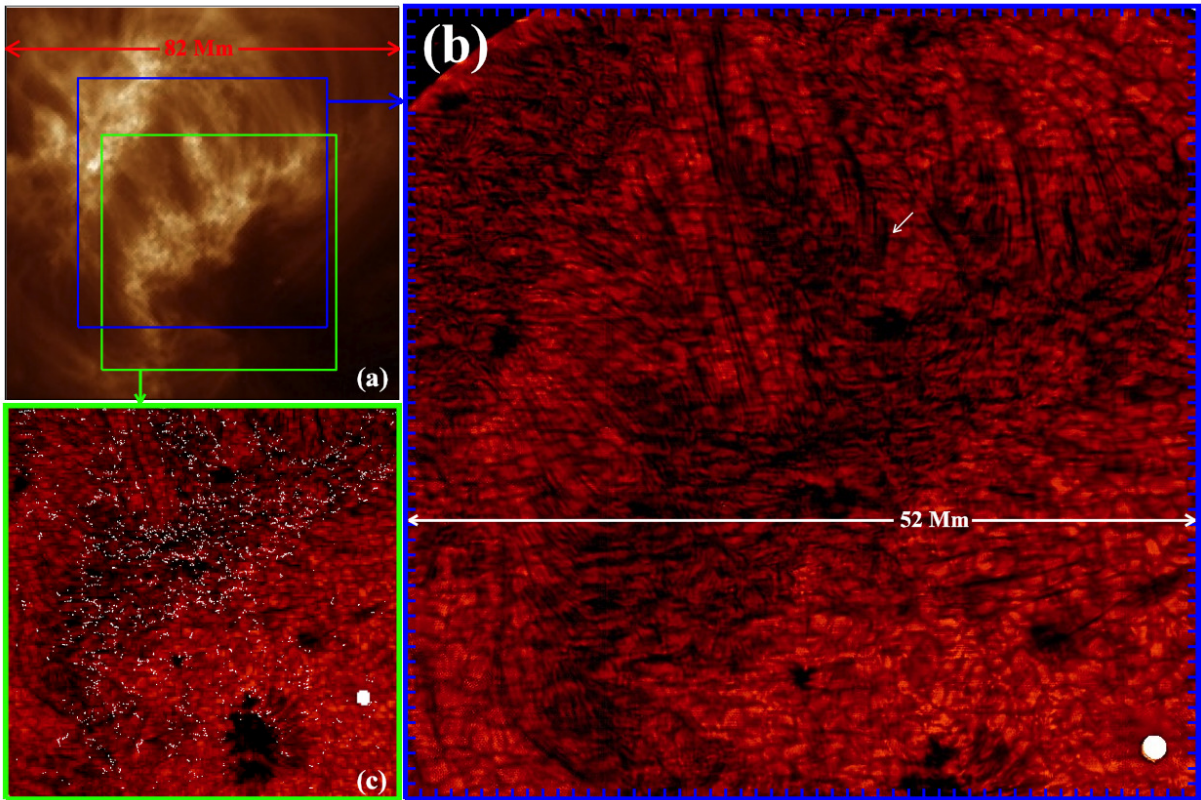


Figure 5: (a) A 193 Å image of coronal magnetic loop complex observed by AIA/SDO. (b) A sample image of NST ultrafine magnetic loops in He I 10830 Å narrow band filtergram (band width of 0.5 Å) at -0.25 Å from line center. The blue wing of the line is shown. (c) A zoomed-in view of the magnetic loops from the green box in (a). The field of view of IRIM is about 50'' × 25''.

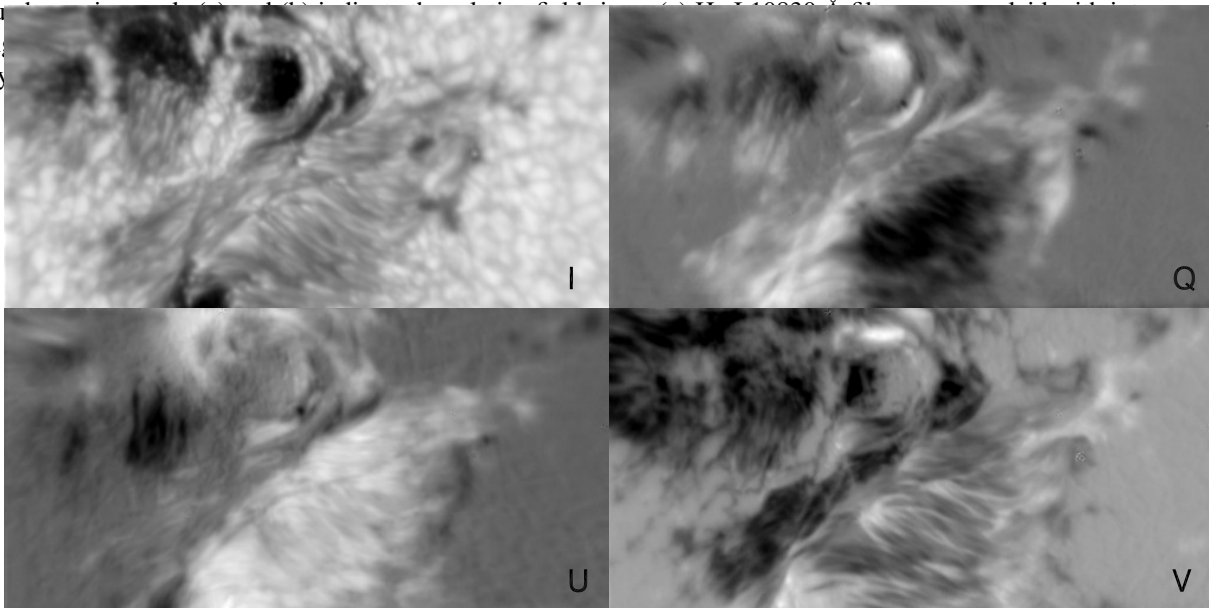


Figure 6: An early, calibrated NIRIS predecessor vector magnetogram without any image reconstruction near AR 11283 at 463W 119N, taken on 7 Sept. 2011. Stokes *I* and *V* are sliced in the blue wing of the Fe I 1564.85 nm line while *Q* and *U* are sliced in line center. Dual-beam technology was employed to minimize seeing-induced noise. The field of view of IRIM is about 50'' × 25''.

Species	λ	Bandpass
Fe I	1564.85 nm	0.1 Å
Fe I	1565.29 nm	0.1 Å
He I	1083.25 nm	0.05 Å
Si I	1082.70 nm	0.05 Å

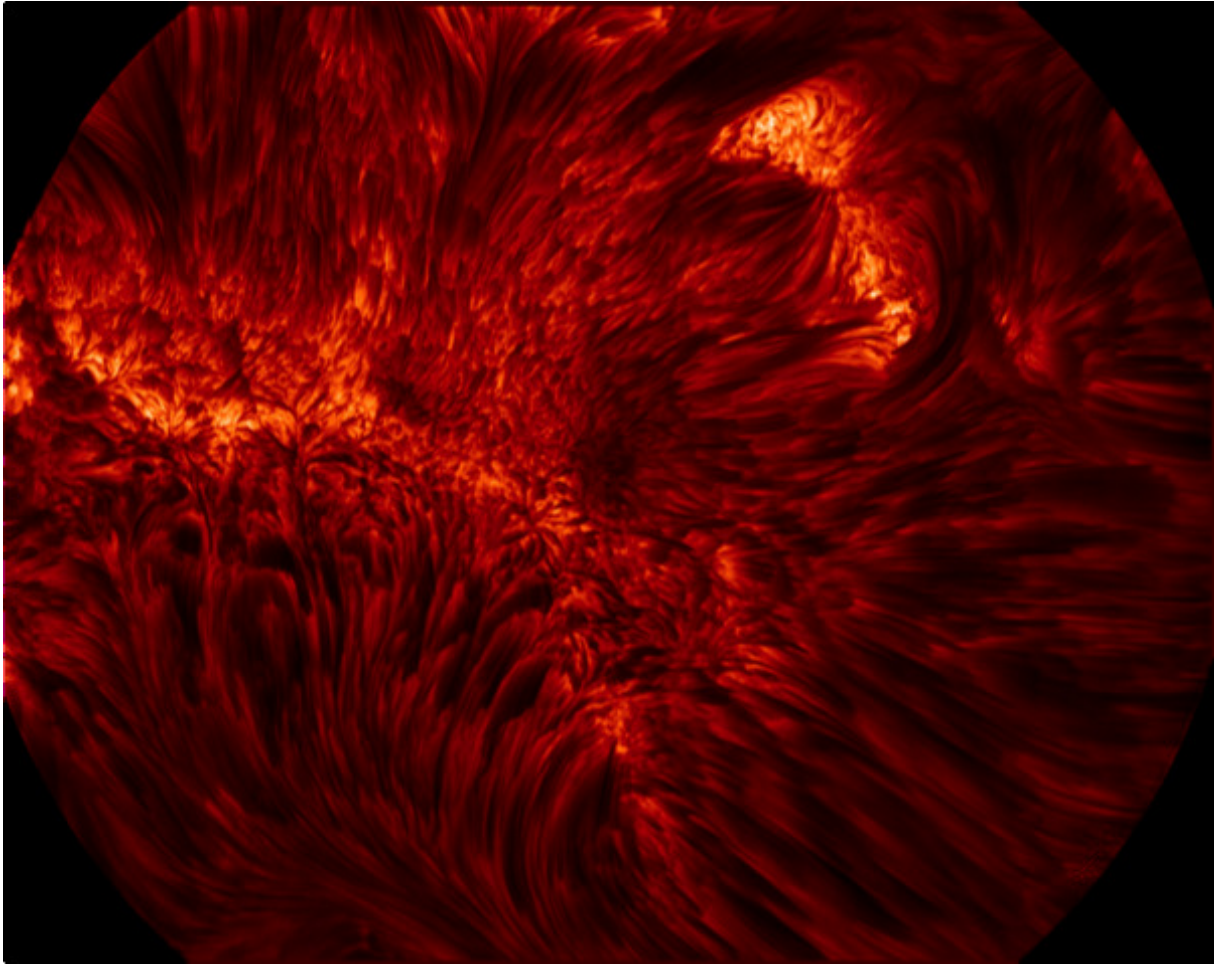


Figure 7: Need details on this image

B.3 VIS - Visible light Imaging Spectrograph

The Visible Imaging Spectrometer (VIS) is a near twin of the NIRIS operating in the visible wavelength range from 550 nm to 860 nm. VIS's Fabry-Pérot etalon produces a bandpass of 0.007nm over a 70 field of view. Available spectral lines include H α , Ca II 854.2 nm, Fe I 630 nm and Na I D2 line (589 nm) OTHER-LINES???. The spectrometric measurement cadence can reach 10 s. VIS has enjoyed first light spectral scans even before the second Fabry-Pérot (see Figure 6). In Figure 7, VIS was fed AO-308 corrected light. The figure shows a flare in centerline H α with fine resolution.

Species	λ	Bandpass
H α	656.3 nm	0.07 Å
Fe I	588.9 nm	0.07 Å
Na I D2	588.9 nm	0.07 Å
Ca II	854.2 nm	0.07 Å

BFIs - Broadband Filter Imagers

The Broadband Filter Imagers (BFIs) collect filtergrams of the AO-corrected field using a high-speed 2048x2048 CMOS camera. Filtergrams are typically taken in short bursts of 100 files every 15 to 30 seconds. Images are then post-facto speckle reconstructed to achieve diffraction-limited images (0.06 arcsec in G-band, 0.09 arcsec at TiO). A TiO image is shown in Figure 7 to be compared to

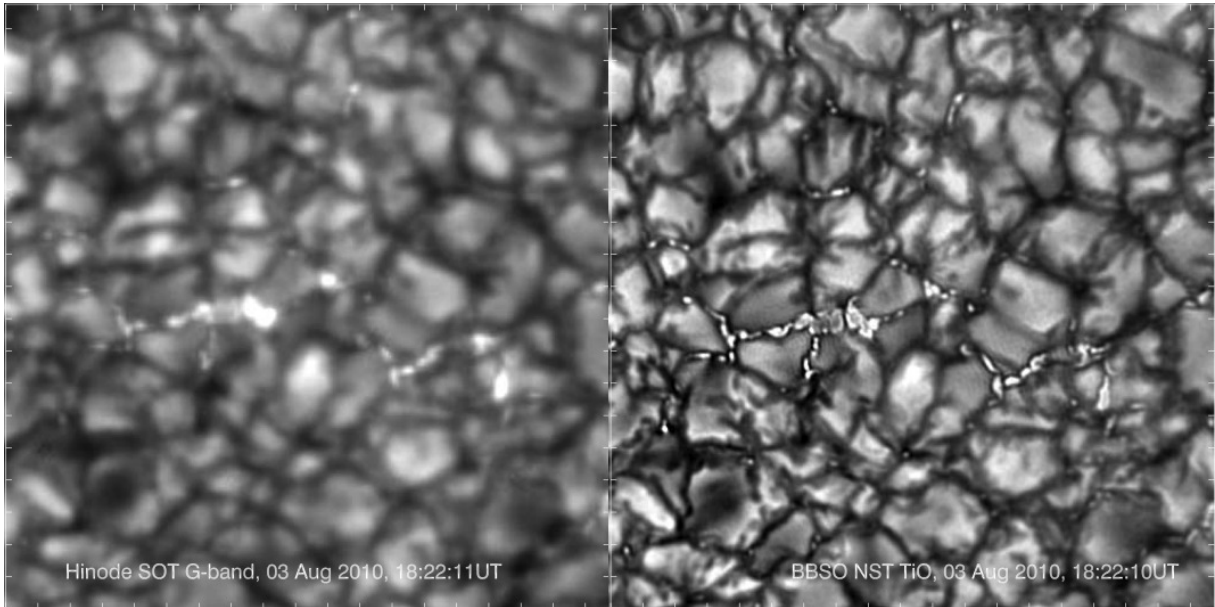


Figure 8: Here we show contemporaneous $19'' \times 19''$ Hinode G-band (left) and NST TiO (right) images of the same area of quiet Sun acquired on Aug 3, 2010 near disk center. Note the one-to-one correspondence between G-band and TiO bright points. The NST image clearly displays several tight clusters of resolved bright points (BPs) near the center of the field of view, which are seen in the Hinode image as single bright patches. There are indications that the dynamics of such clusters is at the heart of the origin of chromospheric upflows and heating events. The spatial and temporal resolution of the data allows us to track these individual BPs during their lifetime.

its Hinode counterpart taken at the same time and place. A comparison shows there is real value in making observations from the ground – large aperture along with AO matters!

B.4 CYRA - Cryogenic Infrared Spectrograph

The BBSO facility infrared spectrometer, CYRA, consists of a fully cryogenic folded Czerny-Turner spectrograph utilizing a 2048×2048 HgCdTe array sensitive through the $1 - 5 \mu\text{m}$ region with a maximum frame rate of 76 Hz. Spectral resolution (R_λ) range from 150,000 up to 750,000 depending on wavelength. The instrument's fore-optics include a correlation tracker for tip-tilt correction, an image de-rotator plus scan mirrors to allow scanning fields of up to 100 arcsec across the 80 arcsec long slit. A rotating waveplate and polarizing beamsplitter are used for dual-beam full-Stokes polarimetry. Zeeman splitting is accentuated in the infrared giving greater sensitivity for mapping weak magnetic features. Carbon Monoxide (CO) forms within the temperature minimum region that resides just above the photosphere and is thus a good probe of that dynamic region. There are several CO bands spread throughout the spectrum, however, the fundamental rotation-vibration lines around 4667 nm are unique in that they are not obscured by the Earth's atmosphere. The S/N for a given integration time will be dependent upon the actual grating efficiency, which has yet to be measured. The instrument scan cadence will be a function of total integration time, number of Stokes parameters and field of view. The resulting cadence is expected to be less than 1 min. Since CYRA operates at wavelengths from $1-5 \mu\text{m}$, AO is not essential because the size of the isoplanatic patch increases as $\lambda^{\frac{5}{3}}$ according to Kolmogorov theory and so a $7''$ isoplanatic patch at 500 nm becomes a $50''$ isoplanatic patch at $2.5 \mu\text{m}$. Thus, on days when the seeing is not so good, CYRA will become the high-resolution instrument of choice. CYRA can also generate daily TB scale data sets to populate the proposed server.

Over the next decade, NSO will build and begin operating the 4 m ATST, the flagship telescope for the solar community. The first light scientific instruments include a 2-channel visible

broad-band imager, a visible spectrograph, a visible tunable filter (VTF), a NIR spectro-polarimeter (NIRSP), and a NIR cryogenic spectrograph. Also, ATST 2010 SWG Meeting has emphasized the role of infrared tunable filter (NIRTF) and suggest it be the first ATST second generation instrument. NIRTF will use the same design concept as the NIRIS. Given the off-axis nature of both the NST and ATST, undoubtedly, NIRIS is an excellent testbed and pathfinder for the development of these ATST spectro-polarimeters including the NIRSP, NIRTF and VTF. As well, NIRIS's operation will provide these ATST instruments with valuable experience.

B.5 Budget

DIDN'T MAKE A TABLE OF JOHN'S BUDGET??? Aberdeen X86 storage server specifications

CPU: Xeon E6-2620 (x2) RAM: 32 GB Operating system disk: 300GB (x2, RAID 1 mirrored)
Expansion card added for two 10GB network ports Storage disks: 64 HGST 4TB, 7200 RPM Disks arranged as 3 RAID 5 arrays: 2 arrays of 24 disks, 1 array of 16.

Total raw capacity: 256 TB Total capacity after allowing for RAID redundancy: 208 TB.

Power requirement for each storage server: 1800W

Price for each storage server: \$39.6K

The archive system will need the following parts. The system will need to be installed in a location with appropriate power, air conditioning and network connections.

Item Price Quantity Total

5 storage servers Aberdeen X86 server as specified above \$39.6K 5 \$198K

1 10GB network switch Netgear ProSafe XS712T \$1.7K 1 \$1.7K 3 full-height racks Rack Solutions 44U \$550 3 \$1.6K 6 UPS units APC Smart-UPS 2200 LCD \$820 6 \$4.9K Tape backup system Quantum Scalar I80 tape library \$13.6K 1 \$13.6K Total \$219.8K

B.6 Prior AFOSR DURIP Support

This project heavily leverages existing infrastructure from a prior NIR instrument under AFOSR support.

With prior AFOSR DURIP support, in the past decade, BBSO/NJIT has developed several generations of instruments for the NST, and in fact, the NST itself. Now, all of this hardware and the telescope itself are functioning and we need a petabyte scale data server to keep on hand two years worth of raw data (in a rolling fashion). The data will be broadly available.

Most recently, AFOSR DURIP paid for half of the NIRIS camera. This 2k×2k, 50 fps camera from Teledyne is HgCdTe doped to have high quantum efficiency from 1-2 μm . Earlier, support came for the IRIM camera. One of the most remarkable achievement is the development of IRIM (InfraRed Imaging Magnetograph) (Cao et al., 2006, 2010a) for the BBSO's now-retired 0.6 m telescope. Using IRIM on the NST, led to the NIR images shown in this proposal.

B.7 Impact on Research and Training Infrastructure

Having a server appropriate for the avalanche of data the NST is now generating, will serve the community well because the data will be more complete and a richer spectrum of data will be available. Data from NST instruments like NIRIS, VIS and CYRA will be available to the broad solar commu-

nity. Senior staff members John Varsik and Vasyl Yurchyshyn will be responsible for bringing server system on line and modifying the user friendly data acquisition system we have in place, respectively.

Over the sixteen years that NJIT has run BBSO, thirteen former students/postdocs, including two women, have moved on to tenure track (or tenured) positions at universities or national centers. We carefully mentor our junior people at BBSO. We do this by carefully integrating each into the research and/or instrumentation teams to broaden experience while maximizing intellectual productivity. We have a video conferencing center on site in Big Bear, so we can have joint seminars and enable classroom teaching from NJIT to BBSO, and vice versa.

B.8 Education, Research Training and Mentoring

NJIT has a diverse student body in an urban environment, with a large minority student population. BBSO highly prizes its special role in the education of the next generation of scientists who build instruments. We currently have three PhD students, who will receive PhD's from NJIT in various fields: applied physics, electrical and computer engineering, and computer science. The very best NJIT students are attracted to the BBSO program. The typical student designs and builds the instruments used to make his/her PhD measurements in BBSO. These students utilize the laboratories and our small observatory on campus to test the instruments for use at BBSO. BBSO also supports 2-3 undergraduate students for summer research at Big Bear.

B.9 Data and Telescope Time

Since NJIT began operating BBSO, its telescope time and data have been open to the community. Many scientists have had observing time. Students from around the world have used BBSO data as a central part of their thesis. Data requests come to BBSO on a daily basis from around the world. The NST equipped with NIRIS, VIS and CYRA will generate far more data than before. Our purpose here is to make more data available to a broader community. As discussed earlier, NST data are already available on our website². We have implemented an internal fiber optic link and a RAID array for our FTP archive. We are an active participant in the Virtual Solar Observatory (VSO), but still all of this requires a server to to which VSO can point. For users of our telescopes and data, we are only asked that they acknowledge BBSO in their resulting publications. Many observers have used our data to help plan their observing campaigns.

The observing time of the first, next generation solar telescope in the US, the NST, will be over-subscribed because of its much improved scientific capability compared to the old 0.6 m telescope, especially after it is equipped with NIRIS, VIS and CYRA. We will continue our open observing time and open data policies. We plan to make a portion of observing time available to the community. The Telescope Allocation Committee will rank the proposals and allocate time. NST data will be on line immediately, if it is not part of a special observing program. A web page describing all the requests will ensure that researchers will not duplicate their data analysis efforts.

B.10 Personnel Management Plan and Timelines

PI Goode is responsible for overall management of the project. Co-PI Cao is responsible for implementing the interface of the data server to the data stream. John Varsik will bring the server on-line,

²<http://www.bbso.njit.edu/>

Table 1: Tasks and Assignments for the Data Server project.

Task	Person In Charge
Overall Management and Coordination	Goode
Interface with NST Data Stream	Cao
Bringing Server On-line	John Varsik
Community Data Pipeline	Vasyl Yurchyshyn

and Vasyl Yurchyshyn will update his software package that enables users to automatically receive NST data. The problem is the avalanche of data. NEEDS SOME WORDS ABOUT HOW THIS PROBLEM WILL BE SOLVED.