# ANNUAL REPORT OF THE NATIONAL SOLAR OBSERVATORY



# **FY 2008** (01 October 2007 – 30 September 2008)

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# **1 EXECUTIVE SUMMARY**

This report summarizes scientific, operational, and programmatic activities at the National Solar Observatory (NSO) for the period 01 October 2007 to 30 September 2008.

NSO's mission is to advance our knowledge of the Sun, both as an astronomical object and as the dominant external influence on Earth, by providing forefront, ground-based observational capabilities to the scientific community that allow scientists to probe all aspects of the Sun, from its deep interior to the interface in the outer atmosphere with the inter-planetary medium. The NSO staff also participates with the community in both collaborative and independent research on frontier topics in solar astrophysics and closely related fields, as well as in instrument development. Finally, the NSO engages in educational and public outreach, and contributes to programs that increase the number and diversity of students and scientists in solar physics and related fields.

The NSO operates major telescope systems on Kitt Peak, Arizona, and at Sacramento Peak, New Mexico, along with six smaller facilities distributed around the world. The NSO facilities for observing and data reduction are available to the entire astronomical community. The NSO Home Page, accessible through the World Wide Web at <u>http://www.nso.edu/</u>, provides online information about NSO services, including telescope schedules, instrument availability, and information about how to apply for telescope time.

The NSO long-range plan calls for development of the next generation of solar observational capabilities. The centerpiece of this program is the Advanced Technology Solar Telescope (ATST). Since its approval by the National Science Board in fall 2008 for inclusion in future NSF budgets, the ATST project is now preparing for a Final Design Review (FDR) in March 2009. Depending on funding, this could lead to construction beginning in late FY 2009 or early FY 2010.

Another major component of providing the next generation of solar capabilities is SOLIS (Synoptic Optical Long-term Investigation of the Sun). The SOLIS vector spectromagnetograph (VSM) and the integrated sunlight spectrometer (ISS) are currently operational on Kitt Peak and are producing frequently accessed synoptic data. Calibration of SOLIS vector spectro-polarimetric data was recently perfected. The final solar instrument, the full-disk patrol (FDP), will be fielded this winter. The VSM provides unique vector magnetograms that enable new types of synoptic maps. In order to extend vector magnetic measurements to 24-hour coverage, NSO has developed partnerships and submitted to the NSF Division of Atmospheric Sciences (ATM) a proposal for developing a network of vector magnetographs.

The ongoing support of advanced programs of community-based research at our major telescope systems remains a crucial component of the transition plan to the ATST era. The interfacing of new diffraction-limited instrumentation to the two high-order adaptive optics (AO) systems at the Dunn Solar Telescope (DST) continues in conjunction with our partners at the University of Hawai'i (Facility Infrared Spectro-polarimeter (FIRS)), Queen's University (Rapid Oscillations of the Solar Atmosphere (ROSA)), Arcetri Observatory (Interferometric BIdimensional Spectrometer (IBIS)), and with the High Altitude Observatory (Spectro-Polarimeter for Infrared and Optical Regions (SPINOR)). In addition, NSO has upgraded the instrument control system and data collection systems at the DST.

The AO systems at the DST serve as proofs-of-concept for a scalable AO design for the much larger 4meter ATST, which is currently under development. Because correcting the full field of view for existing telescopes and the planned ATST will greatly enhance their scientific return, NSO is pursuing multiconjugate adaptive optics (MCAO). Successful runs of the MCAO prototype were conducted in 2008 at the DST and the results are being used to optimize the MCAO system design. High-resolution data products from GONG are now being widely utilized for local helioseismic exploration of sub-atmospheric structure, and GONG's near-real-time far-side pipeline is fully operational. GONG's rapid cadence magnetograms and far-side imaging are proving to be valuable tools for understanding space weather. In discussions with the Air Force, GONG will add an H-alpha capability and the Air Force hopes to provide part of the operational funds for GONG. This will help meet the Senior Review recommendation that NSO find the majority of GONG funding outside of NSF/Astronomy.

The NSO Array Camera (NAC) continues to make forefront infrared observations. Granulation studies have been extended from 1–5 microns. Using high-speed imaging and the fact that seeing effects fall off at longer wavelengths, high-resolution movies can be obtained with post-observation processing alone. The NAC is now usable with a combination of adaptive optics and the McMath spectrograph for full Stokes polarimetry.

In FY 2008, NSO continued to lead the development of the Virtual Solar Observatory (see *http://vso.nso.edu/*), a unified distributed solar data archive system with access through the Internet.

The NSO remains active in educational outreach through its Summer Research Assistantship (SRA) program for graduate students and its REU program for undergraduates, through collaboration with universities on thesis programs based on NSO data, and through participation in a joint University of Arizona/NSO Summer School in Solar Physics. In 2007, NSO participated with Fisk/Vanderbilt in the successful proposal to the NSF Partnerships in Astronomy and Astrophysics Research and Education (PAARE) program. NSO also partnered on new PAARE program proposals to that program in 2008 with New Mexico State University and California State University, Northridge. We plan to begin training minority students through these programs in the upcoming year.

# **2 PROGRESS TOWARD THE FUTURE**

# 2.1 Advanced Technology Solar Telescope (ATST)

The FY 2007 annual report described the progress of a community-wide project to develop the Advanced Technology Solar Telescope — the next generation, facility-class telescope to advance high-resolution solar physics and the measurement of solar magnetic fields. What follows is an update of the ongoing ATST design effort as well as the construction phase proposal review.

With its 4-meter aperture and integrated adaptive optics (AO), the ATST will resolve areas on the Sun over an order of magnitude smaller than current meter-class solar telescopes. Its high photon flux and broad spectral coverage will allow it to make sensitive magnetic field observations at heights from the photosphere into the corona.

Observations have established that the photospheric magnetic field is organized in small fibrils, or flux tubes, with sizes below current resolution limits. Theory and models predict that these fibrils have scales of just a few tens of kilometers ( $\leq$ 30 km) and that they play fundamental roles in solar dynamo processes, atmospheric heating, and solar activity. Resolving and measuring the properties of the magnetic field at its fundamental scale is thus a primary goal for the ATST. A complete description of science goals, and project information, can be found at <u>http://atst.nso.edu</u>.

# 2.1.1 ATST Science Working Group (SWG)

Current membership of the Science Working Group can be found at <u>http://atst.nso.edu/swg/members.html</u>. The SWG met 13-15 May 2008 to define and expand science Use Cases for first-light instrumentation. Draft science use cases were first laid out in the Science Requirements Document (SRD) and reflected in the science section of the ATST construction proposal. The ongoing effort is to flesh them out in more detail, while taking into account progress in solar physics, and to help fill in details for telescope and instru-ment operations and data handling.

Working groups within the SWG are using a standard template to capture the hypothetical observing programs. The template is modeled as a typical scientific observing proposal, followed by additional information that would more likely be gathered in a planning phase for the experiment. The goal is to provide a common outline on which to describe a range of use cases while guiding the community through various considerations for future observing programs.



**Figure 2.1-1** *Members of the ATST Science Working Group and project team at the NSO/NOAO offices in Tucson.* 

# 2.1.2 ATST Project Organization

NSO Director Steve Keil is the ATST Project Director. The science team reports to Project Scientist Thomas Rimmele, and the engineering team reports to Project Manager Jeremy Wagner.

The Co-PI's and other collaborating institutions participate in both design and science activities. Agreements for the primary efforts in instrumentation and support of the completed site survey were established through Memoranda of Understanding. The following agreements are in place:

- High Altitude Observatory (Visible Light Spectro-Polarimeter Design; Near IR Spectro-Polarimeter Contributions).
- University of Hawai'i (Sky Brightness Monitor and Dust Monitor; Near Infrared Spectro-Polarimeter Design (Lead); Site Survey Operations on Haleakalā and Mauna Kea).
- University of Chicago (Site Survey Project Engineer; Theoretical Support for Science Working Group).
- New Jersey Institute of Technology (Site Survey Operations at Big Bear; Tunable IR Filter Design).

In addition, an international advisory group, chaired by Jeff Kuhn (U. Hawaii), was formed, comprising representatives from several countries including the US, Germany, France, Italy, Spain, the United Kingdom, the Netherlands, Sweden, Japan, and Norway.

# 2.1.3 Construction Phase Proposal Review

Since the successful NSF-conducted Preliminary Design Review (PDR) in October 2006, the project has held various area-specific design reviews. The project moved from "readiness" stage to the final stage of Major Research Equipment and Facilities Construction (MREFC) review at the August 2007 National Science Board meeting, where it was "RESOLVED, that the National Science Board authorizes the [NSF] Director at his discretion to include the construction of the Advanced Technology Solar Telescope in a future budget." The project will hold final System Design Reviews (SDRs) for the Support and Operations buildings, Telescope Mount Assembly and Enclosure on 4-6 November 2008. The NSF has scheduled the Final Design Review for early March 2009.

#### 2.1.4 Proposed Site and Permitting

#### 2.1.4.1 Site Selection

The ATST site survey, which started operating in November 2001, was successfully concluded in January 2005. Six sites were evaluated: Big Bear Solar Observatory, California; Haleakalā, Hawai'i; San Pedro Martir, Mexico; Panguitch Lake, Utah; La Palma, Canary Islands, Spain; and Sacramento Peak, New Mexico. The instrumentation consisted of a solar differential image motion monitor, scintillometer array, dust monitor, weather station, and miniature coronagraph. The site survey data was used to compare the test sites in terms of statistics of the fraction of clear time, seeing, dust levels, sky brightness, water vapor, and weather.

In particular, the scintillometer array produces data that can be inverted to provide a reliable estimate of the structure function, Cn2(h) and thus obtain values of r<sub>0</sub> (the Fried parameter) at heights of up to 50 m above the ground. The value of r<sub>0</sub> at the height of the telescope aperture was the deciding factor in the site selection. The Site Survey Working Group (SSWG) delivered its final report in August 2004. The report was evaluated by the Science Working Group (SWG), which issued its site recommendation for Haleakalā to the project director in October 2004. Taking into account cost and feasibility issues summarized by project management, the ATST director accepted the SWG's recommendation for Haleakalā as the proposed ATST site.

Haleakalā was selected due to:

- High quantities of excellent seeing (r<sub>0</sub> > 12 cm) at the height of the main mirror (28 m).
- Very dark sky with little seasonal variation.
- Low dust counts and benign environment (e.g., outside temperature).

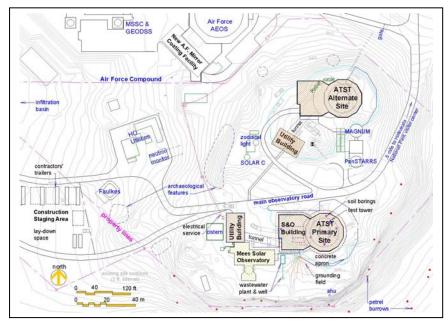
The final report of the SSWG is available at <u>http://atst.nso.edu/site/reports\_final.html</u>. The overall ATST design approach and impact of the selection of Haleakalā on the overall design has been reported previously.

#### 2.1.4.2 Site Permitting

Environmental permitting for ATST at the selected Haleakalā site requires the preparation of a full Environmental Impact Statement (EIS) as defined by Federal and Hawaiian statutes. In 2005, the Mauibased firm of KC Environmental (KCE) was contracted to lead that effort. Following the published Notice of Intent, a series of scoping meetings were held on Maui to elicit early input from the public on the issues to be addressed in the EIS. As reported previously, the main concerns include: the visibility of ATST from below, due to its required height and white color; the potential impact of ATST on native wildlife, particularly the endangered Hawaiian petrel; and increased traffic on the observatory road during construction and operation. Comments from the public and concerned agencies were taken into account in the preparation of the draft EIS (DEIS), which was released in the fall of 2006.

Following release of the DEIS, meetings were again held on Maui to allow the community to verbally respond to the document. During the prescribed review period, written responses were also accepted from the public, community groups and agencies. The input received largely reinforced the concerns that previously had been identified. In particular, the adjacent Haleakalā National Park raised concerns about the construction-related use of the 11-mile section of highway that runs through, and is maintained by, the Park. They cited potential negative impact on Park visitor experience caused by the increased traffic and also by the visual presence of another nearby large observatory. The Park's response pointed out the historic nature of the Haleakalā highway itself and the potential for damage caused by construction traffic. The Federal Aviation Administration, which operates a repeater station on Haleakalā for air-to-ground communication, expressed concern about signal reduction caused by the proximity of the ATST

structure to their antenna. Mutually acceptable measures to address these issues are being discussed in direct contact with the concerned agencies. With regard to the endangered-species issue, the US Fish and Wildlife Service (USF&WS) completed a Biological Opinion on the impact of ATST. In consultation with KCE and project engineers, a set of reasonable mitigation measures were established which resulted in a USF&WS opinion that the ATST project is "not likely to adversely affect the Hawaiian petrel" or other species of concern. This finding was a significant positive development for the ATST EIS.



**Figure 2.1-2.** *Site plan showing potential locations and infrastructure for ATST at Haleakalā Observatories.* 

Environmental permitting also involves satisfying the applicable provisions of the National Historic Preservation Act (NHPA). Section 106 of the NHPA provides the legal framework for addressing such issues as the Park's concern about the historic highway and the Native-Hawaiian community's concerns about the sacred nature of the Haleakalā summit. In conformance with NHPA, a number of meetings with the public and concerned agencies have been held; proposals for mitigation and minimization of cultural impact have been invited and received. Meetings were held in June and August (2008) to begin to finalize a Memorandum of Agreement with the community and agencies.

As the Lead Agency for the Proposed Action, the National Science Foundation is directing that process, and significant progress has been made. Completion of the Final EIS (FEIS) is anticipated this year, and a Record of Decision is expected to follow in 2009. With the release of the FEIS, the project will proceed with the application for a Conservation District Use Permit, as required by Hawaiian statute.

# 2.1.5 Design Progress

Design activities during the past year were focused on completing follow-up activities based on committee recommendations from the Systems Design Reviews (SDRs) held in July 2007. Work has also been focused on completing bid packages in preparation

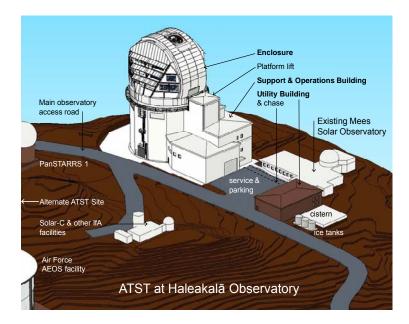


Figure 2.1-3. View of ATST facilities from the northwest.

for a possible 2009 start. To that end, work on the Reference Design Studies and Analyses (RDSA), interface control document (ICD), and bid package documents is proceeding in preparation for the final SDRs in November, 2008.

#### 2.1.5.1 Support Facilities

The basic design of the support and operations (S&O) building and the layout of all the ATST facilities on the Haleakalā site have not changed in the past year, although some significant refinements have been incorporated. The exterior cladding of the S&O building was changed from metal to precast concrete panels for improved passive thermal performance. The tunnel between the S&O building and the utility building was reduced to a simple utility chase as the requirement to use it for air exhaust from the lower enclosure was eliminated.

In a major change to contracting strategy, the entire fixed lower enclosure and the telescope pier were incorporated into the buildings and site work package. These concrete and fixed steel elements will be structurally integrated with the support buildings and can be more logically and economically provided as part of that contract.

Site design efforts have concentrated on further refinement of systems that are relevant to environmental impact assessment. These include the main electrical power service, rainwater catchment, erosion prevention and seismic design. Additional consideration has also been given to logistical aspects of construction at the site, such as staging areas, soil placement areas, strategies for working during the defined petrel-nesting periods when noise and vibration levels are restricted, and the extent of truck traffic that will be required to traverse through Haleakalā National Park.

The main activity during the last part of FY 2008 has been to prepare an updated and expanded set of schematic design documents that fully integrates the buildings, lower enclosure and telescope pier, and defines their relationship to other observatory systems. These drawings and documents will be critical for major project developments that are anticipated to take place in 2009: application for a Conservation District Use Permit (the final phase of environmental permitting), the NSF Final Design Review, final baseline cost estimating, and the initiation of design and construction contracts.

#### 2.1.5.2 Optical Design

The ATST is an off-axis all-reflecting Gregorian telescope. The off-axis design gives the best stray-light performance, which is critical for coronal observations. The all-reflecting characteristic is the only solution that potentially can allow observations at wave-lengths from 300 nm to 12  $\mu$ m with enough

flexibility to use some instruments simultaneously.

The Gregorian optical design forms a prime-focus image in front of an ellipsoidal secondary. This focus is only used as a field stop, where a five arc-minute beam is admitted into the telescope; the rest of the beam is rejected. This reduces the 12 kilowatts of power reflected from the primary to about 300 watts or less on all subsequent optical elements. The



Figure 2.1-4. Current ATST enclosure design.

secondary mirror then relays the prime focus image to an f /13 Gregorian focus, which will be used for calibration and polarization optics during normal operations. The Gregorian image will be relayed to the coudé observing station.

During 2008, the project has made only minimal changes to the reference optical design, focusing instead on preparing contract packages and interface control documents. A change that was made to the baseline is the switch to water-cooled optics for all of the feed mirrors after M2. Most had previously been specified as cooled by chilled air. At present, however, it appears to be more cost effective to use channeled silicon substrates that circulate chilled liquids, and reference designs have been developed in detail to reflect this decision.

The project has also begun to explore details of the interface between the telescope optics, the firstgeneration instruments, and the wavefront sensing optics. The coudé feed optics deliver a collimated beam to the very large (16-meter diameter) coudé room where the instruments will reside. The science requirements and additional derived requirements for each first-generation instrument and the wavefront sensors vary too much to allow one imaging system to work for all instruments. They do not have the same wavelength requirements, fields of view, or image quality requirements, so each will require special beam-conditioning optics. As we work with our partners to complete the instrument designs, the project is continuing to refine what will be a suite of imaging systems.

#### 2.1.5.3 Telescope Mount Assembly

Progress this year on the telescope mount assembly (TMA) has addressed a number of areas, including removal of the Nasmyth rotator and equipment from the telescope, the addition of mounting interfaces for the wavefront correction sensing optics into the coudé rotator, and refinements to the ancillary mechanism design details. The bulk of the year's effort, however, has been focused on structural changes that were made to improve the manufacturability of the TMA.

These changes to the structural design were guided in part by suggestions from large steel manufacturers and machine shops contacted during the past year. In addition, finite element analyses (FEA) were performed to optimize the layout of various structural members. The mount, for instance, was changed from a monocoque plate-steel system to a more traditional tubular steel truss arrangement. In addition to improving constructability, the tubular structure offers somewhat higher stiffness, lower weight, and improved thermal inertia properties when compared to the older design.

The coudé rotator structural design was also further developed. The previous truss-type structure was retained, but has undergone some refinement. Chief among these were changes to help transportation and assembly on site. Member sizes and truss section depths were also changed to help improve strength and stiffness. This latter item was a direct result of discussing requirements with manufacturers and iterating the requirements with the design.

The other major structural element change was to the shape of the concrete telescope pier. The previous design was conical, while the new design employs faceted inward sloping walls to approximate a cone. This change is expected to improve installation of formwork on site and concrete placement, and therefore will result in lower construction costs at the site.

#### 2.1.5.4 Enclosure

Enclosure contract package refinement continues and is scheduled to culminate in a final Systems Design Review (SDR) on 5 November 2008. The contract package for the enclosure has been restructured in order to take a nimble approach to the field of potential contractors. Where previously the enclosure was one design-build contract, it has been split into three separate work packages. The enclosure and the enclosure thermal systems are now structured on a stand-alone bid-design-build basis. The enclosure

control system is structured on a stand-alone design-build basis. This tactic is intended to maximize competition by opening the field to many more contractors which should help contain costs.

In addition to a different contracting strategy, there has been a big push to take the reference design and the contract package documents to the final level of detail for contracting this year. Computation fluid dynamic (CFD) studies, which included thermal effects, were completed to verify the design for the enclosure and facility on the Haleakalā site using data from the site survey. Preliminary results from a site weatherization study identified potential thermal control coatings for use on the enclosure. A suite of safety and hazard analysis meetings were held to validate and further refine the reference design.

The updated contract packages will be the basis for freshening up the cost estimates prior to the Baseline Review next spring. Vendor prequalification and involvement, as we prepare for contracting, will follow.

#### 2.1.5.5 Wavefront Correction (WFC)

The ATST wavefront correction system must achieve the high Strehl requirements at visible and infrared wavelengths called for in the Science Requirements Document. The ATST has several correctors and sensors for wavefront correction, including: 1) quasi-static alignment (QSA) for keeping the entire optical path—most importantly M1 and M2—aligned in closed-loop; 2) active optics (Ao), which has the main of keeping the figure of M1 within specifications, compensating for deformation due to gravitational and thermal distortions; 3) tip/tilt devices for image stabilization; and 4) high-order adaptive optics (HOAO) for correcting atmospheric and internal seeing and residual optical aberrations.

The subsystems of the ATST wavefront correction system include:

*A high-order adaptive optics system.* This sub-system corrects atmospheric seeing at >2 kHz rates. The baseline design has a 1369-actuator deformable mirror (DM) and a fast tip/tilt mirror. The wavefront sensor is a correlating Shack Hartmann sensor with 1280 subapertures. The approach builds on the very successful AO systems deployed at the Dunn Solar Telescope. This system also includes a fast tip/tilt mirror (M5).

*Active optics system.* The main task is to correct slowly changing aberrations that may arise from gravitational and thermal deformations of the telescope structure. One of the main objectives of the system is to keep the figure of the primary mirror within the allowed tolerances.

*Alignment*. The ATST's off-axis optical system alignment requires wavefront measurements at several points within the extended field of view. This multiple field wavefront sensor will be available at the coudé station.

*Blending.* Information from different wavefront sensors (e.g., AO and Ao) will be conditioned and combined by the Wavefront Correction Control System (WCCS), which then drives the appropriate corrector elements.

Each of the wavefront sensors has a computer that processes the wavefront information in real time and outputs information to one or more correctors. This is done either directly, where high bandwidth is required (e.g., DM), or through the WCCS. The WCCS is a system with supervisory role that coordinates all of the wavefront correction systems. It will control which sensing system will control which corrector. It accepts commands from the Telescope Control System (TCS) and passes them on to the appropriate system. The main task of the WCCS is to blend information from the operating wavefront correction systems for M1 figure and adjustments to the telescope optics for alignment. For instance, when both the Ao and HOAO systems are running at coudé, the Ao system is measuring the wavefront at the center and two corners of the field. However, the HOAO is correcting the center of the field and hence the HOAO will off-load quasi-static aberrations from the center of the field to the WCCS.

Based on a recommendation from the SDR committee, the project has acquired a board with digital signal processors and development software to evaluate the computational requirements, data flow, and signal processing latency for the high-order AO system. The project continues to develop interface control documents (ICDs) and system designs.

#### 2.1.5.6 Software

The Observatory Control System (OCS) and Data Handling System (DHS) underwent a preliminary design review in February 2008. The committee was satisfied with the design of both systems but felt there were several other areas where more work was needed. In particular, the committee advised the project that a draft operations plan needed to be in place, and certain policy decisions made, to enable the software team to advance. In May 2008, the Science Working Group met with the project team and devised a number of observing use cases for the ATST. Input from this meeting is currently being translated into an Operational Concepts Definitions document (OCDD) that the software team will use to support the requirements of the OCS and DHS and improve the design of these systems. The OCS design now incorporates all input from the committee, and the DHS design will be updated over the next few months.

The Common Services software framework has been extended to add application support and improve performance. Several new classes of controllers have been created to interface with motion control and digital I/O systems. There are also new controllers for managing operational sequencing and scripting. Other software work has also been completed on communications channels to interface with hardware components.

Work on the telescope subsystems has progressed into the system design area in preparation for upcoming design reviews. All design and documentation work on the telescope enclosure control system and mount control system has been completed, including the reference design, specifications, and interfaces. The M1 mirror and top-end optical assembly control systems have a completed reference design.

#### 2.2 Synoptic Optical Long-term Investigations of the Sun (SOLIS)

The SOLIS project records optical measurements of processes within the solar photosphere and chromosphere, the study of which requires well-calibrated, sustained observations over a long time period (~25 years). The primary and unique SOLIS instrument is the vector spectromagnetograph (VSM), which was installed on Kitt Peak in April 2004 after seven months of preliminary observing at a temporary site in Tucson. Regular observations from Kitt Peak have been underway since May 2004, with several data products available on the Internet. The other two SOLIS instruments are the integrated sunlight spectrometer (ISS) and the full-disk patrol (FDP) imager. The ISS has been operating daily on Kitt Peak since December 2006.

The emphasis in the SOLIS program is on moderate to large spatial scale activity over the course of the solar activity cycle. Other facilities deal more effectively with small spatial scales and short observing campaigns. This emphasis on regular cadence observations for long sustained periods defines the most productive science goals for SOLIS. The FDP was purposely given low priority due to resource constraints and its non-uniqueness, and is now being completed in Tucson prior to its move to Kitt Peak in 2009.

During the period of this report, October 2007 through September 2008, the emphasis has been on completion and stable operation of SOLIS. Both the VSM and ISS are in extended commissioning phases, produce good data, and are making regular observations that are available to the community via the Internet. They are gradually reaching their full potentials for providing unique science results. Information is provided in the following instrument-specific sections.

### 2.2.1 Vector Spectromagnetograph (VSM)

On a daily basis (weather permitting), the VSM is providing full-disk maps for photospheric 630.2 nm longitudinal magnetograms, chromospheric 854.2 longitudinal magnetograms, full-disk chromospheric 1083.0 nm equivalent width images and the location of coronal holes as extrapolated from the 1083.0 nm maps. Synoptic Carrington Rotation maps are provided for the 630.2 nm longitudinal magnetograms and extrapolated coronal hole location.

Full-disk and area-scan vector magnetic field observations have been archived since September 2003. In December 2005, preliminary vector magnetograms were released to beta-testers for community input.

The VSM Vector Working Group (VVWG) continued to make good progress with the final calibration and pipeline code for processing VSM 630.2 nm vector data. The primary task was to better parameterize and remove polarization fringes from the VSM Stokes profile data.

Since the last report, significant progress has been made toward the eventual release of science-grade vector data. In particular, successful fringe-removal algorithms have been developed that are robust enough to clean up the spectra. The fringe-removal code is now being translated from the format it was written in (suitable for diagnostic efforts) to a streamlined code that can operate efficiently within the routine processing platform.

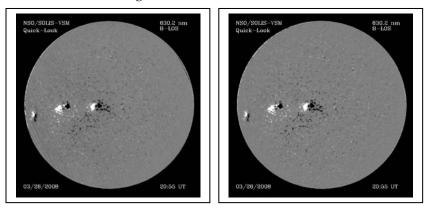
To recapitulate the issues and approaches taken, challenges as of the May 2008 status report included: (1) variable fringing in the polarization signal (Stokes *Q*, *U* and *V*) at the  $3\times10^{-4}$  level of Stokes *I*; and (2) the conversion of the Milne-Eddington inversion code from a small field-of-view application into a full-disk/large field-of-view application. The application of conventional fringe-fitting and removal methods resulted in full-disk images that still contained 'streaking'. The streaking was a periodic artifact with spatially-varying amplitude. It was visible, distracting, and obviously non-solar in origin.

A new approach to the fringe removal was employed, which uses the observed polarization data itself rather than the data from the flat observations, to fit the fringes. The data are now being treated in two stages as follows:

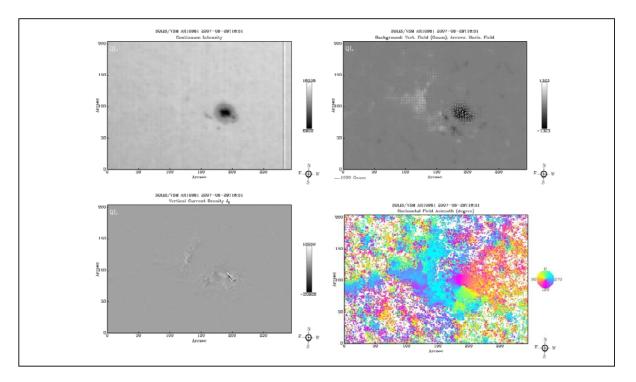
*Stage 1:* The removal of spectra intensity leakage and fitting of the polarization fringes in two-dimensions (i.e., spatial position along slit versus spectral position). The fringe order and amplitude vary slightly as a function of slit position.

Stage 2: The removal of bias and imperfections not detected on an individual scan line basis.

Now that the polarization fringes can be removed with confidence (see sample data, Figure 2.2-1), attention turns to the testing of the inversion codes to ensure accurate results are obtained when inversions are performed on full-disk data. Note that the inversion of spectro-polarimetric data has been traditionally performed for small fields-of-view on the Sun and attempts to invert data over the full disk thus necessitates changes in the code.



**Figure 2.2-1.** Sample data showing polarization fringes before (left) and after (right) removal.



**Figure 2.2-2.** These quick-look images of AR 10960, observed with the VSM on 8 June 2007, highlight some of the parameters publicly available daily: continuum intensity (upper left), vertical field strength with arrows indicating the horizontal field strength and direction (upper right), vertical current density (lower left), and field azimuth (lower right). The quick-look parameters have been corrected for the 180° azimuth ambiguity.

During this interim period, before the full Milne Eddington solutions are available, quick-look vector magnetic FITS-formatted data and JPEG image files are available for recent observations (see sample set, Figure 2.2-2). The VSM quick-look vector data are also available in x3d format such that the data can be explored as a 3D model. All of the VSM quick-look data are corrected for the 180-degree ambiguity using the Non-Potential Field Calculation (NPFC) method developed by Manolis Georgoulis (Johns Hopkins U.).

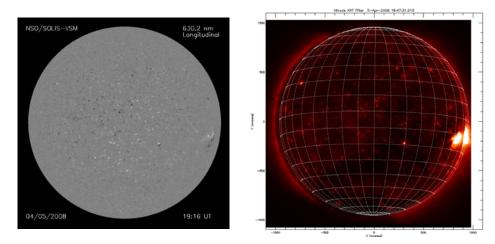
The SOLIS VSM team supported Whole Heliospheric Interval (WHI) observing efforts during 20 March-16 April 2008 by taking data simultaneously with other ground- and space-based telescopes. WHI was an internationally coordinated, four-week observing effort designed, in part, to showcase 2008 as the International Heliophysical Year (IHY). Observations and data analysis will be followed by modeling efforts to characterize the three-dimensional, interconnected, solar-heliospheric-planetary system.

The emphasis for each of the four weeks of WHI was as follows:

- linking the corona to solar wind as observed by the Ulysses spacecraft;
- the origin of the slow solar wind;
- understanding the coronal hole boundaries and low-latitude coronal holes; and
- the characterization of the quiet Sun.

The entire time period corresponds to solar Carrington Rotation 2068.

The Sun was cooperative, providing the desired solar features for study, i.e., an equatorial coronal hole during the third week (see Figure 2.2-3) and very little magnetic activity (i.e., without sunspots) during the fourth week NSO looks forward to the scientific advances made through these coordinated, collaborative efforts.

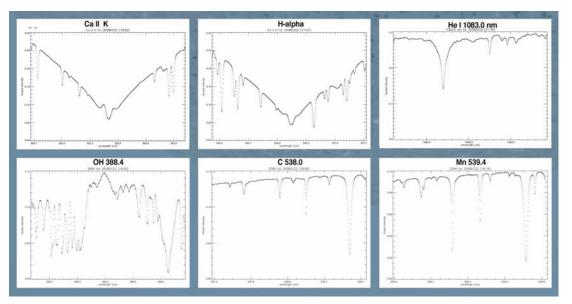


**Figure 2.2-3.** A SOLIS VSM full-disk solar image (left) and Hinode XRT x-ray image (right) for 05 April 2008. These represent only two out of a suite of ~30 participating instruments. The SOLIS VSM image is depicted in grayscale, indicating the line-of-sight magnetic flux as observed in the photosphere with the 630 nm Fe I lines. White/black indicate positive/negative polarity of magnetic fields. The Hinode XRT image shows the x-ray intensity with visible coronal holes at the south pole and another near 30 degrees southern latitude.

The VVWG is also investigating the feasibility of preserving all of the VSM Stokes profile data. The original scope of the SOLIS program did not include archiving the observed Stokes profiles; however, preliminary work has begun to store the profiles in a compressed format using the Expansion in Hermite Functions (EHF) method by del Toro Iniesta and Lopez Ariste (*A&A*, 412, 875).

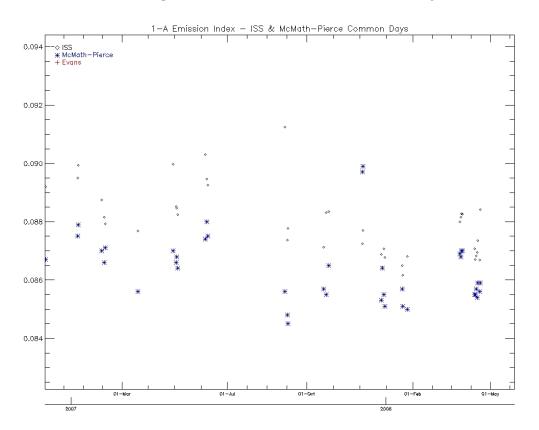
#### 2.2.2 Integrated Sunlight Spectrometer (ISS)

FY 2008 saw ISS science-quality data become available and can be accessed online (<u>http://solis.nso.edu</u>). The ISS is taking daily observations with the following wavelengths: 388.4 nm, 393.4 nm, 396.8 nm, 538.0 nm, 539.4 nm, 656.3 nm (H-alpha), 854.2 nm, and 1083.0 nm, see Figure 2.2-4. All eight spectra have been calibrated for spectral dispersion and are currently available on the Web. Fluxes were normalized to reference values in the Fourier Transform Spectrometer flux atlas.



**Figure 2.2-4.** Sample spectra measured by the ISS. Shown are spectra from the (upper) Ca II K, Ca II H, He I 1083.0 nm, (lower) OH 388.4, C 538.0 and Mn 539.4 nm. The daily ISS program acquires numerous spectral bands, including the six shown here.

These spectral lines correspond to wavelengths Bill Livingston (NSO) has used to monitor the solar cycle with the McMath-Pierce spectrometer. ISS observations are spatially unresolved, which means that the Sun is observed as a star. Scientists will use the data taken with the ISS to understand how the solar cycle modulates the energetic output of the Sun as a function of wavelength. Ultimately, this is one piece in the puzzle of how long-term variations in solar irradiance affect terrestrial climate. In addition, these data will be compared to similar data from solar-type stars in studies of stellar cycles and their dynamo origin. Preliminary analysis, shown in Figure 2.2-5, comparing the Ca II K parameters (December 2006 - May 2007) from the ISS (\$) with data from the synoptic programs at the Evans Coronal Facility (+) at Sac Peak and at the McMath Pierce Spectrometer (\*) at Kitt Peak show excellent agreement.



**Figure 2.2-5.** Comparison of the CaII K parameters (December 2006 - May 2007) from the ISS ( $\Diamond$ ) with data from the synoptic programs at the Evans Facility (+) at Sac Peak and at the McMath-Pierce spectrometer (\*) at Kitt Peak.

# 2.2.3 Full-Disk Patrol (FDP)

The Full-Disk Patrol will record full-disk intensity images of the Sun using filtered portions of spectrum lines considered important to the study of solar activity. Completion of this final instrument for the SOLIS three-instrument suite has been the last to be scheduled since similar observations are available from other sources. All major hardware has been purchased and the operating software completed. The system has been aligned up to the final beam splitter and has had the mechanism motors tuned for reliable operation. A printed circuit board for controlling the visible tunable filter FeLCs has been designed and fabricated. Preliminary data will be taken during the first quarter of FY 2009 prior to completion of the limb guider. Calibration and data processing algorithms are required for FDP observations before the instrument is deployed. Once the instrument has passed qualification testing in the lab, it will be moved to Kitt Peak and installed beside the VSM on an independent declination mount. Currently, the instrument is expected to be fully assembled by the end of calendar year 2008, with lab qualification tests to take place in the first half of 2009.

#### 2.2.4 SOLIS Software

The code within SOLIS has been modified to make it Portable Object Adaptor (POA)-compatible and usable with the upgraded version of Java. The code is now ready to be installed into the main SOLIS release when the Linux machines are upgraded. In addition, the connection to VxWorks using a new version of OmniORB name service has been tested, also in anticipation of machine upgrades. A study has been completed that outlines in detail the hardware and software upgrade path for SOLIS data processing. The study includes estimates of resources and risks associated with various approaches. Hardware will be purchased in stages to maximize processing power and ensure long term serviceability.

Resources were spent on implementing a test bed for pipeline testing. The test bed has been extremely helpful because it permits frequently-needed testing and code modification to be made in an environment insulated from science code development and the summit pipeline. This has accelerated the updating of pipeline code on the summit so that it now reflects as closely as possible the code that is up to date in the Concurrent Versions System (CVS) repository. Stokes full-disk two-pass processing infrastructure is in place and Stokes pipeline processing is nearing completion, awaiting new science code. Statistics of observations taken with the pipeline show a steady 10% yearly increase in number of observations from 2005–2007. In February 2008, routine observations taken weekly were increased to meet science requirements and this has led to an expected 50% increase in observations over the previous year.

#### 2.2.5 SOLIS Hardware

Work has been completed on upgrading the Kitt Peak SOLIS Tower (KPST) storage area network (SAN) to a RAID-1 in order to avoid data loss when one SAN disk fails and to have serviceable parts. Loss of observing time due to SAN disk failures has since been reduced from approximately two days to three hours, and additional improvements to the observing environment have enhanced ease and reliability of observations.

Implementation of the new SOLIS Data Acquisition System (DAS) and Sarnoff cameras is nearing completion. Three cameras (one spare) have been purchased and delivered from Sarnoff with modifications to better meet the VSM scientific requirements. Work on the new DAS to replace the current, non-supportable SOLIS digital signal processing (DSP)-based system has been completed and testing performed in the lab and at the observing site. Data have been taken in the lab to develop routines for removing fringes caused by the cameras. Modifications to data analysis software are now at a point where actual observations are required to progress further. Installation of the cameras will proceed as weather permits during the first quarter of FY 2009.

The scientific requirements for the VSM call for three different types of polarimetry modulation at two different wavelengths, 630.2 nm and 854.2 nm. To achieve these requirements, three separate modulator packages were fabricated using ferroelectric liquid crystals (FeLC) purchased from Displaytech. The large (50 mm diameter) modulators within the VSM, however, appeared to degrade in quality with variations in polarization modulation across the field of view. In November 2007, a wiring error to the motors was found and corrected, and degradation has since ceased. In addition, recent work to remove polarization fringes in the 6302V data has determined that the fringes are from the <sup>1</sup>/<sub>4</sub> wave plates and not from the FeLCs. This problem can be resolved in the future by purchasing higher quality wave plates. There are field effects that appear from striations near the central field of view, but these and other features due to camera electronics and scattered light are now corrected with the revised data reduction routines.

The most recent design for implementing the guider array readout electronics involves replacement of the analog multiplexing scheme with four, dual-channel analog and digital converter integrated circuits (ADC ICs) which were not commercially available until recently. An upgraded version of the signal processing board was obtained from the original board manufacturer for testing purposes but,

unfortunately, the science requirements could not be realized. Requirements were then modified to better match commercially available hardware. The current design is to use the new detector head with the original digital signal processor (DSP) board but modify the method by which the solar limbs are detected. Approximately two person- months have been estimated for completion of the position encoder development and another two person-months for components controller driver development and integration into the FDP instrument (Fall 2008) in preparation for integration into the VSM.

In January 2008, NSO submitted a pre-proposal to the NSF/Atmospheric Sciences Division Mid-Size Infrastructure (ATM/MSI) Opportunity program to build two near-duplicates of the VSM to be stationed in the Canaries (Spain) and Western Australia (Learmonth). Oskar von der Lühe and Pere Pallé (KIS, Germany and IAC, Spain) and Phil Wilkinson (Director, Ionospheric Prediction, Radio and Space Services, Australia) supplied letters of interest in which they offered support for operational costs. The NSO was subsequently invited to submit a full proposal in June 2008. In addition, a paper and poster about the proposed VSM network was presented at the June 2008 SPIE conference on Ground-Based and Airborne Instrumentation for Astronomy.

# 2.3 Adaptive Optics (AO)

With the completion and deployment of the high-order AO systems at the Dunn Solar Telescope and at Big Bear Solar Observatory (BBSO), the technical efforts of the AO project are now focused on the development of multi-conjugate adaptive optics (MCAO) and an advanced AO system for the ATST. Multi-conjugate adaptive optics is a technique that provides real-time diffraction-limited imaging over an extended field-of-view (FOV). The development of MCAO for existing solar telescopes and, in particular, for the next generation large-aperture solar telescopes is thus a top priority. The Sun is an ideal object for the development of MCAO since solar structure provides "multiple guide stars" in any desired configuration. During FY 2005, a first successful MCAO engineering run was performed at the DST. Different algorithms for controlling the two deformable mirrors (DMs) were tested and one of the deformable mirrors was tuned through different conjugate heights in the atmosphere. The system demonstrated its capability to deliver an extended corrected field. However, further development is needed before operational solar MCAO can be implemented at future large-aperture solar telescopes such as the ATST. MCAO development must progress beyond these initial proof-of-concept experiments and should include laboratory experiments and on-sky demonstrations under controlled or well characterized conditions, as well as quantitative performance analysis and comparison to model predictions.

In FY 2008, a dedicated MCAO bench was implemented at the DST with the goal of developing wellcharacterized, operational MCAO. The MCAO system uses two deformable mirrors conjugated to the telescope entrance pupil and a layer in the upper atmosphere, respectively. DM2 can be placed at conjugates ranging from 2 km to 10 km altitude. For our initial experiments, staged approach is used in which the 97 actuator, 76 subaperture correlating Shack-Hartmann solar adaptive optics system normally operated at the DST is followed by the second DM and the tomographic wavefront sensor, which uses three "solar guide stars". Modal reconstruction algorithms were used for both DMs. The MCAO system was successfully and stably locked on artificial objects (slides), for which turbulence screens are generated directly in front of the DMs, as well as solar structure. The height of the upper conjugate DM was varied between 2 km and 7 km and strictly simultaneous images after the pupil DM and after the upper layer DM were recorded. Comparing these images allows us to evaluate the performance of the MCAO stage and directly compare to the conventional AO. In addition, wavefront sensor telemetry data for closed and open loop were recorded

Jose Marino, now at the University of Florida as an ATST fellow, has produced MCAO reconstructors as well as performance models for the DST MCAO. These models can be compared to the actual achieved system performance. Initial results of the MCAO work have been presented at the Advanced Maui Optical and Space Surveillance Technologies 2008 (AMOS08) conference.

The MCAO development is done in close collaboration with the University of Florida and the Kiepenheuer Institute (KIS) in Freiburg, Germany. Two KIS graduate students spent several months at NSO in FY 2008 to actively participate in the MCAO development and experiments. This collaboration will continue into FY 2009 and beyond. Additional MCAO runs at the DST are already scheduled and KIS students and senior personnel, as well as Jose Marino, will participate. During these upcoming engineering runs, a global reconstruction algorithm will be implemented that promises to provide better performance. In addition, the number of guide stars will be increased.

The ATST will require an AO system that has an order of magnitude more subapertures and actuators compared to the AO76 currently operating at the DST. In order to mitigate the development risk, NSO is partnering with the New Jersey Institute of Technology/Big Bear Solar Observatory (NJIT/BBSO) in the development of a high-order AO system for the New Solar Telescope (NST). The system will have 300-400 degrees of freedom and hence can be regarded as a natural intermediate step towards the ATST AO. In fact, a substantial amount of the software and hardware development involved with the NST AO will be directly portable to the ATST AO. A proposal for the NST AO development has been submitted to the NSF-ATI program with T. Rimmele as the PI. If successful, the three-year development effort would start in FY 2009.

# 2.4 Global Oscillation Network Group (GONG)

The Global Oscillation Network Group is an international, community-based program that conducts detailed studies of the internal structure and dynamics of the Sun by measuring acoustic waves that penetrate throughout the solar interior. In order to overcome the limitations of observations imposed by the day-night cycle at a single observatory, GONG operates a six-station network of extremely sensitive and stable solar velocity mappers located around the Earth, obtaining nearly continuous observations of the "five-minute" pressure oscillations.

The instruments obtain images of velocity, intensity, and magnetic flux once a minute with a duty cycle near 90%. Data products, including individual images, time series, *p*-mode frequencies, and "science products," such as flow maps and potential field source surface extrapolations of the magnetic field, are available online at <u>http://gong.nso.edu</u>.

GONG continues to provide photospheric line-of-sight magnetograms, and intensity images in the 6768 A Ni line. The high-time-cadence magnetograms (one per minute) are being used for many solar physics studies; among them, flare-related field changes, magnetic field oscillations, solar wind predictions, and x-ray bright point origins. This is due to the upgraded polarization modulators and accompanying electronics that were installed around the network in 2006, resulting in a zero-point background of only  $\pm 0.1 \text{ G}$  — some 30 times smaller than the previous level and among the lowest zero points in all available data. The low background noise and unprecedented cadence combine to produce magnetic synoptic maps with extremely high signal-to-noise ratios. These maps, which are produced on an hourly basis, along with full-disk magnetograms produced every ten minutes, are available to the user community on the GONG Web site in near-real-time. NASA's STEREO mission is using the GONG magnetograms for mission support, context, and science. In addition, the Hinode mission, the US Air Force Research Laboratory, the Space Science Laboratory at the University of California Berkeley, the University of Alabama in Huntsville, NOAA's Space Weather Prediction Center, and several groups developing numerical simulations of the coronal magnetic field, are all using GONG magnetograms. This year, we have been concentrating on improving the data reduction to further reduce the zero point, to improve the estimated polar fields, and to provide high-quality one-per-minute merged magnetograms.

GONG continues to operate the automatic pipeline that produces daily maps of the back, or "far side," of the Sun using near-real-time data. Produced with acoustic holography, these images assist in forecasting active regions up to two weeks before they rotate into view, thus providing useful information to a broad range of users, from solar astronomers planning upcoming observing campaigns to space weather forecasters. It has been determined that the far-side signal is correlated with the area and magnetic field strength of very large active regions. Using this metric, a calibration relationship is now available, and will be further improved with the application of a newly developed method that extends around the limb and on to the front side of the Sun, allowing continuous tracking of the active regions. The calibration is being pursued to create a flare forecast probability for regions identified on the far side. In addition, we have recently found that the far-side phase shift averaged over the entire back side of the sun is an excellent and sensitive measurement of the sun's acoustic radius.

The local helioseismology Ring Diagram pipeline has now produced maps of the horizontal flow over the outer 16,000 km of the solar convection zone for 80 consecutive Carrington rotations (2160 days). These flow maps have been analyzed to reveal a strong correlation between subsurface tornado-like motions, intense surface magnetic fields, and high flare activity. Preliminary results using a statistical discriminant test indicate that the addition of a vorticity measure does improve the identification of potentially dangerous active regions. We are currently working on using the temporal behavior of the vorticity to derive a method of predicting the flare productivity of an active region. The US Air Force and NASA's Johnson Space Flight Center are interested in developing these observations into an operational space weather predictive tool.

Observations and analyses of the intermediate-degree global p modes continue to track the evolution of the interior through the solar cycle. GONG continues to observe the first complete (and long) solar cycle (Cycle 23) to be investigated using helioseismic techniques, obtaining excellent measurements of the torsional oscillation (a region of faster rotation) propagating toward the equator. These observations indicate that the torsional oscillation associated with the next cycle (No. 24) appeared midway through 2002, approximately six years before the anticipated onset of substantial surface activity. The torsional oscillation pattern associated with Cycle 24 is qualitatively different from that of Cycle 23, suggesting that the torsional oscillation might be useful for space weather prediction. Since there are indications that Cycle 23 is peculiar, and there are a number of widely discrepant predictions for the strength of Cycle 24, it will be extremely valuable to continue global helioseismic observations well into the next cycle. In addition, having seen the long-standing neutrino deficit resolved in favor of the Sun and supporting new physics of the neutrino, we are watching the debate around the substantial changes in the internal structure implied by a newly proposed lower value of the heavy element abundance (Z). GONG data are being used to test new solar models based on the new abundances, and the current results imply that the new abundance measurements are incorrect. Finally, new analyses of the correlations between the mode frequencies and the surface magnetic field indicate that there may be two distinct and different types of interaction between the modes and the field, with one coming from the weak background field and the other from the strong and active fields.

GONG has formed a partnership with the US Air Force Weather Agency (AFWA) to supply space weather data for their operational needs. AFWA is already using GONG's magnetograms. Under this partnership, GONG is starting to develop an H-alpha imaging system that will be installed at all sites. The new capability will supply 2048 × 2048 pixel full-disk images in H-alpha with a passband of 0.4 Å. The images will be obtained at a one-minute cadence at a given site, with the time of acquisition staggered by 20 second for geographically adjacent sites. The images will be returned to Tucson within one minute after acquisition and AFWA will transfer them from Tucson to their forecast center in Omaha, Nebraska. Once the H-alpha network is operational, which should be deployed in early 2010, AWFA will provide a significant portion of GONG's annual operating budget.

The site and instrument operations team continues to face and meet the challenge of maintaining and improving network reliability and maintainability. With the anticipated H-alpha system and its associated rapid data return requirement, the team is now monitoring the actual communications bandwidth, with the eventual aim of bringing all of the GONG data to Tucson via the Internet alone. The near-real-time transfer of reduced resolution data has already resulted in more automated and efficient data verification and diagnostics, which contribute to maintaining a high duty cycle. In terms of data, the team continues to streamline the data processing with the use of efficient computer servers and shared resources, and with the implementation of process-controlled pipelines. The data operations team has pioneered the path for near-real-time data transfer from the sites with the development of the far side and magnetogram pipelines.

# 2.5 Virtual Solar Observatory (VSO) and Digital Library

In FY 2008, NSO continued to lead the development of the Virtual Solar Observatory (see *http://vso.nso.edu/*), a unified distributed solar data archive system with access through the Internet. Version 1.2.3 of the system was released for public use on 10 March 2007. Since December 2004, approximately 80,000 searches have been performed using the VSO, which provides access to data from 63 different observatory/instrument sources, both space- and ground-based. The data can be searched on the basis of observatory or instrument, physical, observable, time, event, and spectral range. The VSO provides two types of interfaces—a Web-based interface for browsing, and an Application Programming Interface (API), which allows users to access the VSO directly from their own personal software.

In FY 2008, further development of the VSO was completed, providing more improvements to the display of files returned from a search, and additional catalogs of active region data. In FY 2009, VSO development will include the ability to select data on the basis of spatial area, and the addition of data from the Solar Dynamics Observatory (SDO) and the Dutch Open Telescope. The VSO is being constructed by NSO, NASA Goddard Space Flight Center, Stanford University, Montana State University, and the Harvard/Smithsonian Center for Astrophysics.

The need for a VSO is clearly demonstrated by the experience of NSO in providing synoptic data sets over the Internet to the research community. In FY 2008, the NSO Digital Library distributed approximately 2.2 TB of data files to approximately 1000 users. These figures exclude any NSO or NOAO staff members. Currently, the Digital Library holds the entire set of daily solar images from the Kitt Peak Vacuum Telescope, Fourier Transform Spectrometer data, a portion of the Sacramento Peak spectroheliograms, OSPAN/ISOON images, GONG data, and SOLIS magnetograms. With the advent of the VSO, solar researchers as well as educators and the general public can now easily find solar data for their research or educational needs.

# **3 SCIENTIFIC AND KEY MANAGEMENT PERSONNEL**

The NSO staff is located in Sunspot, New Mexico and Tucson, Arizona. The observatory director is Dr. Stephen Keil, who is based in Sunspot but spends time at both operational sites. Dr. Mark Giampapa is deputy director and responsible for the Tucson operations, with Ms. Priscilla Piano as administrative manager. Mr. Rex Hunter is support facilities and business manager at Sacramento Peak in Sunspot, and Mr. Steve Hegwer is the project and telescope manager at Sunspot. Dr. Aimee Norton is the SOLIS program scientist and Mr. Kim Streander is the SOLIS program and NSO/Kitt Peak projects manager. Dr. Frank Hill is the GONG program scientist and Ms. Patricia Eliason is the GONG program manager in Tucson. The ATST project scientist is Dr. Thomas Rimmele. Mr. Jeremy Wagner is the ATST project manager, and Mr. Dave Dooling is the ATST/NSO educational outreach officer. NSO and affiliated scientific staff are listed below, along with their primary area of expertise and key observatory responsibilities.

#### 3.1 Sunspot-Based Scientific Staff

#### NSO Staff

- **David F. Elmore** Ground-based spectrograph and filter-based polarimeter development; ATST instrumentation.
- Stephen L. Keil NSO Director; ATST PI; solar variability; convection.
- Alexei A. Pevtsov Solar activity; coronal mass ejections; ATST broadband imager.
- **Thomas R. Rimmele** Solar fine structure and fields; adaptive optics; instrumentation; ATST Project Scientist; Dunn Solar Telescope Program Scientist; ATST/AO program lead.
- Han Uitenbroek Atmospheric structure and dynamics; radiative transfer modeling of the solar atmosphere; Ch., NSO/SP Telescope Allocation Committee; ATST thermal IR.

#### **Grant-Supported Staff**

- Alexandra Tritschler Solar fine structure; magnetism; Stokes polarimetry; ATST polarimetry.
- Friedrich Wöger High-resolution convection; solar fine structure, convection; magnetic fields.

#### Air Force Research Laboratory Staff at Sunspot

- Richard C. Altrock Coronal structure and dynamics.
- K. S. Balasubramaniam Solar activity; magnetism; polarimetry; ATST.
- **Timothy A. Howard –** Coronal mass ejections.
- Richard R. Radick Solar/stellar activity; adaptive optics.
- S. James Tappin Coronal mass ejections.

#### **Thesis Students**

• Brain Harker – Solar activity; magnetism; polarimetry.

#### Active Emeritus Staff (not in residence at Sunspot)

- **Donald Neidig** Solar activity and flare prediction.
- George Simon Convection.
- Jack Zirker Solar prominences.
- Jacques M. Beckers Optical telescope design.
- **Raymond Smartt** Solar eclipses and coronal structure.

#### 3.2 Tucson-Based Scientific Staff

#### NSO Staff

- Olga Burtseva Time-distance analysis; global helioseismology; leakage matrix.
- Mark S. Giampapa NSO Deputy Director; stellar dynamos and magnetic activity; asteroseismology; astrobiology; Ch., NSO/KP Telescope Allocation Committee; Ch., Scientific Personnel Committee; SOLIS PI.
- Irene E. González Hernández Local helio-seismology; helioseismic holography; ring diagrams.
- Frank Hill Solar oscillations; data management; GONG Program Scientist.
- Carl J. Henney Solar MHD; polarimetry; space weather; SOLIS Data Scientist.
- **Rachel Howe** Helioseismology; the solar activity cycle; peak fitting.
- John W. Harvey Solar magnetic and velocity fields; helioseismology; instrumentation; SOLIS Project Scientist.

- Shukur Kholikov Helioseismology; data analysis techniques; time-distance methods.
- John W. Leibacher Helioseismology; atmospheric dynamics.
- Aimee A. Norton Solar MHD; observational constraints for solar dynamo theory; instrumentation; SOLIS Program Scientist.
- Matthew J. Penn Solar atmosphere; solar oscillations; polarimetry; near-IR instrumentation; Co-Site Director, NSO REU/RET Program; McMath-Pierce Facility Scientist; ATST near-IR.
- Clifford G. Toner Global and local helioseismology. Image restoration; data analysis techniques.

#### Grant-Supported Scientific Staff

- Michael Dulick Molecular spectroscopy; high-resolution Fourier transform spectrometry.
- John A. Eddy Solar-terrestrial physics; Earth system science; history of the Sun and climate.
- Rudolph W. Komm Helioseismology; dynamics of the convection zone.
- Gordon J. D. Petrie Solar magnetism; helioseismology
- Andrew E. Potter Sodium and potassium atmospheres of the Moon and Mercury
- Nour-Eddine Raouafi Solar magnetic fields.
- William H. Sherry Evolution of stellar activity; protoplanetary disks.
- Sushanta C. Tripathy Helioseismology; solar activity.
- Roberta M. Toussaint Helioseismology; image calibration and processing; data analysis techniques.

#### Active Emeritus Staff in Tucson

- William C. Livingston Solar variability.
- Harrison P. Jones Solar magnetism and activity.

# **4 SCIENTIFIC RESEARCH AND DEVELOPMENT HIGHLIGHTS**

#### 4.1 Observation of Alfvén Waves in the Solar Corona

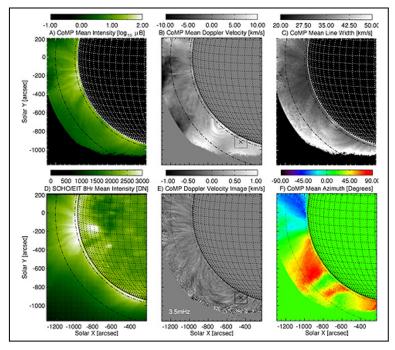
Why the solar corona reaches temperatures of millions of degrees while the solar surface (photosphere) is only a few thousand is a longstanding problem in solar physics. Alfvén waves, which are incompressible, transverse oscillations that propagate along field lines with magnetic tension as the restoring force, have long been postulated as a possible source of the energy that heats the solar corona.

To first order, Alfvén waves do not create detectable intensity fluctuations, and thus the imagers used for most coronal observations will not see them. Velocity fluctuations inferred from Doppler shifts of emission lines require spectrograph or narrow-band filtergraph measurements; most coronal work has been performed with spectrographs that cannot observe over a large enough field of view in a time that is sufficiently short compared to wave periods. Thus, in spite of their importance for coronal heating, definitive observations of Alfvén waves in the coronal plasma have been lacking.

The data used in this study by HAO scientists Steve Tomczyk, Scott McIntosh, and Phil Judge, Steve Keil (NSO), REU students Tom Schad and Justin Edmondson, and RET teacher Dan Seeley, were obtained with the Coronal Multi-channel Polarimeter (CoMP) attached to the Coronal One Shot (COS) coronagraph mounted on the Hilltop spar at Sacramento Peak. CoMP is a combination polarimeter and narrowband tunable filter, which can measure the complete polarization state of coronal emission lines in the near-infrared. Observations consisting of images of the corona between 1.05 and ≈1.35 solar radii (Rsun) in the four Stokes parameters (*I*, *Q*, *U*, and *V*) at three wavelengths across the Fe XIII 1074.7 nm line (red wing, line center, and blue wing) were obtained every 29 seconds on 30 October 2005, between 14:15 UT and 23:33 UT. The spatial sampling was 4.5 arcsec per pixel. The Fe XIII 1074.7 nm line is formed at about

1.6 MK. After removing residual image motion between frames, Tomczyk et al. computed the velocity and intensity at line center by fitting Gaussians to the three wavelength points at each pixel. They also computed the degree of linear polarization and the azimuthal direction of the magnetic field in the plane of the sky.

The first three panels in Figure 4.1-1 show maps of mean intensity, velocity, and line width for the part of the corona that were analyzed. This section of corona contained both active region loops and a coronal cavity. A movie of the velocity images reveals ubiquitous, quasi-periodic fluctuations with a root mean-square amplitude of 0.3 km s<sup>-1</sup>. Power spectral analysis of these velocity fluctuations results in a broad peak near five minutes. Phase analysis, performed by taking each pixel as a reference point





and computing its cross-spectral with every other pixel in the surrounding area, showed that in regions of high coherence, the phases had signatures of propagating waves with speeds of 1–3 Mm s<sup>-1</sup>. Most of these waves were propagating outward and aligned well with the direction of the magnetic field.

Tomczyk and colleagues believe that the waves they observed were Alfvén waves because: a) the observed phase speeds ( $\approx 2$  Mm s<sup>-1</sup>) are much larger than the sound speed ( $\approx 0.22$  Mm s<sup>-1</sup>), therefore, the waves are not slow MA mode waves; b) the spatio-temporal properties of the velocity oscillations and the linear polarization measurements show that these waves propagate along field lines, which would not be the case for fast MA mode waves in the corona; and c) the associated intensity fluctuations are very small.

#### 4.2 The Tilted Solar Magnetic Dipole

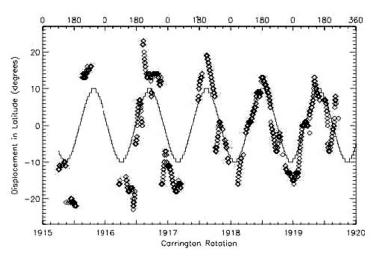
Astrophysical bodies often have magnetic axes not aligned with their rotational axes. For instance, the magnetic axes of Earth and Uranus have tilt angles of 11° and 60° with respect to their rotational axes. The Sun has a magnetic dynamo acting in the interior, with toroidal bands of magnetism at the base of the convection zone being the source of sunspots. In discussing a "magnetic axis," Aimee Norton, Gordon Petrie, and Nour-Eddine Raouafi (NSO) refer directly to the dipole component of the magnetic field.

Norton and colleagues examined the tilt of the solar magnetic dipole near the 1996 solar minimum. They are motivated by the idea that a persistent tilted dipole may result from an MHD instability acting upon the toroidal magnetic bands in the interior. Non-axisymmetric eruption of sunspots mapping out an m=1 (or 'tilted band') pattern in longitude has been predicted by dynamo theory and observed in sunspot location patterns (Norton and Gilman, 2004). The decay of the follower spots and the pole-ward migration of flux could create polar caps misaligned with the N-S rotational axis. Coronograph data from the Large Angle and Spectrometric Coronagraph Experiment (LASCO) are used to study the global coronal geometry for Carrington Rotations (CRs) 1900-1932.

Simultaneously observed East and West limb streamer profiles are compared by cross-correlating the brightness as a function of latitude. To display the evolution of the dipole tilt, the latitudinal

displacement was plotted as a function of time (see Figure 4.2-1). A damped sinusoidal pattern results for CRs 1915-1919, indicative of a dipole tilt with amplitude decreasing in time, which may be a signature of the descent toward solar minimum.

The center-of-gravity (COG) of the magnetic polar caps and the polar coronal holes were also investigated using Kitt Peak Vacuum Tower (KPVT) magnetograms and SOHO Extreme Ultraviolet Imaging Telescope data. To determine the COG, the edges of the polar holes are selected visually, with coordinates translated into latitude and longitude. A similar method is employed for the magnetic polar caps. For comparison, the potential-field sourcesurface (PFSS) model was used, with KPVT magnetogram data as input, to model the coronal hole boundaries and the magnetic dipole term.



**Figure 4.2-1.** The displacement in latitude that results in the best cross correlation between streamers on the East and West limb of the Sun (diamonds). A periodic signal is expected from a dipole geometry tilted with respect to the rotational axis. A  $10^{\circ}$  tilt is over plotted as a solid line for reference.

This research represents an effort to connect the current understanding of the dynamic magnetic field at the base of the convection zone with non-axisymmetry observed in solar surface magnetism. The proposed mechanism could contribute up to 10° to the tilt of the magnetic dipole. The equatorial streamers map out a sinusoidal structure in longitude and latitude about the equator for CR 1915-1919 with ~10° amplitude in latitude. The polar caps defined by the coronal holes and modeling exhibit a tilt with values ranging from 1 to 10° with an average value of 4–6°.

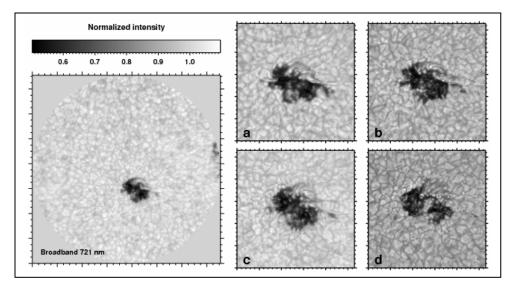
These are acceptable amplitudes to result from the MHD instability of the toroidal bands. However, without the polar cap geometries determined from the unipolar magnetic regions as seen in surface flux (and not just as determined from the polar hole locations), the viability of the proposed mechanism for creating a non-zero magnetic dipole tilt at solar minimum remains in question. For a more in-depth treatment on this topic, see Norton and Raouafi (*ASP Conf. Series*, 383, 2008) and Norton, Petrie and Raouafi (*ApJ*, 682, 2008).

# 4.3 Observations of a Small Emergent Bipolar Flux Region

The Sun has not been very active lately, with only a handful of active regions appearing on the disk in many months. For this reason, Alexandra Tritschler (NSO), Kevin Reardon and Gianna Cauzzi (Arcetri Observatory) were excited about being able to capture the emergence phase of a small, old-cycle, bipolar region close to disk center on 22 April 2008. During almost four hours of exceptionally good seeing conditions, the Interferometric BIdimensional Spectrometer (IBIS) scanned repeatedly through four spectral lines (Fe I 709.04 nm, Na I 589.6 nm, H I 656.3 nm, Ca II 854.21 nm), covering the height range from the photosphere to the chromosphere. The narrow-band observations are supported by simultaneous broad-band observations at 721 nm and in the G Band around 430.5 nm.

Although IBIS was operated in a non-polarimetric mode, these observations are of particular interest and importance for two reasons. First, Tritschler and colleagues witnessed the transformation of filamentary structures (a rudimentary penumbra) into a small but fully developed penumbral segment in the photospheric layers of one of the formerly naked umbrae, in concert with the formation of a small light bridge. The evolution of active regions has been extensively studied for decades, and much progress has

**Figure 4.3-1.** Left panel: Normalized broad-band intensity at 721 nm (in units of the mean quiet Sun) showing the 75 × 75 arcsec FOV observed with IBIS. Right panel: Individual speckle reconstructions showing four different time steps during the transformation process of a rudimentary penumbra into a penumbral segment.



been achieved in understanding how flux is transported from deep in the convection zone to emerge at the solar surface in the form of sunspots. However, a comprehensive picture of the detailed process of penumbral formation and decay is still nonexistent, because observations of this precious moment in time are extremely rare.

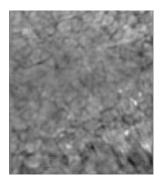
Figure 4.3-1 shows the 75 × 75 arcsec field of view (FOV) of IBIS (left) and depicts some moments during the transformation process based on speckle-reconstructed broad-band observations (right, from a to d in time, 26 × 26 arcsec FOV). Second, the chromospheric observations give strong evidence for large redshifts in both legs of the loop(s) that connect the two pores. Preliminary line-of-sight (LOS) velocities confirmed this impression, indicating line-core Dopplershifts that correspond to velocities in the range of 10-20 km/s. Inspecting the Ca II 854.21 nm line profiles directly, the observers note the presence of strong line asymmetries in the form of redshifted line satellites.

In between the two red-shifted legs, indication of a blueshift is seen. Considering the closeness to disk center, the measured LOS velocities are interpreted as real upflows and downflows and Tritschler, Reardon and Cauzzi speculate that they have captured the drainage of the rising magnetic loop associated with the bipolar region. Supersonic chromospheric downflows have been detected before, particularly in the footpoints of arch filament systems from H-alpha observations (e.g., Bruzek, *Sol. Phys.*, 1969), but the combination of spectral and temporal coverage and excellent spatial resolution makes our observations very unique.

#### 4.4 New High-Resolution Quiet-Sun Images at 4667 nm

New imaging observations have been made at the McMath-Pierce Solar Telescope using the NSO Array Camera (NAC). With a narrowband filter centered at 4667 nm, which includes several very strong CO absorption lines, very rapid exposures were taken during good seeing at the disk center quiet Sun on 21–23 March 2008. Individual exposure times on the order of 20 milliseconds were obtained using the single-frame read mode of the NAC camera. Adaptive optics was not used, but the atmospheric seeing was excellent during the observations. After extensive correction for background variation and flat-fielding, the raw images showed solar granulation, as well as bright features in the intergranule dark lanes.

Figure 4.4-1 shows a reconstructed image from the center of the solar disk on 22 March 2008 produced with the multi-object, multi-frame blind iterative deconvolution (MOMFBD) procedure described in



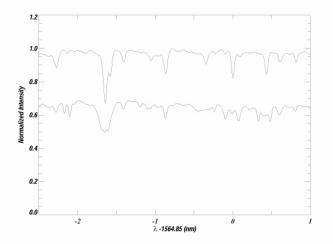
**Figure 4.4-1.** An image of the solar granulation from 22 March 2008 taken with the McMath-Pierce telescope and the NAC at 4667 nm (which includes several strong CO absorption lines). The field measures  $45 \times 35$  arcseconds, and details at the diffraction limit of the telescope (0.8 arcsec) are visible. The granulation has low contrast, but bright points in the dark intergranular lanes are visible near the right edge of the field. Time sequences from 21-23 March show similar small-scale bright points, which have long lifetimes and are thought to be similar to the G-band bright points.

Noort, et al. (2005). The intensity is scaled between  $\pm 2$  percent around the mean intensity. Features at the telescope diffraction limit (0.8 arcsec) are seen in the image, which measures roughly 45 × 35 arcsec across. While the granulation contrast is low, the bright intergranule features (middle of image, right side) show contrast of 3 percent or greater. These features resemble the magnetic bright points seen in high-resolution G-band images, and a time sequence from March 23 showing similar small-scale bright features reveals that they have a lifetime that far exceeds the granulation turn-over time; currently it is thought that they represent locally heated regions of high magnetic field where the CO molecule is dissociated and the absorption spectrum is absent.

#### 4.5 Using the Near-Infrared to Study Sunspot Umbral Dynamics

The NSO NAC was also used with adaptive optics by NSO staff (A. Norton, M. Penn, C. Plymate, and E. Galayda) to search for a dependence of magnetohydrodynamic (MHD) wave speeds on the average field strengths in several sunspot umbrae. They measured velocity signals with the Fe I 1564.8 nm line and the molecular OH lines at 1562.7 nm. The OH lines are formed approximately 90 kilometers higher than the Fe line in the solar atmosphere. Norton and colleagues identified characteristics of oscillatory signals and any associated propagation speeds.

Since the dominant umbral oscillations are the slow MHD waves, acting similarly to a pure acoustic wave, they should not show a dependence on umbral field strength. This hypothesis was tested by obtaining time-series with a duration of 3,040 minutes and a 20-second sampling resolution for different active regions. The near-IR data are especially interesting because so few sunspot studies have been conducted at this wavelength, and it is not adversely affected by scattered light.



**Figure 4.5-1**. Sample spectra observed with the NSO Array Camera in the 1564-nm region. A quiet-Sun spectrum is plotted in the top line and an umbral spectrum plotted below. The spectral lines of interest are the OH molecular lines near 1562.7 nm and the Fe I magnetically sensitive line at 1564.8 nm. Note that the molecular OH lines at 1562.7 nm are only formed in cool umbrae. The Fe I 1564.8 nm line is magnetically sensitive with an effective Landé factor of three. The splitting of the line is obvious in the umbral spectra.

Preliminary results show that the dominant umbral signal has a periodicity of 23 minutes and phase lags between the Fe and the OH lines are positive, meaning the Fe signal leads the OH signal. This indicates upward propagation of waves with phase speeds of 15–30 kilometers per second. There are plans to continue observational efforts and determine if the wave characteristics show a dependence on field strength, but Norton and colleagues may have to wait until the new solar cycle has truly begun before this study can be completed.

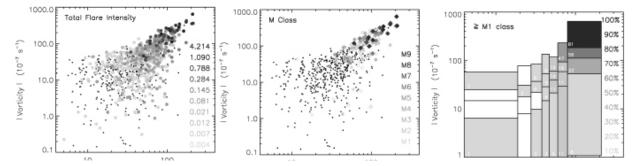
#### 4.6 Do Solar Subsurface Vorticity Measurements Improve Flare Forecasting?

Regions of strong magnetic fields (active regions) are the locations of strong eruptive phenomena such as flares and coronal mass ejections which can disrupt technology on Earth. Highly twisted magnetic fields are very probably responsible for these phenomena. These fields extend from below the surface through the solar atmosphere into the interplanetary medium (heliosphere). Flows below the solar surface are accessible with the techniques of local helioseismology, which are currently the only way to measure anything related to active regions below the solar surface.

The subsurface flows below active regions are highly twisted. In a previous study with Douglas Mason (NSO 2005 REU student, USC; Mason et al., 2006), a quantity to capture this pattern in a single value was defined and it was found that flare activity is intrinsically linked to subsurface phenomena on time-scales and spatial scales comparable to the lifetime and size of active regions. The question remains whether the measured vorticity of subsurface flows can help to improve the forecasting of flare activity of active regions.

Rudi Komm, Frank Hill and NSO 2008 REU student Ryan Ferguson (Michigan State U.) have begun to address this question using the data set from the previous study, which Ferguson extended to include data through 2007. The data set is the largest of its kind and consists of 1009 active regions and their subsurface flow measurements derived from GONG data. The data set also includes the magnetic flux of each active region from NSO/Kitt Peak and SOLIS synoptic maps and the corresponding X-ray flare information from the Geostationary Operational Environmental Satellite (GOES). Komm, Hill, and Ferguson determined solar subsurface flows with a ring-diagram analysis and removed the average differential rotation and the average meridional flow to focus on the variation of the flows associated with active regions.

The left panel of Figure 4.6-1 shows the total flare intensity of active regions, a proxy of their total X-ray flare activity over an active region's lifetime. A flare-prolific active region is clearly characterized by large magnetic flux and large vorticity values. A large magnetic flux is not sufficient to determine whether a given active region will be flare-prolific or not. Even at high flux values, there are active regions with low vorticity that do not produce energetic flares. The middle panel shows the same for the M-class of X-ray flares. (Of the 1009 active regions analyzed, 425 regions produced at least a C-class flare, while 130 regions produced at least an M-class flare and only 19 regions produced an X-class flare.) It is clear that the strongest flares occur when both the flux and the vorticity values are high. From this result, it can be deduced that the probability that an active region within a certain range of vorticity and magnetic flux produces an M-class flare, as shown in the right panel. This probability is 81% for a region in the bin with the largest flux and vorticity values compared to an overall probability of 44% for the four bins with the



**Figure 4.6-1.** The left panel shows the surface magnetic field B and vorticity of 1009 active regions. Grey circles indicate the flare intensity levels summed over all flares in each region. (Black crosses indicate non-flaring active regions). The flares occur mainly when the active regions have high values of both B and vorticity. The middle panel shows a similar plot but for M-class flares only. Filled (open) diamond symbols indicate active regions that produced multiple (only one) M-class flares. The right panel divides up the active regions so that each box contains an equal number of points. The number in the bins are the percentage of active regions with at least one flare with an M-class or greater magnitude. Grey scales indicate the probability levels in steps of 10%, white is zero. It is clear that the strongest flares occur when both B and vorticity are high.

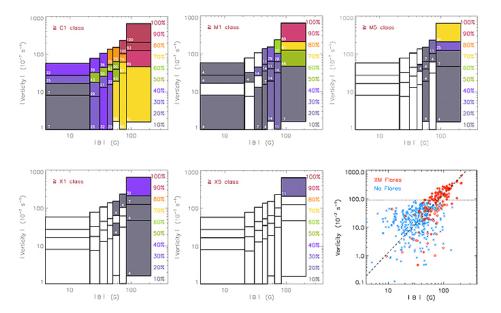
largest magnetic flux or only 13% for the whole data set. It is clearly beneficial to include the vorticity information in this case. Similar results were found for C- and X-class flares.

The inclusion of subsurface vorticity improves the ability to distinguish between flaring and non-flaring active regions compared to using magnetic flux alone. The results presented here characterize the average behavior of active regions during their disk passage and not their evolution on much shorter time scales. Results on the temporal variation of subsurface flows of active region related to their flare activity will be presented in the near future.

# 4.7 GONG High-Cadence Magnetograms

GONG's high-cadence magnetograms continue to capture the attention of the community and funding agencies, and are eliciting interest in wider participation in operational support of GONG. In addition, progress in the development of active-region prediction tools is sparking queries from additional potential partners.

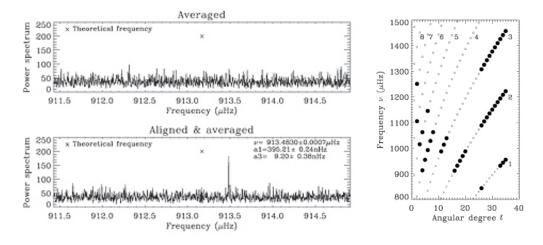
Recently, the GONG team developed a calibration between the farside signal and the magnetic field strength and area of large active regions, which has enabled the production of synoptic maps that incorporate an estimate of the farside field. These front-side "plus" farside synoptic maps should improve the field extrapolations and solar-wind predictions. Looking below the surface with one of GONG's standard helioseismic data products, a 16-degree across three-dimensional subsurface map of horizontal flow, we can now determine various fluid dynamics quantities that tell us how the plasma is moving apart (divergence) and the twistedness (vorticity) of the flows. A statistical study of some 400 active regions found that if the region is associated with a combination of high vorticity and high surface magnetic field, then there is a very high probability of strong flare activity. We now have a quantitative measure of flare occurrence probabilities, which is what space-weather forecasters really need for a timely warning, as shown below.



**Figure 4.7-1.** The lower right panel shows the surface magnetic field *B* and vorticity of approximately 400 active regions. Dark symbols indicate active regions that produced flares, while light symbols show active regions that did not flare. The preponderance of flares occur when the active region has high values of both *B* and vorticity. The remaining panels divide up the active regions so that each box contains an equal number of points. The numbers in the bins are the percentage of active regions with at least one flare with a magnitude above the indicated class. Grey scales indicate the probability levels in steps of 10%, white is 0%. It is clear that the strongest flares again occur when both *B* and vorticity are high. This suggests that measuring the subsurface vorticity will become a useful way to identify active regions that potentially could produce dangerous flares.

#### 4.8 New Analysis Technique for Measuring Low Radial-Order *p* Modes in Spatially-Resolved Helioseismic Data

While much of GONG's current effort is focused on space weather products and local helioseismology, the field of global helioseismology is still thriving. David Salabert (Instituto de Astrofisica de Canarias, Tenerife, Spain), John Leibacher (NSO), and Thierry Appourchaux (Institut d'Astrophysique Spatiale, Orsay, France) recently developed a new way to estimate the parameters of oscillation modes at low frequencies, below 1.5 megahertz. This region of the spectrum is dominated by power from non-oscillatory solar phenomena, such as convection, which makes it difficult to identify and fit the peaks from the *p* modes. The new method, illustrated in Figure 4.9-1, exploits the three-dimensional nature of the oscillation spectrum by shifting in frequency and then averaging the spectra as a function of azimuthal degree *m*. The magnitude of the frequency shift is adjusted until the resulting averaged peak for the mode is as narrow as possible, providing an estimate of the mode parameters. This method has added about 30 extremely precise modes to the set that can be fitted, and has improved the precision of the inversions below the convection zone.



**Figure 4.9-1.** Traditionally, global helioseismic analysis based on the fitting of individual modes has been limited to modes with frequencies above approximately 2000  $\mu$ Hz, as at lower frequencies, the mode amplitudes decrease rapidly and the background arising from solar convective motions increases. However, for each radial harmonic (n) and spherical harmonic degree ( $\ell$ ), there are actually  $2 \ell + 1$  modes with different values of the azimuthal order (m), whose degeneracy is broken by differential rotation and asphericities of the internal structure. By optimally shifting the individual m spectra and averaging over m, we have been able to detect many modes never seen before, which because of their long lifetimes can be measured with exquisite precision, substantially improving our knowledge of the structure and dynamics throughout the solar interior. (Left panel) The  $\ell = 4$ , n = 4 multiplet, which is very clearly detected from ten years of GONG data in the aligned m-averaged spectra (lower panel) compared with the unaligned spectrum (upper panel). The estimated central frequency and shift (a) coefficients are indicated. The cross indicates the position of the corresponding theoretical central frequency calculated from Christensen-Dalsgaard's model S, suggesting that we still have a ways to go in refining the model of solar internal structure. (Right panel)  $\ell - \nu$  diagram of the "never-before-seen" modes ( $1 \le \ell \le 35$ ) detected in the GONG data (•) along with already known modes ( $\circ$ ) and predicted modes (×).

# **5 BRIDGES TO THE FUTURE**

#### 5.1 Kitt Peak

# 5.1.1 NSO Array Camera (NAC)

The ATST will be an all-reflecting, open solar telescope; currently the closest analogy is the NSO/Kitt Peak McMath-Pierce Solar Telescope (McMP). The all-reflecting design of the McMath-Pierce gives it access to the entire solar spectrum that is transmitted through the Earth's atmosphere. Exploring the infrared parts of this spectrum is a high priority for NSO, and the wavelength range from 1,000-5,000 nm is the focus of the new NSO Array Camera program. The NAC is a closed-cycle cooled, InSb 1024 × 1024 pixel camera and now routinely obtains images and spectroscopy from 1,000 to 5,000nm, and polarization data in the 1,000-2,2000 nm window. The NAC has replaced the aging NSO Near-Infrared Magnetograph (NIM) instrument.

In 2008, the NAC instrument obtained science data at several wavelengths from 1200 nm through 4666 nm, including short-exposure, high-resolution granulation images from 1000 to 2200 nm. The NAC is now available to the solar community as a facility instrument at the McMP and is in high demand for solar infrared studies. Instrumental development included completion of the full Stokes polarimeter and observations at 1565 nm of Stokes *IQUV* profiles of a sunspot, reduction of fringes with a new wedged CaF window, and the establishment of instrument setups for both nighttime and solar direct imaging on the NAC.

The next step for the NAC system is to investigate and develop solar polarimetry in the 3000-5000 nm wavelength region. There are several promising spectral lines in this region that will produce the most sensitive magnetic diagnostics of the solar photosphere, chromosphere and corona. The NAC, in combination with the McMP (which provides the largest IR flux of any solar telescope currently available), will provide a unique opportunity to study these new lines. A first attempt to purchase polarization analysis optics for this wavelength range was unsuccessful, and now vendors are being sought in conjunction with NASA investigators. The NAC system is also planned to be a bridge to the Advanced Technology Solar Telescope near-infrared instrumentation. The NAC dewar is flexible, with an abundance of internal space available, and can accommodate upgrades for use with the ATST first-light instrumentation. The scientific discoveries that will come from the NAC observing runs during the next few years will drive near-infrared science programs at the ATST.

# 5.1.2 Seeing Improvement

Tests of potential improvements to the telescope seeing have been conducted during the last several years, including fans blowing air across the McMath-Pierce image-forming (#2) mirror. The #2 mirror is heated by the incoming sunlight, which heats the air layer directly above. This hot layer of air can rise convectively across the solar beam and distort the final image. It is believed that installing fans to flush ambient temperature air across the #2 mirror will diminish or eliminate this contribution to the telescope seeing. Preliminary air flushing tests have been conducted with the McMath-Pierce main and 0.9-m West Auxiliary telescope. Knife-edge images show blowing air across the #2 mirrors clearly affects this seeing layer. The tests demonstrated a need for greater flow volume. Further tests have been scheduled, with full implementation on the main telescope as resources allow.

The wavefront sensor in the adaptive optics system has also revealed other sources of telescope seeing, such as the interface between the telescope and the observing room. Appropriate changes have been made to improve these sources of internal seeing. New tests of the atmospheric seeing will be made from the McMP using a Seykora seeing monitor from Sac Peak, and a project to develop a higher order adaptive optics system for the McMP by collaborators at California State University-Northridge is being proposed to the NSF.

#### 5.1.3 Adaptive Optics (AO)

The infrared adaptive optics system at the McMath-Pierce Solar Telescope is now in routine use for scientific observations at the main spectrograph. The optical bench configuration has proven to be extremely flexible and has been used to feed the corrected beam to 2D IR imagers as well as to the spectrograph's input slit. Spectral imaging is achieved by scanning the AO output beam splitter using a stepper-motor-controlled translation stage. This moves the corrected image plane across the spectrograph slit. Most infrared observing runs now routinely request the adaptive optics system. The system can be used with any high-contrast feature smaller than the wavefront analysis camera's sub-aperture field of ~20 arcseconds. The AO has a special 1D correction mode for solar limb observations. A commercial, 37-actuator deformable mirror is used for wavefront correction, while image motion is canceled by a high-speed, two-axis, piezo-electric tip-tilt mirror. The system also allows tip-tilt errors to be sent to the telescope for auto-guiding corrections. The autoguide function has proven to be especially useful for tracking objects transiting across the solar disk, such as sunspots.

As currently visualized, the limb guider will need to be placed on the optical table situated above the main spectrograph; thus a new adaptive optics bench has been developed and is located below the optical table. The final design, programming, construction and implementation of the guider, are planned for 2009.

Fully AO-corrected observations of Mercury and other solar system objects are of high interest to future US and European space missions. The current AO bench has been successfully locked onto the planet Mercury and to stars down to magnitude 2.6. This demonstration led to the successful funding of a NASA proposal for the construction of another AO bench which has been built at the McMath-Pierce.

The predecessor to the full AO system is an image stabilizer based on the same high-speed piezoelectric tip-tilt correction mirror and wavefront camera used on the AO bench. The image stabilizer is still in high demand for planetary and 12-micron solar observations. Seeing at 12 microns is typically lower than the diffraction limit of the McMath-Pierce, making full AO unnecessary. Increasing the integration time on the wavefront camera now allows image stabilized IR observations of Saturn. With the incorporation of an image intensifier, the image stabilizer has been successfully demonstrated on objects down to 7th magnitude. A duplicate of the tip-tilt correction mirror was purchased by NASA/GSFC and incorporated into the transfer optics of the 12-micron cryogenic spectrometer, CELESTE, for use at the McMath-Pierce. The CELESTE image stabilizer still relies on the use of the NSO wavefront camera and computer.

#### 5.1.4 McMath-Pierce Telescope Control System (TCS)

The telescope control system (TCS) for the McMath-Pierce telescope is antiquated and in need of an upgrade for the telescope to remain competitive and maintainable. Budget constraints prohibited the full upgrade of the TCS, and a more cost-effective solution was needed that would be consistent with future decommissioning as outlined in the Senior Review.

An economical solution of software emulation has been implemented that addresses a key aspect of the TCS reliability problems—the PDP 11/73 control computer (PDP) and peripherals. Because of their age, the system disks and the nine-track tape drives attached to the PDP were prone to failure, and spares were becoming increasingly scarce. The CAMAC crates attached to the TCS computer via a Kinetic Systems 2061 Parallel Data Highway were not replaced as there is a sufficient supply of spare parts. However, from the standpoint of increasing the overall reliability of the TCS, this subsystem should be next on the list for upgrade, should budget and other considerations permit.

The emulation software is run in Linux on a generic PC, with a garden variety multi-port serial card. The system disk and tape drive are emulated as files, so disk backup and tape data maintenance now simply consist of file copy operations (such as ftp over the ethernet) in Linux. The existing qbus backplane was

used to house the qbus adapter card for the data highway. The only drawback to the emulation solution was that a special-purpose PCI-to-qbus adapter card (BCI-2104) was needed to interface to the Kinetic Systems qbus card. The drawback was mitigated by purchasing spares. This solution had the distinct advantages of being the cheapest, the most flexible and maintainable, and one of the easiest to implement. The total cost was \$30K in hardware and required three months for design, implementation, and testing.

To augment pointing accuracy of the telescope, the NSO is investigating the design of a new guider system for the McMath-Pierce. The new guider will permit precision pointing and tracking of features on and above the solar disk. The current concept utilizes a limb-tracking system mounted above the spectrograph on a computer-controlled, two-axis translation stage. Four limb sensors mounted at 90° intervals will feed limb- position information to a control computer. The telescope's field of view is sufficient such that at least two of the limb sensors are illuminated when imaging any part of the solar disk. The guider-control computer will analyze the sensors, apply the necessary coordinate rotation between telescope coordinates and spectrographic (guider) rotation and send guide corrections to the telescope. The control computer will communicate with the NAC to synchronize movements of the translations stage to enable 2D scanning of the solar surface.

# 5.1.5 Integral Field Unit (IFU) for the McMath-Pierce Telescope

A grant from the NSF Advanced Technology Instrumentation (ATI) program is funding development of a state-of-the-art, all-reflective image slicer integral field unit. The IFU is being developed for AO-corrected infrared observations with the McMath-Pierce vertical spectrograph. D. Ren (California State U., Northridge) and C. Keller (U. of Utrecht) are co-investigators on this project that will divide a  $6.25 \times 8$  arcsecond 2D field into 25 slices to produce a 200 arcsecond-long slit with a width of 0.25 arcseconds for diffraction-limited spectroscopy and polarimetry in the IR. The IFU is designed to be used over the 0.8–5.0 micron range and is optimized for 1.56 micron observations of the strongly Zeeman-split (g=3) Fe I line. The IFU is enclosed in a ~1.2 m × 0.3 m × 0.3 m box that mounts in the optical beam between the current AO system and spectrograph slit.

The IFU was tested on the main spectrograph at the McMath-Pierce telescope during 2008, when it was discovered that the mirror alignment hardware for the image slicing mirror needed to be re-built. Otherwise the device worked well and the IFU is expected to become a user instrument at Kitt Peak in 2009.

# 5.2 Sacramento Peak

# 5.2.1 Spectro-Polarimeter for Infrared and Optical Regions (SPINOR)

SPINOR is a joint NSO/HAO program to replace the existing advanced Stokes polarimeter (ASP) at the Dunn Solar Telescope. The ASP has been the premier solar research spectro-polarimeter for the last decade. The ASP wavelength range, however, was restricted to the visible, limiting its ability to sample new solar diagnostics. SPINOR extends the wavelength of the ASP from 750 nm to 1600 nm with new cameras and polarization optics, provides improved signal-to-noise and field-of-view, and replaces obsolete control equipment. Software control of SPINOR will be integrated into the DST camera control and data handling systems as opposed to the stand-alone ASP system.

SPINOR will be the primary DST spectro-polarimeter instrument for joint observations with Hinode and will augment capabilities for research spectropolarimetry at the DST and extend the lifetime of state-of-the-art research spectropolarimetry at the DST for another decade.

Engineering and staff science observing runs are on-going in an effort to bring SPINOR to a facility class instrument.

#### 5.2.2 Diffraction-Limited Spectro-Polarimeter (DLSP)

The Diffraction-Limited Spectro-Polarimeter remains fully integrated with one of the high-order AO systems (Port 2). A 1 Å K-line imaging device and a high-speed 2K × 2K G-band imager with speckle reconstruction capability, as well as a slit-jaw imager, have been integrated with the DLSP and high-order AO as permanent capabilities. A diffraction-limited resolution mode (0.09 arcsec/pixel, 60 arcsec FOV) and a medium-resolution mode (0.25 arcsec/pixel, 180 arcsec FOV) are available. The Universal Birefringent Filter (UBF) can be combined with the DLSP/imaging system. The full-up instrumentation set continues to be available for users.

The DLSP has been used to implement a "solar queue observing mode" at the Dunn Solar Telescope. Predefined observations, or observations of targets of opportunity, are carried out by the observing support staff. Implementation of this mode allows for more efficient use of the best seeing conditions. A similar operating model is envisioned for the ATST, and the DST/DLSP experience will be crucial for developing an efficient operations strategy for the ATST.

#### 5.2.3 Interferometric Bldimensional Spectrometer (IBIS)

IBIS is an imaging spectrometer built by the solar group of the University of Florence in Arcetri, Italy. IBIS delivers high spectral resolution (20 mA), high throughput and consequently high cadence. In collaboration with NSO and HAO, the Arcetri group upgraded IBIS to a vector polarimeter. The wavelength range of IBIS extends from visible to near IR and allows spectroscopy and polarimetry of photospheric and chromospheric layers of the atmosphere. NSO has a Memorandum of Understanding with the University of Florence for continued operation and support of IBIS at the Dunn Solar Telescope. A joint upgrade effort between NSO and the Arcetri group is currently underway to replace the existing science camera and further integrate IBIS into the DST camera control and data handling systems.

# 5.2.4 Rapid Oscillations in the Solar Atmosphere (ROSA)

ROSA is a joint program between NSO and the Queen's University Belfast (QUB). ROSA is a synchronized, multi-camera, high-cadence, ground-based solar imaging system. QUB has completed a contract with Andor Corp. for a turnkey camera system. The system includes six high-speed cameras, synchronization electronics, main server, low-level software, GUI, SCSI RAID and LTO3 drives.

The science expected to be accomplished with ROSA include studies of: a) the photosphere and chromosphere as one coupled system; b) waves (200 km – 2000 km) – mode coupling; c) flares – H $\alpha$  diagnostics of electron beams (timescales 0.1 second); d) radiative hydrodynamics of flares; and e) magnetic field changes at high cadence.

The ROSA commissioning run at the DST was successfully completed in August 2008. Additional observing runs are expected to continue in the first quarter of 2009.

# 5.2.5 Facility Infrared Spectro-Polarimeter (FIRS)

This is a collaborative project between the NSO and the University of Hawai'i Institute for Astronomy (IfA) to provide a facility-class instrument for infrared spectropolarimetry at the Dunn Solar Telescope. H. Lin (IfA) is the principal investigator of this NSF/MRI- funded project. This instrument will be able to take advantage of the diffraction-limited resolution provided by the AO system for a large fraction of the observing time at infrared wavelengths. Many of the solar magnetic phenomena occur at spatial scales close to or beyond the diffraction-limited resolution of the telescope. A diffraction-limited achromatic reflecting Littrow spectrograph allows for diverse wavelength coverage. A unique feature of FIRS is the multiple-slit design, which allows high-cadence, large FOV scans (four times faster than SPINOR and DLSP) and is a vital feature for studying dynamic solar phenomena such as flares. The high-order Echelle grating allows for simultaneous multi-wavelength observations and thus 3D vector polarimetry.

The instrument now resides on port-4 of the DST and is configured to collect science data at .6302 and 1.56 microns. The addition of a high resolution optical feed is currently in progress. The remaining major tasks required to bring FIRS to a facility class instrument include; integration to the DST data handling system, implement required common services functions, completing the operators manual, and providing observer training.

The NSO is contributing mechanical design work and manufacturing, and assisting with electronic and optical design.

# 5.3 Evans Solar Facility (ESF)

The US Air Force (AF) currently provides support for the ESF to continue their synoptic coronal emission line program. Other users are given access to the facility if they can provide their own support. Currently, the High Altitude Observatory (HAO) would like to use the facility for some experiments in coronal magnetometry and has reached an agreement with NSO and the AF program. Preliminary observations with the system were conducted in the spring of 2008.

#### 5.3.1 Prominence Magnetometer (ProMag)

ProMag is a joint project between the HAO and NSO. The NCAR-funded ProMag is an instrument that will address basic problems of coronal magnetism by engaging in a long-term program of vector field measurements in prominences and filaments. ProMag will do spectropolarimetry in prominences, and filaments in the He I lines at 587.6 nm (D3) and 1083.0 nm, using dispersion grating and a slit assembly.

The ProMag instrument will reside at the Evans Solar Facility, and will serve primarily as a research instrument for HAO. After the first year of operation, the instrument support requirements will be evaluated and NSO/HAO may consider making the instrument available to others within the solar community. Integration of ProMag into the ESF began in 2008 and should be completed in 2009.

# 6 EDUCATIONAL & PUBLIC OUTREACH

NSO has a comprehensive public affairs and educational outreach plan that includes public programs, media information, elements of distance learning (Internet) education, K-12 education, undergraduate and graduate research, teacher research and research-to-classroom experiences. Scientists at each site have responsibility for the local educational and public outreach program, with additional support provided by other members of the scientific and support staff and, during the summer, by resident students. In addition to conducting public relations and outreach as part of the ATST program, Educational and Public Outreach (EPO) Officer Dave Dooling coordinates the ATST educational and public outreach efforts with that of the NSO and other ATST partners.

#### 6.1 Educational Outreach

# 6.1.1 Research Experiences for Undergraduates (REU), Research Experiences for Teachers (RET), and Other Summer Research Assistantship (SRA) Programs

During summer 2008, a combination of six REU students and three graduate SRA students participated in research opportunities at locations in Tucson and Sunspot. In August 2008, NSO submitted a proposal to the NSF MPS/AST Special Programs in Astronomy for four additional years of funding of the NSO REU/RET Program beginning in summer 2009. During the past five years, 31% of our REU students have

co-authored a refereed paper, and more than 60% of graduating NSO/REU participants have entered a graduate program in Physics, Astronomy, or Engineering.

Four US astronomy graduate students participated in the 2008 International Research Experience for (Graduate) Students (IRES) Program. Sponsored by a grant from the NSF Office of International Science and Engineering (OISE), the eight-week program started on 11 June and took place in Bangalore, India under the auspices of the Indian Institute of Astrophysics (IIA).

## 6.1.2 Research-Based Science Education (RBSE)

As part of the summer 2008 RBSE solar program, Claude Plymate, with NOAO's Connie Walker, conducted five days of successful observing and data analysis at the McMath-Pierce Solar Telescope with three high school science teachers in June. A fading active region at 1565 nm and velocities in granulation (space-time diagrams) at 1579 nm were observed.

#### 6.1.3 Project ASTRO

As a Project ASTRO partner, Kerri Donaldson Hanna gave a presentation to a class of fourth graders (approximately 25 students) at Robbins Elementary school in Tucson on what it means to be an observational astronomer. She described what it's like to go to a telescope, how to collect data, what data look like, how to reduce data and what is done to the final data set.

NSO, in collaboration with the New Mexico Museum of Space History and the Astronomical Society of the Pacific, hosted the Project ASTRO-New Mexico Teacher/Astronomer Workshop on 12-13 October at Sunspot.

#### 6.1.4 Further Undergraduate and Graduate Education

NSO continues with its strong commitment to supporting undergraduate and graduate education and attracting students to solar physics research. Aimee Norton, in collaboration with the University of Arizona (UofA) Lunar and Planetary Laboratory (LPL), created a flyer as part of the effort to recruit students into the new graduate program in solar and heliospheric physics at the UofA LPL and to NSO's summer research programs. The flyer was posted on the NSO EPO Web site and widely distributed.

On 16-20 June at NSO/Sac Peak, the UofA/LPL and NSO hosted the third in a series of five weeklong Solar Physics Summer Schools designed for advanced undergraduate and beginning graduate students interested in the physics of the Sun and possible careers in solar physics, space physics, or related fields. About 20 lectures were delivered to more than 30 student and faculty participants. At the end of June, Claude Plymate delivered a lecture and data collection demonstration remotely (from the McMath-Pierce Solar Telescope facility) to students at Mt. Wilson as part of the Mt. Wilson 2008 Consortium for Undergraduate Research and Education (CUREA) program. The live video lecture was delivered via Skype while data were taken with the NSO Array Camera at 1579 nm. The resulting data were sent in near-real-time to a Web page for the CUREA students to download, reduce and analyze.

The NSO is pleased to be a formal partner with three institutions that submitted proposals in July 2008 for funding through the NSF Partnerships in Astronomy and Astrophysics Research and Education (PAARE) Program. As described by the NSF synopsis, "the objective of PAARE is to enhance diversity in astronomy and astrophysics research and education by stimulating the development of formal, long-term, collaborative research and education partnerships between minority serving colleges and universities and the NSF/AST Division-supported facilities projects or faculty members at research institutions including private observatories." Through this program, NSO scientists will mentor students from Fisk/Vanderbilt University, California State University, Northridge, and New Mexico State University.

Whenever possible, NSO staff serve as advisors to undergraduate students who choose to do an independent study course in space/solar physics. The staff also serve as graduate thesis advisors or on graduate thesis committees, and as guest lecturers at universities and colleges within or outside of Arizona and New Mexico, and abroad, and host NSO facility tours involving undergraduate and graduate students. For example, during the fall 2007 semester, Han Uitenbroek gave a three-hour visiting lecture, "An Introduction to Solar Radiative Transfer," to students at the University of Nice, France, and Alexei Pevtsov taught two on-line courses (ASTR-105G) on "The Planets," involving 40 students at New Mexico State University. John Leibacher served as a member of the PhD Jury of Savita Mathur (Universite' Paris-Sud 11) for her 18 December thesis presentation on "A la recherche des modes de gravite: etude de la dynamique du coeur solaire." As one of two "reporters" on the thesis, Leibacher provided a detailed report on the thesis and whether it merits presentation to the university. Leibacher also worked with several other PhD students at the University of Paris. Dave Dooling taught an introductory Astronomy 110G course in all semesters at New Mexico State University, Alamogordo. Tim Henry has given lectures and tours to several university groups from Texas, and with Dooling, exhibited at the Holloman Air Force Base Entertainment, Arts, and Tourism (HEAT) event near Alamogordo on 26 September.

In August 2008, Dave Dooling started developing plans for broadening participation in NSO activities and outreach. Specifically, he spoke with minority educators in Huntsville, Alabama, about connecting NSO to historically black colleges and universities (HBCU) and other institutions. Dr. Marilyn Lewis, Education Projects Coordinator in the Academic Affairs Office at NASA/Marshall Space Flight Center, advised that NSO start with one or two universities, then expand based on lessons learned from that experience. NSO has talked with Dr. Mohan Aggrawal, physics department chair, and other educators at Alabama A&M University about extending REU awareness and other activities there. A&M is affiliated with the NSF-funded Center for Interactive Space-Weather Modeling. NSO also will talk with Fisk University and is reviewing public schools with large Hispanic and Native American populations in the New Mexico/Arizona area for further involvement. Dooling also spoke with Dr. Gail Porter, chair of the physics department at Old Dominion University and Dr. Don Michels, ex-Naval Research Laboratory scientist and Catholic University professor emeritus, about science education and public outreach issues.

# 6.1.5 Other Educational Outreach

Throughout the year, scientific staff at both sites gave talks at local elementary schools and organized star parties for students, parents and teachers. NSO officials from Sac Peak and Tucson also assisted with city and regional science fairs in their areas. NSO staff and/or current and past RET teachers regularly represent the NSO at State and National Teachers conferences. For example, Rob Hubbard gave a presentation on solar physics and the Advanced Technology Solar Telescope (ATST) on 17 October 2007 to two Gifted and Talented Education (GATE) science classes in the Tucson Unified School District (TUSD). Each class involved approximately 20 middle school students. In November 2007, Dave Dooling held a workshop on the solar system model at the New Mexico Science Teachers Convention, and NSO's exhibit from 2007 at the National Atomic Museum was reprinted for use in the Sunnel exhibit at the McMath-Pierce Telescope.

As part of an effort to enhance its partnership with NSO, the New Mexico State University (NMSU), Las Cruces, developed a solar program in 2007 and advertised a tenure-track assistant professor position in solar astrophysics in its Department of Astronomy. NSO scientific staff were involved with the search process for this position. Location of the NSO-Sacramento Peak site in proximity of the NMSU campus will facilitate and enhance the collaborative opportunities available to a new solar physics faculty member of the NMSU community.

#### 6.2 Public Outreach

#### 6.2.1 Sunspot Visitor Center

A continuing effort has been the development of a community solar system centered on the Sunspot Astronomy and Visitor Center. The overall objective is to learn about the need for solar studies by providing an 18-foot walkthrough model of the Sun as the destination in a 16-mile trip across the solar system starting in Cloudcroft. In September 2008, NSO and the State of New Mexico Tourism Department signed a Memorandum of Understanding for \$75,000 in state funds for NSO to develop the first phase of the model. The model was redesigned so the initial components could be fit within this budget,

Sunspot Astronomy & Visitor Center Summary of Visitors and Tours (12 Months Ending 09/30/08)		
Group/Program	No. of Visitors	
General Public Tours (Visits to Center and Self-Guided Tours)	13,222	
Guided Public Tours: - School Groups K-12 - Special Tours	192 453	
Total Visitors	13,867	

including purchase of the radar dome, models of the planets, and new graphics. Significant design work went into developing the graphics that complement the model and take the visitor's mind from the center of our Sun to the edge of the universe. Major components of the graphics were developed and presented in a temporary exhibit at the National Atomic Museum in Albuquerque during March-September 2007. Signs will be placed at appropriate locations along the Sunspot Scenic Byway (NM 6563). The signs have a minimalist design so drivers are not invited to stop on the mountain highway (explanatory signs will be on existing turnouts). The Visitor Center will have models of the Sun (18 ft. radome) and planets outside on the patio painted a neutral color to encourage touching by blind visitors. Graphics inside the Visitor Center will present the planets in color. The concept was expanded from two graphics panels (The Sun from the Inside Out and Sizing Up Your Solar System) to four (addition of One Star Among Many and A Map of the Universe). Partners on this project include the Cloudcroft Chamber of Commerce, Space Museum in Alamogordo, the Las Cruces Museum of Natural History, the state Scenic Byways office, and the Otero County Tourism Council.

Dave Dooling is developing two assessment surveys for review and comment by the NSO/SP scientific staff. The first survey queries the public about their general knowledge of the Sun. The second is designed as pre/post-visit survey to be given to students visiting the Sunspot Solar System Model. Dooling will train in Federal guidelines for conducting public surveys to ensure that participants are aware of the purpose and feel no undue pressure to participate. This will include approval of the survey through a recognized Institutional Review Board. He has consulted with Dr. Debbie Treise, associate dean in the University of Florida School of Journalism and Communications, on how to improve the surveys and on a possible joint proposal to NSF. Treise has experience in conducting public surveys of knowledge in health and science communications fields.

During the year, the Visitor Center hosted over 600 visitors. Another 13,222 visitors toured the NSO grounds (open sunrise to sunset) without entering the Visitors Center. Public lectures, and guided tours were held daily at 2 pm during the summer months when SRAs and REU interns were available. To enhance this experience, Dooling started work on a standalone video that can be played on demand when tour guides are not available at the Visitor Center.

#### 6.2.2 Other Public Outreach

On 01 March, GONG Program Manager Pat Eliason and ATST Systems Librarian Ruth Kneale participated as career panelists for the 2008 Expanding Your Horizons (EYH) Conference on the University of Arizona (UofA) campus. The conference was presented by Women in Science, Engineering and Technology (WISE), a program of the UofA Women's Studies Department and the Southwest Institute for Research on Women. The EYH conference works to motivate teenage female students to enter careers in science, engineering, mathematics and technology and to support them in their studies.

NSO scientific staff presented posters and the NSO was an exhibitor at the 27-30 May Solar Physics Division (SPD) meeting held jointly with American Geophysical Union at Fort Lauderdale, Florida. On 26 May, prior to the SPD meeting, NSO exhibited segments of the Sunspot Solar System Model at the Exploration Station sponsored by the SPD EPO. Materials included a 3' x 10' color poster showing the planets to the scale of a STARLAB planetarium dome representing the Sun.

Public talks presented by NSO throughout the year included: a talk about the Sun ("El Sol") by Irene González Hernández to ~30 members of the Galileo Astronomy Club from Instituto Senda, Obregon, Mexico on 17 May in the NOAO/NSO main conference room; a talk, at the request of the New Mexico (NM) State Park Service, by Dave Dooling about the National Solar Observatory to a small audience at Elephant Butte Lake State Park on 20 June; "on air" interviews by Jackie Diehl with FM Radio Station 97.7 NM regarding astronomy in the Sacramento Mountains, and talks by Jackie at the Tularosa, NM Career Day on 02 May.

Kim Streander and Claude Plymate hosted tours of the McMath-Pierce Telescope facility as part of the 13 September 2008 Open House of Observatories at Kitt Peak for the Tohono O'odham Nation. Organized by KPNO, the Open House provides a chance for members of the Tohono O'odham Nation to tour the Kitt Peak mountain facilities, view the Sun and the night sky through some of the telescopes, meet KPNO, NOAO, and NSO staffs, and learn a bit about what we do as we support and operate telescopes for astronomical research. The Open House also gives our staff a chance to learn more about the Tohono O'odham and their culture.

# 6.2.3 External Coordination

NSO exhibited an ATST poster at the annual Coalition for National Science Funding (CNSF) event, held 25 June 2008, at the Rayburn House Office Building. Dave Dooling talked with staff members from the offices of Senator Daniel Akaka and Representative Bart Gordon, among others, about the ATST project, and provided copies of the Leadership Briefing Package.

NSO continued its support of the Southwest Consortium of Observatories in Public Education (SCOPE) with a classroom math exercise on the size of sunspots for the reverse side of a new poster. The October 2007 SCOPE meeting hosted by Apache Point Observatory and the New Mexico State University was held at the Sunspot Astronomy and Visitor Center, where plans for the NSO 1:250-million-scale Solar System Model were presented.

#### 6.3 Media and Public Information

#### 6.3.1 Press Releases and Image Releases

A major effort during the year was development of a short informational video on ATST. This was produced in late 2007 when Maui Community College requested a narrated presentation on ATST to balance an anti-ATST video then running on its community cable TV system. The seven-minute video was reviewed at the AURA Member's Meeting in April 2008 and suggestions were taken on how to improve it. At the ATST Science Working Group (SWG) meeting in May, Dooling recorded interviews with Tom Berger, Jeff Kuhn, Lyndsay Fletcher, and Christoph Keller (and Gene Parker at the Solar Physics Summer School) for use in a revised and expanded video. The new script has been written and a "beta" version of the video is being produced for internal review. Release of the new video is expected by the end of calendar year 2008.

During the year, NSO produced four issues of the ATST Quarterly Newsletter, which goes to members of the ATST project team, Science Working Group, and the news media. Dave Dooling updated the Leadership Briefing Package (formerly called the Congressional briefing book) consisting of a series of picture pages explaining the need for and design of ATST, and backed with a set of fact sheets. The intended audiences include Senators and Representatives and their staffs, and members of the media.

New graphics were produced as part of this package. An ATST Press Kit, including the Congressional book, was developed and started in the review cycle. The ATST trifold, first printed in 2003, was updated and a new version printed this spring.

In December 2007, NSO produced an update on ATST for the SPIE Newsroom (<u>http://spie.org/x18359.xml</u>), and on 23 January 2008, a press release, "SOLIS and GONG++ See the Start of Solar Cycle 24," was issued (<u>http://www.noao.edu/intranet/proxy.cgi/000000A/http/www.nso.edu/press/cycle24.html</u>).

An article about the Advanced Technology Solar Telescope (ATST), "Building the World's Largest Solar Telescope," was written by Dave Dooling and published in the February 2008 issue of the online magazine 400 Years of the Telescope (http://www.400years.org/newsletter/400\_news\_0208.pdf).

In April, NSO/Sac Peak hosted video crews from Foolish Earthling Productions and from Interstellar Studios. Foolish Earthling was working on historical aspects of NSO/Sunspot and interviewed both Dooling and NSO director Steve Keil. Interstellar is producing "400 Years of the Telescope" as an NSF-funded contribution to the International Year of Astronomy. Dooling provided an article on ATST, linking its future research to Galileo's initial observations of the Sun, for Interstellar's first newsletter.

#### 6.3.2 Web-Based Outreach

The NSO WWW site (*http://www.nso.edu*) contains several public outreach areas. These include a live solar image that is updated once per minute so the public (and the scientific community) can see how the Sun is behaving in H $\alpha$ . These images allow the observer to quickly assess the state of solar activity. Virtual tours of NSO sites, including telescope descriptions, are available. There is an interactive solar tutorial that provides information about the Sun and its processes. "Ask Mr. Sunspot" provides an area where questions can be asked about the Sun and astronomy in general. Answers are posted on the Web and indexed so visitors can easily look at past answers by subject. A data archive is also available. While intended for scientific research, it is also accessible by the general public and to students working on solar projects. NSO also now is posting links to solar physics stories in the quarterly *NOAO/NSO Newsletter*.

#### 6.3.3 Image Requests

NSO responded to several requests from *Science* magazine, Foolish Earthling Productions (historical stills), and others. Plans are being developed for a Web-based catalog of NSO-related images, especially ATST images that would be easily searched by the media and educators.

# APPENDIX A OBSERVING AND USER STATISTICS

In the 12 months ending 30 September 2008, 82 observing programs, which included 17 thesis programs, were carried out at NSO. Associated with these programs were 54 scientists, students, and technical staff from 42 US and foreign institutions.

NSO Observing Programs by Type (US and Foreign)		
12 Months Ending September 2008	Nbr	% Total
Programs (US, involving 4 non-thesis grad		
students & 1 undergrad)	53	65%
Programs (non-US, involving 3 non-thesis grad students)	12	15%
Thesis (US, involving 11 grad students)	10	12%
Thesis (non-US, involving 12 grad students)	7	9%
Total Number of Unique Science Projects*	82	100%

\*Includes observing programs conducted by NSO/NOAO staff scientists.

Users of NSO Facilities by Category					
	Visitors			NSO/NOAO Staff	
	US	Non-US	Total	% Total	
PhDs	42	28	70	72%	13
Graduate Students	9	15	24	25%	0
Undergraduate Students	1	0	1	1%	0
Other	2	0	2	2%	21
Total Users	54	43	97	100%	34

\*\*Note: Total number of institutions represented by users do not include departments or divisions within an institution as separate entities (e.g., US Air Force and NASA are each counted as one institution even though different sites/bases/centers are separately listed in the data base.

Institutions Represented	by Vi	siting U	sers**	
	US	Non-US	Total	% Total
Academic	15	8	23	55%
Non-Academic	14	5	19	45%
Total Academic & Non-Academic	29	13	42	100%

Numbe	er of Us	ers by Nationalit	y
Australia	1	Japan	2
Canada	1	Mexico	1
France	2	Netherlands	6
Germany	8	Norway	3
India	2	Spain	2
Ireland	5	United States	88
Italy	10		

#### INSTITUTIONS REPRESENTED BY USERS

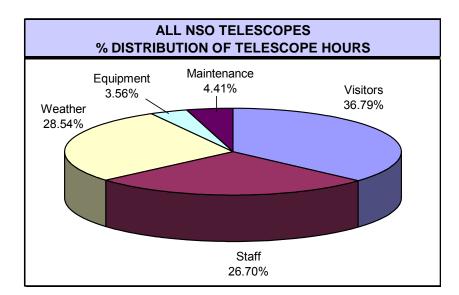
### Foreign Institutions (19)

Foreign Institutions (19)
Astrophysikalisches Institut Potsdam, Germany
Catania University, Catania Astrophysical
Observatory, Italy
Delft University of Technology, Delft, The Netherlands
Indian Space Research Organization (ISRO), India
Instituto de Astrofisica de Canarias, Tenerife, Spain
INAF - Arcetri Astrophysical Observatory, Italy
INAF - Osservatorio Astronomico di Roma, Italy
Kiepenheuer Inst fuer Sonnenphysik, Freiburg, Germany
National Astronomical Observatory of Japan
Queen's University, Belfast, Ireland
TNO Institute of Applied Physics, Delft, The Netherlands
Universidad de Monterrey, Mexico
University of Calgary, Canada
University of Koeln, Germany
University of Nice-Sophia Antipolis, France
University of Oslo, Norway
University of Rome "Tor Vergata", Italy
University of Sydney, Australia
Utrecht University, The Netherlands
US Institutions (23)
Boston University
Caifornia State University, Northridge
Catholic University of America
Dickinson College
Edinboro University
Harvard Smithsonian Center for Astrophysics
Mount Holyoke College
New Jersey Institute of Technology/Big Bear
Solar Observatory
University of Arizona
University of Colorado
University of Florida
University of Hawaii, IfA
University of Maryland
University of Washington
University of Wisconsin, Madison
Adler Planetarium, Chicago
High Altitude Observatory, NCAR, Boulder
Jet Propulsion Laboratory, Pasadena, CA
Lockheed Martin Solar & Astrophysics Laboratory
Mt. Wilson Observatory
NASA/Ames Research Center
NASA/Goddard Space Flight Center (NASA/GSFC)
Southwest Research Institute, San Antonio
US Air Force, Los Angeles
US Air Force/Philips Lab (USAF/PL/GSS)
• • •

# FY 2008 USER STATISTICS – TELESCOPE USAGE AND PERFORMANCE DATA

In the fiscal year ending 30 September 2008, 36.8% of the total available telescope hours at NSO/Sacramento Peak and NSO/Kitt Peak went to the observing programs of visiting principal investigators; 26.7% were devoted to those of NSO scientists. Scheduled maintenance (including instrument tests, engineering, and equipment changes) accounted for 4.4% of total allotted telescope hours.

Total "downtime" (hours lost to weather and equipment problems) for NSO telescopes was 36.5%. Almost all of these lost observing hours were due to bad weather (28.5%), with 1.4% lost to equipment problems.



NSO TELESCOPES Percent Distribution of Telescope Hours (Scheduled vs. Downtime) October 1, 2007 - September 30, 2008						
		% Hours	Used By:	% Hour	s Lost To:	% Hrs. Lost To:
	Hours Available	Visitors <sup>a</sup>	Staff	Weather	Equipment	Scheduled Maintenance
Dunn Solar Telescope/SP	3,648.3	25.9%	28.1%	32.6%	2.1%	11.3%
McMath-Pierce*	4,298.0	32.5%	40.8%	22.3%	3.0%	1.5%
KP SOLIS Tower <sup>b</sup>	1,523.0	0.0%	0.0%	0.0%	0.0%	0.0%
FTS Lab*	74.0	0.0%	0.0%	0.0%	0.0%	0.0%
Evans Facility	1,180.0	42.1%	0.0%	48.6%	9.3%	0.0%
Hilltop Dome	80.0	100.0%	0.0%	0.0%	0.0%	0.0%
All Telescopes	10,803.3	36.8%	26.7%	28.5%	3.6%	4.4%

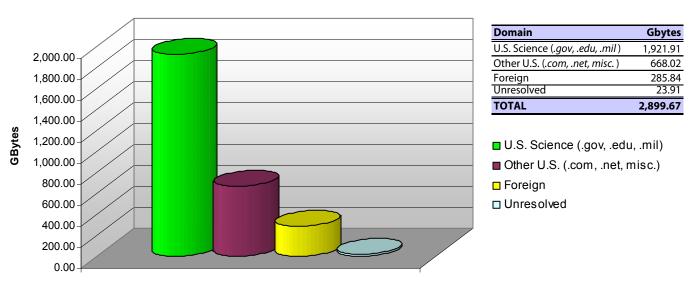
<sup>a</sup>Includes synoptic programs for which all data are made available immediately to the public and scientific community at large.

<sup>b</sup>*Kitt Peak SOLIS Tower (KPST); formerly the Kitt Peak Vacuum Telescope (KPVT).* 

\*Totals include both day and night hours. (All others are day only.)

# FY 2008 USER STATISTICS – ARCHIVES & DATA BASES

All statistics *exclude* the use of NSO archives and data bases from within the NSO Local Area Network in Tucson and at Sac Peak, and from NOAO as a whole.



## DATA (Gbytes) DOWNLOADED FROM NSO FTP & WWW SITES 01 October 2007 - 30 September 2008

#### PRODUCT DISTRIBUTION BY DOWNLOADED GBYTES 01 October 2007 - 30 September 2008

Site	Product Type	Gbytes	%
Т	GONG Helioseismology	1,780.90	61.6%
SP	Realtime Images and Movies (OSPAN, Other)	261.42	9.0%
SP & T	Other	175.62	6.1%
SP	SMEI Experiment & Data Pages	131.77	4.6%
Т	SOLIS/VSM	114.53	4.0%
Т	GONG (Magnetograms, spectra, time series, frequencies)	101.02	3.5%
SP	General Information	61.00	2.1%
SP	Press Releases	58.94	2.0%
SP	Staff Pages	35.69	1.2%
Т	FTS (Spectral atlases, general archive)	24.81	0.9%
SP	Corona Maps & Other Images	23.30	0.8%
SP	Icon & Background Images	19.68	0.7%
SP	OSPAN Project Pages	19.17	0.7%
Т	KPVT (magnetograms, synoptic maps, helium images)	18.47	0.6%
SP	Telescope Home Pages	18.13	0.6%
SP	Adaptive Optics Pages	17.10	0.6%
SP	Public Relations	16.58	0.6%
T	Evans/SP Spectroheliograms (Hα, Calcium K images)	14.02	0.5%
TOTAL		2,892.15	100.0%

# **APPENDIX B**

### FY 2008 PUBLICATIONS October 2007 through September 2008

Author-NSO StaffAuthor-REUAuthor-RETAuthor-Grad StudentAuthorNon-REUUndergrad

The following is a partial list of papers published during FY 2008 by NSO staff, as well as papers resulting from the use of NSO facilities.

#### **Refereed Publications (105)**

- 1. Andretta, V., Mauas, P.J., Falchi, A., Teriaca, L. 2008, "Helium Line Formation and Abundance during a C-Class Flare," ApJ, 681, 650-663.
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# **APPENDIX C**

#### **ORGANIZATIONAL PARTNERSHIPS**

Through its operation of the majority of US ground-based solar facilities and its ongoing synoptic programs, NSO is clearly important to the solar community. In turn, NSO must work closely with the solar community and provide leadership to strengthen solar research, renew solar facilities and to develop the next generation of solar instrumentation. Some past examples of NSO meeting this responsibility include development of GONG and enhancement of the GONG network, development of solar adaptive optics and multi-conjugate adaptive optics, development of infrared observing capabilities in collaboration with the University of Hawai'i, California State University-Northridge, and NASA, and participation in the development of the advanced Stokes polarimeter in collaboration with HAO. Table C-1 lists several ongoing joint projects and development efforts.

NSO sponsored several community workshops and forged an alliance of 22 institutions to develop a proposal for the design of the ATST and its instrumentation. NSO will continue to work closely with this group in leading the successful completion of the design and transition to construction of the telescope. NSO hosted a series of workshops on ATST science operations to provide guidance for developing a sound plan for exploiting the full potential of the ATST.

NSO's strategic planning embraces the interdisciplinary nature and dual objectives of solar physics in that it is both basic science and applied research. Likewise, NSO's relationships to its users reflect the diversity and richness of the communities they represent—solar and stellar astronomy, space plasma physics, solar-terrestrial relationships, space weather prediction, terrestrial atmospheric chemistry, and more. Table C-2 is a summary of the current partnerships that provide operational support.

NSO's long standing relationship with the US Air Force space science group will continue into the ATST era. The Air Force Office of Scientific Research (AFOSR) has expressed a desire to keep their basic solar research program collocated with NSO and has indicated that they will help purchase and polish the mirror for the ATST. Currently, NSO is vigorously pursuing other partnerships. We have had discussions with many organizations and have received letters of intent from several institutions to support ATST construction. These include organizations in Germany, the United Kingdom, a consortium of the Netherlands, Sweden and Norway, and the US Air Force. Other potential partnerships include Italy, Japan, Spain and Canada. Scientists from Italy, Japan and Spain are currently involved on the ATST Science Working Group. We have formed a close working relationship with the University of Hawai'i for ATST operations and we expect other partners to have some involvement in operations as well.

GONG is actively seeking operational partnerships with members of the space environment community, including international partnerships for site operations and data processing, and has successfully formed a partnership with the US Air Force Weather Agency (AFWA) to supply space weather data for AFWA's operational needs. In June 2008, NSO submitted a full proposal to the NSF/Atmospheric Sciences Division Mid-Size Infrastructure (ATM/MSI) Opportunity program to build two near-duplicates of the SOLIS VSM to be stationed in the Canaries (Spain) and Western Australia (Learmonth); the status of that proposal is pending.

Table C-1. Joint Development Efforts				
Telescope/Instrument/Project	Collaborators			
Advanced Technology Solar Telescope (ATST)	HAO, U. Hawai'i, U. Chicago, NJIT, Montana State U., Princeton U., Harvard/Smithsonian, UC-San Diego, UCLA, U. Colorado, NASA/GSFC, NASA/MSFC, Caltech, Michigan State U., U. Rochester, Stanford U., Lockheed-Martin, Southwest Research Institute, NorthWest Research Associates, California State U. Northridge			
Adaptive Optics	NJIT, Kiepenheuer Institute, AFRL			
Diffraction-Limited Spectro-Polarimeter ((DLSP)	НАО			
Spectro-Polarimeter for Infrared and Optical Regions (SPINOR)	НАО			
Rapid Oscillations in the Solar Atmosphere (ROSA) Instrument	Queen's University, Belfast			
Narrowband Filters and Polarimeters	Arcetri Observatory, U. Alabama, Kiepenheuer Institute			
Synoptic Solar Measurements	USAF, NASA			
Fourier Transform Spectrometer	NASA, NSF/CHEM			
IR Spectrograph and Cameras	U. Hawai'i, California State U. Northridge			
Advanced Image Slicer & Integral Field Unit	California State U. Northridge			
Virtual Solar Observatory	NASA, Stanford, Harvard-Smithsonian Center for Astrophysics, Southwest Research Institute			
H-alpha Imaging System (GONG)	Air Force Weather Agency (AFWA)/AFRL			

Table C-2. Current NSO Partnerships					
Partner	Program				
Air Force Research Laboratory	Solar Activity Research at NSO/SP; Telescope Operations; Adaptive Optics; Instrument Development; 4 Scientists Stationed at NSO/SP; Daily Coronal Emission Line Measurements; H-alpha Imaging System (GONG); Provides Operational Funding: \$400K-Base and Various Amounts for Instrument Development.				
NASA	<ul> <li>Funding for SOLIS Science Goals: Postdoctoral Research Associates (1.25 FTE); Instrument/Observing Specialist (0.5 FTE).</li> <li>McMath-Pierce: Support for Operation of the FTS (1.0 FTE); Upper Atmospheric Research; Solar-Stellar Research; Planetary Research.</li> <li>Dunn: Support for a Research Fellow for Hinode mission support (coordinated observations, science planning, mission operations, data analysis) (via Lockheed-Martin sub-award).</li> <li>GONG: 3.0 FTE Scientific Support; SDO/HMI Pipeline Development Support (0.7 FTE).</li> <li>Funding for 1 Postdoctoral Research Associate in Astrobiology.</li> <li>Virtual Solar Observatory Development Support (1.0 FTE).</li> <li>Development of VSM advanced flux estimate map for next general model of the corona and solar wind (via SAIC sub-award).</li> </ul>				
NSF Chemistry	FTS Support				