NJIT Ground-based Solar Observatories

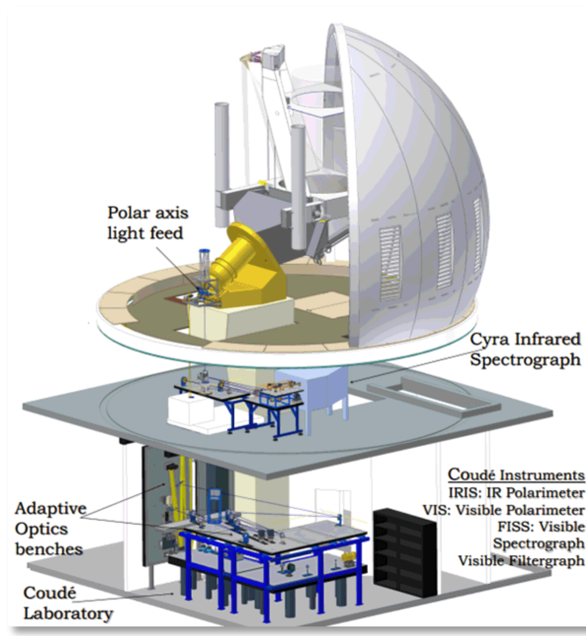
The New Jersey Institute of Technology operates two major ground-based solar observatories, both of which have recently undergone major upgrades in hardware and instrumentation. This document describes the instrumental capabilities and operating modes expected to be in place during 2016

Figure 1: New Solar Telescope as viewed from inside the dome.

NJIT's Ground-based Observatories

The two operating observatories are the Big Bear Solar Observatory (BBSO), which includes the world's largest solar telescope, the off-axis New Solar Telescope (NST) of 1.6 m aperture, and the Expanded Owens Valley Solar Array (EOVSA), a 13-antenna solar-dedicated interferometric radio array currently operating in the range 2.5-18 GHz. These two observatories work in tandem to study solar structure and processes of solar activity from the temperature-minimum region to the corona.

Figure 2: Cut-away view of telescope and instrumentation.



1. Big Bear Solar Observatory

The Big Bear Solar Observatory is the site of the high-order adaptive-optics (AO)-corrected NST and its post-focus instrumentation (which consists of a broadband filter imager—BFI; visible imaging spectrometer—VIS; near-infrared imaging spectropolarimeter—NIRIS; fast-imaging solar spectrograph—FISS; and a cryogenic infrared spectrograph—Cyra). Also on the site is an H-alpha full-disk imager (part of the Global H-Alpha Network) and a Global Oscillations Network Group (GONG) station.

1.1 NST Instrumentation

High-Order and Multi-Conjugate Adaptive Optics

The AO-308 system, with its 308 sub-apertures, provides high-order correction of atmospheric seeing within an isoplanatic patch (about 6" at 500 nm in summer), with a gradual roll-off of correction at larger distances. We are developing a new system called Multi-Conjugate Adaptive Optics (MCAO), using two deformable mirrors that can correct turbulence at two layers simultaneously—the ground layer at < 500 m, and the boundary layer at 3-6 km. This system will be operational within a year or two, and can be expected to provide diffraction-limited correction over a much wider area of the image in the era of Solar Probe Plus and Solar Orbiter. The diffraction limit of a 1.6 m telescope is 0.08" at 500 nm, and 0.16" at 1 micron.

Broad-Band Filter Imager—BFI

The broad-band filter imager provides continuum context data over an AO-corrected field using a high-speed 2048x2048 CCD camera. Three bands currently used are G-band (430.5 nm, 5- Å bandpass) with a field of view of 55" and 0.027"/pixel image scale, red continuum (668.4 nm, 4-Å bandpass) and TiO (705.7 nm, 10-Å bandpass) with a field of view of 70" at 0.034"/pixel image scale. Filtergrams are typically taken in short bursts of 100 frames every 15 s, and processed via speckle reconstruction to achieve diffraction-limited images (resolutions of 0.06" in G-band, 0.09" in TiO).

Visible Imaging Spectrometer—VIS

VIS currently uses a single Fabry-Pérot etalon to produce a narrow 0.07-Å bandpass over a 70" circular field of view, tunable from 550-700 nm. Plans are underway to upgrade VIS to a dual-etalon system. Available spectral lines include H-alpha, Fe I 630 nm, and Na I D2 (589 nm). Plans are underway to add the He I D3 line. The image scale is 0.034"/pixel, and typically 11 line positions are sampled in 15 s, although the number of line positions (and corresponding time resolution) is a settable parameter. Bursts of typically 25 frames are used for speckle reconstruction at each line position. The purpose of VIS is to provide spectral diagnostics of solar features at the diffraction limit of the telescope.

Near Infra-Red Imaging Spectropolarimeter—NIRIS

NIRIS uses dual Fabry-Pérot etalons that provide an 85" round field of view. We have just brought into use a new Teledyne camera, a 2024 x 2048 HgCdTe, closed-cycle He cooled IR array. The system utilizes half the chip to capture two simultaneous polarization states side-by-side, each 1024 x 1024 pixels in size, providing an image scale of 0.083"/pixel. The other half of the chip will be used in the future for two out-of-focus images to be used for phase-diversity correction. The primary lines used by NIRIS are the Fe I 1565 nm doublet, and the He I 1083 nm multiplet. The Fe I bandpass is 0.1 Å while the He I bandpass is 0.05 Å. The polarimetry is done via a rotating waveplate that samples 16 phase angles at each line position, and more than 100 line positions at a cadence of 10 s per full spectroscopic measurement (full-Stokes I, Q, U and V). The inversion of these data to provide magnetograms and other spectral diagnostics is currently under development. The system can also be operated in a fixed-phase-angle, dual-polarization mode that would allow speckle reconstruction of I and V images for diffraction-limited line-of-sight magnetic field diagnostics.

Fast-Imaging Solar Spectrograph—FISS

FISS is a scanning Echelle-type spectrograph provided as an NST post-focus instrument through a collaboration between two Korean groups, Seoul National University (SNU) and Korean Astronomy and Space Institute (KASI). Lines typically observed by FISS are the Ca II H and K lines near 854 nm and the H-alpha line. Both spectral regions can be observed simultaneously using a dual-camera system. The spectrograph slit is 40" long, and a field of view of 40" x 60" is typically scanned in 10 s. The H-alpha camera is a 512 x 512 CCD, while the Ca II camera is a 1004 x 1000 CCD. The slit width is 32 μm, which corresponds to a spatial sampling of 0.16". The spectral sampling at H-alpha is typically 0.019 Å and at Ca II it is 0.025 Å, and the resolving power ($\lambda/\Delta\lambda$ = 1.4×10^5) gives a spectral resolution of 0.05 Å and 0.06 Å, respectively. The purpose of FISS is to study fast dynamics of solar features at moderate spatial resolution.

Cryogenic Infra-Red Spectrograph—Cyra

Cyra is still under development, and when completed will constitute a fully cryogenic, folded Czerny-Turner spectrograph based on a 2048 x 2048 HgCdTe array sensitive through the 1-5 μm region. A correlation tracker is available for tip-tilt correction, and an image-rotator has been completed and is undergoing tests now. When complete, the system will include a rotating waveplate and polarizing beamsplitter for dual-beam, full-Stokes polarimetry. Test observations of the CO lines near 4667 nm (resolving power 250,000) have succeeded in showing off-limb emission. Photospheric lines of interest are Fe I 1565 nm, Ti I 2231 nm, Fe I 4064 nm, and Si I 4143 nm, while chromospheric lines are Ca I 3697 nm, Mg I 3682 nm, and the aforementioned CO lines. The instrument scan cadence will be a function of total integration time, number of Stokes parameters, and scanned field of view, but is expected to be under 1 min. The instrument is expected to be completed by 2017.

1.2 H-alpha Full-Disk Imager

The H-alpha full-disk patrol telescope is a 10 cm aperture refractor equipped with a Zeiss Lyot 0.025 nm bandpass filter with a tunable range of +/- 0.3 nm. The detector size is 2048 x 2048, 12-bit, for a spatial scale of about 1"/pixel. The exposures are typically 30 ms, and frames are taken at a cadence of 1 frame/minute except during flares, when the cadence can be manually increased to 1 frame/15 s. The images are used in real time to aid in target selection of the NST, and are also used for context for the high-resolution NST data. In addition, the station is part of a world-wide network called the Global H-alpha Network (GHN) comprising BBSO, Kanzelhöhe Solar Observatory in Germany, Catania Astrophysical Observatory in Italy, Meudon and Pic du Midi in France, Huairou and Yunnan Observatories in China, the Mauno Loa Solar Observatory in Hawaii, and the Uccle Solar Equatorial Table in Belgium.

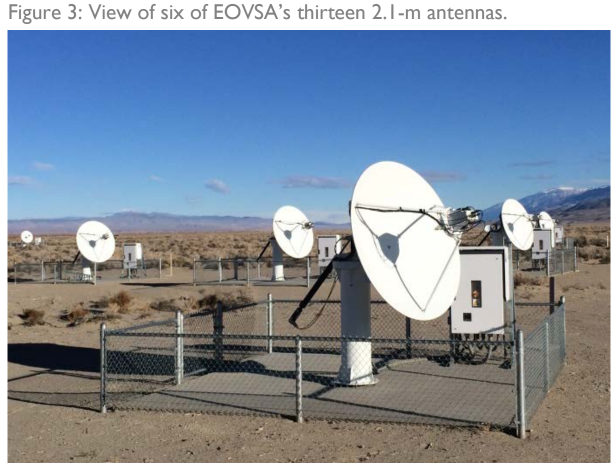
1.3 Global Oscillation Network Group—GONG station

GONG is a network of six identical instruments located at Big Bear Solar Observatory (California), Learmonth Solar Observatory (Australia), Udaipur Solar Observatory (India), Observatorio del Teide (Canary Islands), Cerro Tololo Interamerican Observatory (Chile), and Mauna Loa Observatory (Hawaii). A description of the instrumentation and capabilities of GONG is given in the National Solar Observatory summary document.

2. Expanded Owens Valley Solar Array

EOVSA is a newly expanded, solar-dedicated radio interferometer consisting of 13 small, 2.1-m antennas (see Figure 3) for observing the Sun and 2 large, 27-m antennas (Figure 4) equipped with He-cooled receivers for calibration. The receivers are designed to cover the frequency range 1-18 GHz, although currently they operate from 2.5-18 GHz pending a modification to the design to eliminate debilitating radio frequency interference around 2 GHz. It is expected that the design modification will not be completed in 2016, however.

Figure 3: View of six of EOVSA's thirteen 2.1-m antennas.



The 2.1-m antenna size is chosen to permit full-disk coverage of the Sun at all frequencies, so that flares and active regions occurring anywhere on the Sun will be within the field of view. Hence, the antennas continuously track the center of the Sun. In addition, the radio receivers take advantage of new optical transmitter technology that permits the transmission

of the entire 1-18 GHz band from the antenna to the environmentally-controlled operations building. In the operations building, this bandwidth is sub-divided into 500 MHz bands for digitial processing at a sampling-time of 20 ms/band, with all 34 sub-bands processed within 1 s. Thus, the instrument processes radiation from the entire Sun in the range 1-18 GHz each second. The full-Sun and full-band coverage highly simplifies the operation of the instrument, and permits mono-mode observing that addresses all science goals continuously without compromise. The digitally-sampled 500 MHz bands are further sub-divided into >3400 channels (>116,000 channels over the 34 bands), which are combined in real-time post-processing into variable-width science channels that currently provide independent measurements at 332 frequencies in the 2.5-18 GHz band. When the design modification to allow 1-18 GHz operation is complete, there will be 448 science channels.

Figure 4: EOVSA's 27-m antennas, used for calibration (and nighttime science).

The array size is 970 x 1217 m, with maximum baseline of 1556 m, providing a maximum spatial resolution of 39.8"/f_{GHz}. Thus, the resolution at 18 GHz is 2.2" (a factor of ~6 better than the Nobeyama Radioheliograph at 17 GHz). All EOVSA data are processed in pipeline mode, where daily data products (dynamic spectra and images) are generated in near-real-time. Calibrated visibility data are also recorded for further off-line processing if desired. The pipeline processing steps are still being developed, but it is expected that daily, dual-polarization full-disk images will be produced at roughly 100 frequencies several times per day, while "partial-frame" dual-polarization images of flares will be obtained at 1-s cadence at >300 frequencies for the duration of the burst. Additional data products such as coronal magnetograms and F10.7 images and derived indexes will also be produced.