# NATIONAL SOLAR OBSERVATORY Long Range Plan Fy 2009-2013









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# MISSION

The mission of the National Solar Observatory (NSO) is to provide leadership and excellence in solar physics and related space, geophysical, and astrophysical science research and education by providing access to unique and complementary research facilities as well as innovative programs in research and education and to broaden participation in science.

NSO accomplishes this mission by:

- providing leadership for the development of new ground-based facilities that support the scientific objectives of the solar and space physics community;
- advancing solar instrumentation in collaboration with university researchers, industry, and other government laboratories;
- providing background synoptic observations that permit solar investigations from the ground and space to be placed in the context of the variable Sun;
- providing research opportunities for undergraduate and graduate students, helping develop classroom activities, working with teachers, mentoring high school students, and recruiting underrepresented groups;
- innovative staff research.

## **RESEARCH OBJECTIVES**

The broad research goals of NSO are to:

- **Understand the mechanisms generating solar cycles** Understand mechanisms driving the surface and interior dynamo and the creation and destruction of magnetic fields on both global and local scales.
- **Understand the coupling between the interior and surface** Understand the coupling between surface and interior processes that lead to irradiance variations and the build-up of solar activity.
- **Understand the coupling of the surface and the envelope: transient events** Understand the mechanisms of coronal heating, flares, and coronal mass ejections which lead to effects on space weather and the terrestrial atmosphere.
- *Explore the unknown* Explore fundamental plasma and magnetic field processes on the Sun in both their astrophysical and laboratory context.

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#### **EXECUTIVE SUMMARY**

The National Solar Observatory is the primary provider of key ground-based solar facilities to the U.S. solar community. NSO currently provides a range of assets that allow solar astronomers to probe all aspects of the Sun, from the deep interior to its interface in the corona with the interplanetary medium. NSO provides scientific and instrumentation leadership in helioseismology, synoptic observations of solar variability, and high-resolution studies of the solar atmosphere in the visible and infrared.

A key strength of the NSO, necessary to achieve its mission, is its scientific staff, who engage in frontier research, actively and visibly participate in the community, develop advanced instrumentation, participate in educational outreach, and establish new initiatives. Of equal importance is community confidence in the NSO as expressed in the Decadal Survey's endorsement of the NSO organization, confidence in NSO's leadership for the Advanced Technology Solar Telescope (ATST), and the desire of the community for NSO's participation in its other ground- and space-based projects. A further strength is that, as a federally-funded research and educational institution, the NSO is able to provide leadership, continuity and stability for the conduct of long-term programs and projects that are a scientifically necessary component of solar and solar-terrestrial research. Finally, the interdisciplinary nature of, and multi-agency participation in, solar astrophysics enables the formation of productive partnerships with the NSO that result in a stronger and broader-based program.

NSO has developed a strong and vital student program for undergraduate and graduate students, including the support of thesis students in both solar physics and instrumentation. The student program enables participants to gain experience in hands-on solar research. The NSO also helps train high school teachers through the Research Experiences for Teachers (RET) program. It also conducts K-12 outreach programs as well as outreach to the general public.

Major actions that NSO will undertake to advance solar physics include the following:

- Begin construction of the Advanced Technology Solar Telescope through the NSF Major Research Equipment Facilities Construction (MREFC) program. The ATST will be the premier ground-based facility for high-resolution studies of solar magnetism and dynamics in the solar atmosphere. It will support the next generation of solar researchers as a primary tool for probing the Sun.
- Engage the national and international community in developing a multi-station synoptic network based on experience gained with the Synoptic Optical Long-Term Investigations of the Sun (SOLIS) and Global Oscillation Network Group (GONG) programs. Long-term synoptic observations are critical to fully understanding the Sun's variable output. In particular, these data are crucial for a benchmark comparison with the variability of Sun-like stars, discerning the fundamental properties of the interior dynamo that generates the solar (and stellar) magnetic field, and placing the Sun in an astrophysical context.
- Develop an NSO structure that effectively operates new capabilities, consolidates the scientific staff currently separated in Tucson and Sunspot, and provides effective support for the observational and data needs of the solar research community. Plan for divestiture and/or closure of existing NSO high-resolution and IR facilities when ATST is operational.
- Maintain existing facilities as needed to ensure continued scientific productivity until future equivalent assets (i.e., ATST) are in place.
- Use the opportunities provided by ATST development, SOLIS, the enhanced GONG network, and the new AO and IR capabilities to promote a strong university/student basis for solar physics. University partnerships will be formed through such programs as the new NSF Partnerships in

Astronomy & Astrophysics Research and Education (PAARE) Program and the Fisk-Vanderbilt Masters-to-PhD Bridge Program to increase the diversity of NSO and the solar community by recruiting candidates from underrepresented communities.

- Take a leadership role in developing a community-wide roadmap for ground-based solar facilities and work closely with NASA to link space-based and ground-based facilities to maximize their synergy for advancing understanding of the Sun.
- Provide the astronomical community with fundamental data and results on dynamo-related activity on the Sun, the structure and rotational profile of the solar interior, outer atmospheric heating, and elemental abundances.
- Provide the space weather community with the data needed to monitor, model, and ultimatly predict solar activity and variability through the development and operation of enhanced and new observing capabilities (e.g., continual near-real-time GONG magnetograms, SOLIS vector magnetic field maps, calibrated GONG farside images). These data are equally applicable as inputs for the understanding of the role of solar variability in global climate change.
- Provide data and results to the physics community on plasma processes occurring in the unique plasma physics laboratory presented by the solar atmosphere.
- Continue to enhance the NSO digital library so that all NSO data collected on behalf of the community are available online. Continue to partner with NASA and universities in the development of the Virtual Solar Observatory, which provides community access to all aspects of solar data.
- Continue NSO scientific and instrumentation leadership by balancing staff responsibilities, increasing staff opportunities for research and postdoctoral support, developing strong university collaborations, and strengthening partnerships with other solar organizations. Develop and strengthen connections with the university community of researchers and educators in solar physics; assist them in strengthening their programs through participation in the NSO program of research, education, and the implementation of new scientific capabilities.

Ongoing and future NSO efforts are summarized in Figure 1 and explained in detail in the body of this proposal. The ongoing program is strongly focused toward NSO operations in the ATST era, while still maintaining NSO's high-quality user support as the ATST is developed. Approval of programs at the large NSO telescopes is based on contributions to ATST technology and operations, such as diffraction-limited imaging and spectropolarimetry, infrared technologies, and telescope and instrument controls.

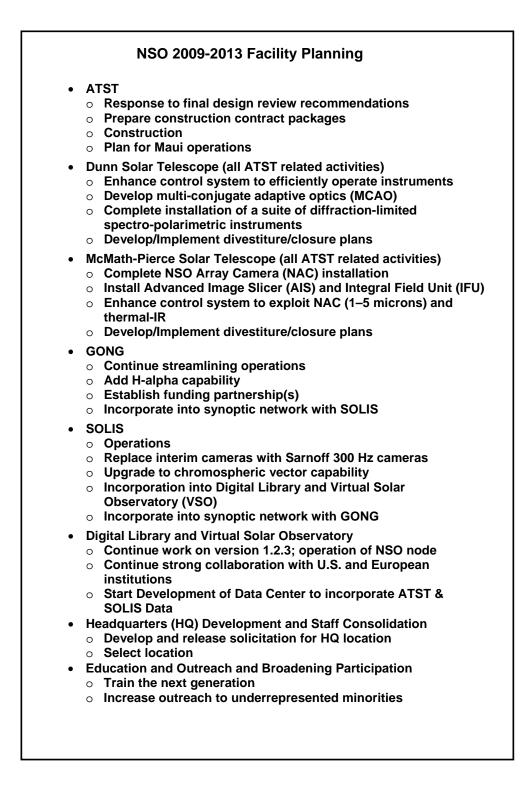


Figure 1. Planned and ongoing programs and projects at NSO.

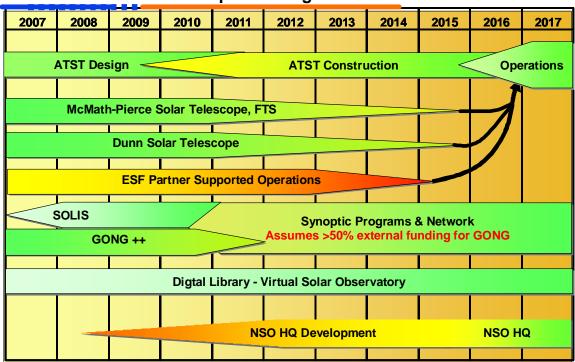
NSO and its co-principal investigators at the High Altitude Observatory (HAO), New Jersey Institute of Technology (NJIT), University of Hawai'i, and University of Chicago, along with collaborators at 17 other institutions representing a broad spectrum of the solar community, have developed a design for the ATST. The ATST project is nearing the end of the NSF MREFC approval phase. In preparation for construction, the project has completed the environmental impact studies (EIS) for siting the telescope on Haleakalā and is currently receiving public comment, will retire the remaining high-risk areas, and will prepare the request for proposal packages for final design and construction contracts of major subsystems in anticipation of an FY2010 construction start. The NSO has successfully built and demonstrated a scalable solar adaptive optics system that has revolutionized the use of current telescopes, and has developed instruments that fully exploit diffraction-limited observations. These are paving the way for achieving diffraction-limited observations with the ATST, thus retiring one of the primary risks. NSO is now targeting thermal and telescope controls and other factors that could affect telescope performance.

The SOLIS vector spectromagnetograph (VSM) and the integrated spectrometer (ISS) are currently operational on Kitt Peak and are producing highly accessed synoptic data. The VSM provides unique vector magnetograms that enable new types of synoptic maps. VSM full-disk and selected active region vector magnetograms of unparalleled precision are available from the NSO Digital Library and are being used to support Hinode. A worldwide network of SOLIS instrumentation was one of the low-cost recommendations of the previous Decadal Survey, a recommendation endorsed by the Senior Review of the NSF Division of Astronomical Sciences. NSO will use the experience gained with implementing the VSM to explore partnerships for developing a network of vector magnetographs.

High-resolution data products from GONG are now being widely used for local helioseismic exploration of sub-atmospheric structure, and GONG's near-real-time farside pipeline is fully operational. GONG's rapid cadence magnetograms and farside imaging are proving to be valuable tools for understanding space weather. In light of this, NSO is actively seeking funding for GONG to address the recommendations of the Senior Review. Recently, the U.S. Air Force has provided GONG with funds to implement an H-alpha imaging capability, in anticipation of providing operational funds.

NSO, with sites currently operating at Tucson, Arizona and Sunspot, New Mexico, plans to decommission the telescopes at those sites and consolidate its scientific staff at a headquarters location and ATST operating site upon completion of the ATST. NSO's plans, discussed in Section 5, outline plans for consolidation and for operations in the ATST era. A series of community-wide workshops to define modes of ATST science operations has been held and will continue over the next few years. The road map in Figure 2 summarizes the Observatory's strategic plan, showing when new NSO capabilities will become operational and when older, replaced facilities can be phased out. Note that in the figure, it is assumed that ATST construction will commence in FY2010 and be completed in FY2017. Phase-out of the Dunn Solar Telescope (DST) and McMath-Pierce Solar Telescope (McMP) are shown as occurring with the beginning of ATST operations. The exact phase-out date for the Evans Solar Facility (ESF) is uncertain, because its primary support is currently provided by the U.S. Air Force solar group collocated with NSO at Sunspot. The High Altitude Observatory is also interested in maintaining operation of the 40-cm coronagraph in the Evans facility. NSO will continue operating the Evans facility as long as support is provided by external sources.

NSO's spending plan (Section 5.7) reflects the need to continue the strong community momentum developed for the ATST project, the resurgence of significant interest in producing high-resolution images with existing facilities using adaptive optics and new diffraction-limited instruments, and exploitation of the new, highly valuable synoptic data sets that result from the GONG upgrade for at least a solar activity cycle, and completion of SOLIS. The plan assumes an ATST construction start in FY2010.



#### — Cooperative Agreement →

Figure 2. Strategic road map for NSO facilities.

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#### **1 INTRODUCTION**

The Sun exhibits many phenomena that defy explanation. Research in solar physics is a critical part of the nation's natural science program and a discipline of proven fundamental importance to physics and astrophysics. The Sun is the only star whose interior, surface, and outer atmosphere can be resolved in detail, hence providing an important and unique base for the study of fundamental physics, astrophysics, fluid mechanics, plasma physics, and magnetohydrodynamics (MHD). The interplay of these aspects of physics creates an essential range of phenomena visible not only on the Sun, but also elsewhere in the universe. The physical and temporal scales observable on the Sun are large enough to properly represent cosmic-scale phenomena, while the Sun is close enough that measurements can be made in great detail. The study of the Sun as a star guides astronomers in their investigations of other stars.

Solar physics is entering a new period in which the coupling of advanced instrumentation and detailed modeling are challenging what solar physicists think they know about the Sun and the solar processes that affect life on Earth and govern interplanetary space. MHD simulations of magneto-convection and models of chromospheric and coronal magnetic fields have enjoyed considerable progress as computation capabilities increase. These models are providing detailed predictions of the evolution of surface structure and magnetic fields that are pushing and often surpassing the ability to test the models with observations having sufficient resolution in both time and space. Solar science is a mature discipline that has developed questions of fundamental importance not only to solar physics, but also to astrophysics and plasma physics. Among these questions are: Why does the Sun have a magnetic field? How does the Sun produce cycles of varying activity? What causes sunspots? How does the Sun produce the Sun on Earth and space weather, and understanding and someday predicting the influence of the Sun on Earth and space weather, and understanding the role of the Sun and its variability in the evolution of life in planetary systems.

The period covered by this Long Range Plan comes at a very dynamic time for solar physics. The continued observations of Hinode and STEREO and the near-term launch of the Solar Dynamics Observatory (SDO) provide solar physicists with a wealth of space-based data. Striking new data and images from space missions have given solar physics high public visibility and revealed a wealth of new phenomena and information about the complexity and dynamics of the corona and chromosphere. Ground-based facilities play a key role by providing simultaneous observations in many spectral lines and at higher spatial and temporal resolution than available from space. More often than not, detailed and flexible ground-based observations are needed to clarify processes and challenge theories. In particular, the Dunn Solar Telescope is providing detailed polarimetric, imaging, and spectral data, and the McMath-Pierce is providing infrared imaging and spectroscopy. Precision spectral polarimetric observations provide the information on velocities and fields needed for comparisons with theoretical predictions. These include theories for the structure of sunspots and models of magnetoconvection and its relationship to chromospheric structure. Measurements with the Interferometric BIdimensional Spectrometer (IBIS), the Spectro-Polarimeter for Infrared and Optical Regions (SPINOR) and the Diffraction-Limited Spectro-Polarimeter (DLSP) at the Dunn Solar Telescope reveal problems with MHD models for these phenomena. IBIS, SPINOR and DLSP show that chromospheric fields and heating mechanisms do not behave in the force-free manner that MHD models predict. McMath-Pierce Solar Telescope IR measurements of cool molecular clouds in the chromosphere are at odds with existing chromospheric heating models. Recent CO 2329 nm scans across the disk show supergranulation-sized cells with Doppler velocities that are a factor of two to three faster than the typical supergranule signal. When the much more powerful ATST is online, it will help answer many of the unresolved questions and undoubtedly reveal even more difficulties with existing models and theories of solar processes and will challenge theorists and modelers to revise what is currently understood about the Sun. The close collaboration between space- and ground-based assets will

continue with the planned launch of SDO in 2009. In addition, ground-based observations provide contextual data and data that provide continuity between space missions for understanding solar variability. In this context, NSO provides continuous observations of the solar interior with GONG as well as daily observations of the surface magnetic field, chromospheric structure, and solar activity with SOLIS, GONG, and, in collaboration with Air Force partners, ISOON (Improved Solar Optical Observing Network).

Section 2 provides a brief description of some of the science areas addressed through NSO facilities. Section 3 discusses the tools required to continue advancing solar astronomers' understanding of the Sun, with emphasis on the development of the ATST. NSO contributions to the development of the next generation of solar researchers and public awareness of solar physics are presented in Section 4. Section 5 lays out the implementation plan, the assumptions on which it is based, and programmatic and budgetary needs for implementing NSO's Long-Range Strategic Plan.

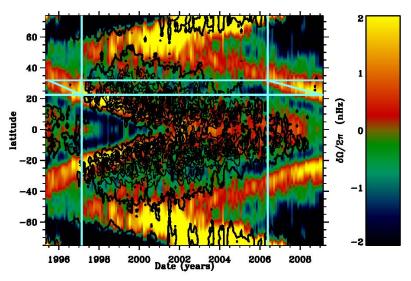
#### 2 SCIENCE PROGRAM

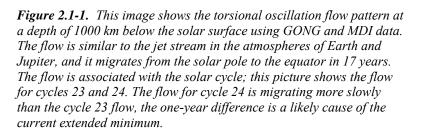
The primary science that the NSO supports can be subdivided into fundamental but overlapping themes. The following sections briefly summarize NSO's pivotal role in addressing these themes and how ongoing science programs will lead into the ATST era. Highlights of NSO supported science during the past year are summarized in the NSO Annual Report (available at *www.nso.edu/general/docs/*).

#### 2.1 Interior Structure and Dynamics

Through the Global Oscillation Network Group (GONG) program, NSO provides a fundamental data set to the community and contributes substantial staff research to the study of the structure and evolution of the solar interior over extended periods of time. Currently, these data are combined with data from the Solar and Heliospheric Observatory/Solar Oscillations Investigations (SOHO/SOI) experiment, and plans are in place to combine the data with data from the forthcoming Solar Dynamics Observatory/Helioseismic and Magnetic Imager (SDO/HMI) experiment. The integration of these helioseismology experiments continues to revolutionize understanding of the Sun. These data enable solar researchers to investigate the structure of the deep solar interior, which maintains its role as a fundamental physics laboratory; to study the nature of the microphysics underlying the theory of stellar structure (e.g., the equation of state, opacities, diffusion of species, and the revolutionary new heavy element abundances); probe the structure of the upper and lower boundaries of the solar convection zone, where the solar dynamos are thought to operate; delineate the properties of subsurface rotation and flows and their evolution with the solar cycle; and investigate the physics of the *p*-mode oscillations themselves.

These helioseismology studies will help distinguish among competing dynamo models, contribute to the prediction of the solar activity cycle, and yield insights on the nature of the operative dynamo mechanism(s) in stars. GONG++ will complete observations covering a full 11-year solar cycle in 2012, marking the first cycle to be completely and consistently sampled with local helioseismology, which averages the solar interior conditions over portions of the Sun. The installation of higherresolution cameras in mid 2001 enabled continual observations of the dynamics of the convection zone and surface activity. There is now only part of a single solar





cycle with these unprecedented observations, which have revealed that the interaction of the subsurface flows and the surface magnetic activity is a complex process. It is imperative that multiple activity cycles be observed by the GONG facility in order to fully understand the interaction and the consequences for space weather.

#### 2.2 Origin of the Solar Activity Cycle and the Dynamo

The presence of a ubiquitous, weak component of magnetic field in the quiet Sun was first discovered using Kitt Peak Vacuum Telescope (KPVT) instrumentation. This weak component appears to be generated by a mechanism different from that which produces the strong fields more often associated with solar activity. However, available data are not of sufficient quality to verify that the mechanisms are distinct, and it is now a goal of the Synoptic Optical Long-term Investigation of the Sun (SOLIS) to address this fundamental issue.

There is preliminary evidence that more magnetic flux may be generated from small-scale turbulent dynamo processes than is seen in the form of active regions. This needs to be verified. Data acquired with the DST and the McMP, using their adaptive optics systems, and data from the SOLIS instruments will be used to investigate the nature of the dynamo models. For example, the helicity of solar magnetic fields contains important information about the interaction between magnetic fields and plasma in the convection zone, as well as the nature of the underlying dynamo. This property of the solar magnetic field will be systematically studied with SOLIS.

The weak, small-scale fields of the quiet Sun "internetwork" regions have been the subject of considerable scientific scrutiny recently. New observations with the DST have attained both higher sensitivity and higher angular resolution, revealing a wealth of small-scale structure, and demonstrating that the net "unsigned" flux of the Sun rivals, or even exceeds, that of the 11-year-period solar active region fields, as well as that from the intense flux concentrations at the boundaries of the quiet solar supergranular network pattern. Theorists have also examined the internetwork fields and speculate that a local, small-scale dynamo may be acting to produce those fields. The reality of this dynamo process, and the influence that the small-scale, mixed-polarity internetwork fields have on heating and dynamics of the solar atmosphere, are issues of considerable prominence in solar physics today. The new Diffraction-Limited Spectro-Polarimeter (DLSP) at the DST is ideally suited to explore this topic. In combination with adaptive optics systems now in place at the DST, much higher angular resolution of the internetwork fields may be achieved, while maintaining very high polarimetric sensitivity.

Observations with GONG and SOLIS show that the photospheric magnetic field in the "quiet Sun" has a ubiquitous and dynamic horizontal component that varies rapidly with time. This field could be a manifestation of changing magnetic connections between eruptions and evolution of small magnetic flux elements in response to convective motions. This could be another manifestation of dynamo process taking place in the Sun near its surface. High-resolution observations with the ATST will help untangle the physics of this process. Possible coupling between magnetic fields apparently generated near the surface and those created at the bottom of the convection zone is an important question, because the former seems to provide a basal magnetic environment and the latter is the source of the solar activity cycle. Are they coupled or not? One potential study motivated by this question is the dependence of the weak solar magnetic field emergence on latitude and the solar activity cycle. SOLIS will be used to make daily high cadence photospheric (at one-minute cadence) and chromospheric (at cadences of one and five minutes) area-scans (for durations of approximately one hour) at the equator, mid-latitudes, and polar regions to study the cycle variation of bipole flux emergence rates, size scales, and strengths. These high-cadence area-scans also will be utilized to further the understanding of recently discovered ubiquitous "seething" horizontal magnetic field and the magnetic power spectrum evolution of umbral and penumbral regions.

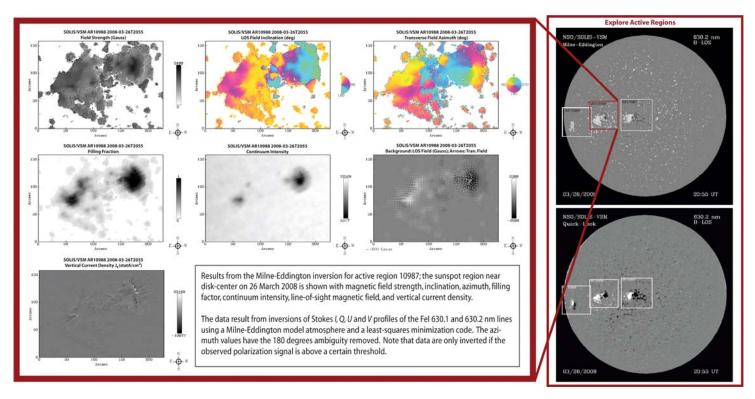


Figure 2.2-1. SOLIS VSM results from the Milne-Eddington inversion for active region 10987

It is impossible to understand the solar dynamo without knowledge of the dynamics and flows below the surface. In the high- $\beta$  regime below the photosphere, where the gas pressure is higher than the magnetic pressure, motions of the plasma dominate the dynamics of the magnetic field. NSO is uniquely able to provide simultaneous measurements of the surface magnetic field and the subsurface flows with the GONG facility.

#### 2.3 Transient Eruptions: Flares and Coronal Mass Ejections (CMEs)

NSO synoptic observing facilities currently provide information on flares and CMEs, but crucial measurements, such as the evolution of the vector magnetic field, are unavailable. SOLIS will provide these as well as a large variety of data suited to address the topic of transient activity. This transient activity is especially relevant to the determination of space weather and its potential hazards to space activity. In addition to SOLIS data, the NSO provides, through the GONG facility, continuous one-minute-cadence longitudinal magnetic flux measurements with a nominal resolution of 5 arcseconds. These data have proven to be of great value in defining magnetic field changes associated with flares. GONG has revealed that strongly flaring active regions are always accompanied by a distinctive flow pattern below the surface. This velocity field is in the form of two horizontal "tornadoes" with oppositely directed senses of rotation. This discovery suggests that subsurface flows from GONG can be developed into a tool for predicting space weather. The combination of GONG and SOLIS data will be a powerful asset in space weather research.

Although CMEs are triggered by small-scale processes, they result in a major large-scale restructuring of the solar corona, causing propagating chromospheric disturbances and coronal/chromospheric waves, and triggering flare outbursts in distant active regions. A unique combination of full-disk observations (e.g., SOLIS and ISOON) will enable a comprehensive study of the complex phenomena associated

with the CME eruptions. The results, in turn, will be of particular relevance to the space weather community since Earth-directed CMEs are now recognized as major drivers of the physical conditions in the near-Earth space environment.

What causes some filaments to quickly become unstable and erupt, often leading to coronal mass ejections? High-speed spectral images using the Interferometric BIdimensional Spectrometer (IBIS) and Stokes polarimetry with the DLSP and Spectro-Polarimeter for Infrared and Optical Regions (SPINOR) will measure the interaction between flows and the vector magnetic field to understand the stability of filaments and what triggers their eruptions. The full vector field is needed to accurately model overlying loops in the corona. To understand the consequences of flow-magnetic field interaction seen in the photosphere and chromosphere at higher atmospheric layers, these data

will be combined with data from Hinode, STEREO, and eventually SDO. Data from SOLIS and ISOON will provide a global picture of how the filaments are interacting with other magnetic regions and will detect eruptions spanning greater spatial distances on the solar surface. The DST and its instruments will provide the high-resolution imaging and polarimetry needed to follow the complex interactions in the lower atmospheric layers.

The DST, McMP, and later the ATST will provide crucial information on the basic physical processes involved in transient eruptions, with particular emphasis on high-resolution, visible and infrared investigations of the origins of these events at the footpoints of magnetic fields in the solar photosphere.

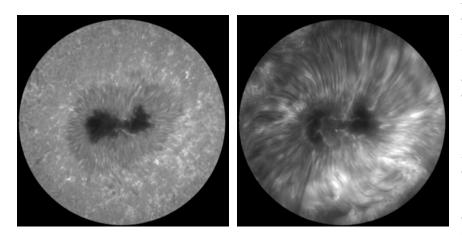


Figure 2.3-1. Images of a sunspot taken with the Interferometric BIdimensional *Spectropolarimeter in the wing* (left) and core of the Ca II 8542 spectral line. IBIS was used to scan 42 wavelength positions in 11 seconds, spanning from the red to blue continuum. The IBIS instrument is fed by one of the DST high-order adaptive optics systems. These data can be used to study velocities and waves as they propagate out of the sunspot and excite loops in the higher atmosphere.

The evolution of the footpoints as seen in the infrared He 1083 nm line were captured during an X1.8 flare at the McMP using the NSO array camera (NAC) system. The very bright line-center emission and extremely rapid downflows that were observed will provide new windows for studying the energetics of such a powerful flare.

Recent progress with numerical simulations and observations raise new questions about the nature of solar flares and CMEs. For example, the processes (emergence or reconnection) and timing (prior, or during, the eruption) of magnetic flux rope-structure formations that are commonly associated with CMEs are not well understood. The knowledge of pre-eruptive/pre-flare history is crucial in understanding and forecasting of CME phenomena. A combination of full-disk synoptic (e.g., SOLIS, ISOON) and high-resolution (ATST, DST, McMP) observations will provide important data for CME modelers. Sequential chromospheric brightenings (SCBs), associated with flares and CMEs may provide clues about processes taking place in the corona immediately after a CME lift-off. Other NSO

studies suggest an alternative explanation for Moreton waves, a well-known phenomenon associated with flares. These studies raise the possibility of Moreton waves being triggered by erupting CMEs, not by flares as previously thought. Both SCBs and Moreton waves might provide earlier warning of a CME eruption, even in the absence of traditional CME indicators (e.g., filament eruption). These studies took advantage of unprecedented datasets from the full-disk H $\alpha$  telescope (ISOON) operating at NSO facilities. ISOON data will continue to play a critical role in studies of flares and CMEs, as well as the potential GONG H $\alpha$  capability.

#### 2.4 Origin of Variability in Solar Irradiance

SOLIS, provides basic magnetic field maps that are successfully used in modeling solar irradiance variations. The Radiative Inputs from Sun to Earth/Precision Solar Photometric Telescope (RISE/PSPT) network, developed at NSO and now operated by HAO, the University of Rome, and California State University at Northridge, provides highly accurate intensity images of the Sun to identify the regions with increased or decreased solar irradiance. The use of PSPT data with SOLIS magnetograms and new high-resolution observations of magnetic fine structure using the DST and McMP may shed light on how magnetic fields interact to provide the energy driving these irradiance variations. Spectral observations of sunspots in the infrared at the McMP during the last two solar cycles have shown physical changes in the sunspot umbrae during the solar cycle. This work will have direct impact on irradiance models and will provide new clues about the solar magnetic cycle. GONG farside maps, calibrated to magnetic field, are now being introduced into global irradiance models.

#### 2.5 Heating of the Outer Atmosphere and Origin of the Solar Wind

The fact that temperatures in the chromosphere and the corona are generally higher than temperatures in the photosphere indicates that a non-radiative process heats the upper solar atmosphere. Several mechanisms for the origin of non-radiative heating have been studied, but combining observations and models to identify the mechanism(s) have yet to yield a plausible scenario. Similarly, the detailed mechanism(s) responsible for the acceleration of the solar wind has been elusive. The questions to be answered are related to the nature of the process(es) responsible for heating the chromosphere and the corona and the mechanism(s) responsible for heating and accelerating the solar wind.

Observing and understanding chromospheric fields are extremely important to understanding the link between photospheric fields, which are relatively easy to measure, and coronal fields, which are difficult to measure, but are where much of solar activity is manifested. Accurate measurements of coronal fields will require the ATST. Currently, coronal fields are usually inferred from loop observations and/or models based on photospheric footpoints. Having direct measurements of the chromospheric field will provide much better boundary conditions, linking models based on photospheric measurements with the coronal field.

As shown by SOLIS/VSM observations, the polar magnetic fields of the Sun are much more readily studied using chromospheric, rather than photospheric, magnetograms. This advantage comes from the canopy phenomenon that develops at chromospheric heights and the smaller noise from seething horizontal fields in the chromosphere. Polar fields are important because much of the structure of the heliosphere and solar wind can be traced to the poles. Present ideas implicate the polar fields as a crucial agent in the early stages of a solar activity cycle. The VSM has a unique capability to measure these fields in order to test contemporary ideas. It also reveals interesting dynamics associated with the emergence of magnetic bipoles in polar regions that may bear on the question of coronal heating.

Inference of chromospheric magnetic fields using a limited set of spectral lines such as H $\alpha$ , Ca II 8542 Å, and Mg I 5172 Å, are intricately tied to an assumption of a model atmosphere coupled with non-local thermodynamic equilibrium (NLTE) radiative transfer. NLTE radiative transfer methods have

been developed at NSO and elsewhere to simulate chromospheric lines under varied magnetic field strength conditions. Using Stokes polarimetry measurements of photospheric and chromospheric spectral lines at the DST, these NLTE methods will be applied to chromospheric Stokes spectra in order to derive chromospheric magnetic fields. These will be combined with photospheric field measurements to understand the 3-D magnetic structure of active regions.

Even a brief look at the solar corona leaves no doubt that magnetic field plays a crucial role in the structure and heating of the solar upper atmosphere. The exact mechanism(s) of coronal heating, however, remains a mystery. Recent studies conducted by NSO scientists suggest new mechanisms of coronal heating, such as reconnection between new and pre-existing magnetic flux and turbulent properties of magnetic field in active regions. The results of these studies suggest that making further progress in understanding the solar corona would require its modeling as a global, interconnected, and dynamic system. To understand such a global system, one would need a combination of full-disk and high-resolution data, and collaborated studies between space-borne (e.g., Hinode, STEREO, and SDO) and ground-based instruments (SOLIS, GONG, DST, and McMP).

The most important contribution to understanding coronal heating and solar wind acceleration probably will be the direct and accurate measurements of the coronal magnetic field. Recently, infrared coronal Zeeman observations have been demonstrated with 25-arcsecond resolution and one-hour time resolution using half-meter-class coronagraphs. The ATST will be a coronagraph with almost 100 times the collecting area. By direct extrapolation, NSO is confident that the ATST will measure fields at spatial resolution similar to the provocative TRACE images of coronal loops and within the time scales of their evolution.

The McMath-Pierce telescope enables observations of the cool component of the chromosphere by studying carbon monoxide in the thermal infrared. Such combined measurements in the optical and thermal IR are necessary to diagnose the structure of the chromosphere and the associated heating mechanisms. As a prelude to an important ATST application, the McMath-Pierce also has been used for direct measurements of coronal magnetic field strengths using IR spectral line diagnostics of high excitation features formed in the solar corona. The ATST will have a major impact in understanding chromospheric and coronal structure and heating. Among the salient investigations that will be conducted is the detection of MHD waves in the photosphere through the measurement of temporal variations of the Stokes parameters in individual flux tubes.

Many coronal structures (e.g., coronal bright points, loop-like structures, transequatorial loops) may be formed as a result of magnetic reconnection. Although these structures are typically observed in the EUV or X-ray from space-borne instruments, observation of the vector magnetic fields in the photosphere and chromosphere are essential for understanding and modeling the process of magnetic reconnection. The full-disk SOLIS vector magnetograms are currently being used with Hinode EUV observations for such studies.

#### 2.6 Surface and Atmosphere Structure and Dynamics

Using the Dunn Solar Telescope adaptive optics system and image reconstruction techniques, visiting scientists and NSO staff have obtained the highest resolution time sequences ever of solar magnetic, intensity, and velocity fields (~0.14 arcsec). They have discovered a wealth of features inside magnetic pores, intergranular lanes, and sunspots that suggest there is unresolved fine structure below the resolution of existing solar telescopes. Establishing accurate physical parameters for small-scale flux is crucial for testing the results of numerical simulations and addressing flux formation and dynamics. NSO scientists have made observations of oscillatory magneto-convection, sub-arcsecond convective motions inside magnetic pores. In addition, NSO scientists have utilized the McMath-Pierce to discover the occurrence of rapidly moving magnetic elements in sunspot penumbrae. DST observations have been used to uncover dynamic plasma flows associated with canceling magnetic features. A

combination of magnetic and coronal data suggested the existence of very specific changes in magnetic field twist at early emergence of active regions. The continuation of such studies using a combination of ground-based and space-borne instruments is a necessary step toward achieving further understanding of the evolution of magnetic flux in the solar atmosphere. For example, the Solar Optical Telescope (SOT) on board Hinode is investigating properties of various features of quiet- and active-Sun with high spatial resolution. The SOT/Hinode project is benefiting from collaborations with high-resolution, ground-based observations from IBIS and the DLSP as well as other NSO instruments.

SOLIS is now providing both high-quality line-of-sight magnetograms and full disk and active region vector magnetograms. These can be used as boundary conditions for models of the solar corona structure and the solar wind that are important in space weather forecasting. Now that vector magnetic field observations are available regularly from SOLIS, more realistic MHD models can be used to more accurately infer coronal fields.

With the ATST, individual flux tubes will be resolved and the joint variations of plasma, magnetic field, and temperature within and around the flux tube will be accurately measured, allowing direct comparison with theory. Moreover, as mentioned in Section 2.5, the ATST will also provide accurate measurements of coronal magnetic fields off the limb in the infrared. Visitors at the McMath-Pierce telescope have confirmed the earlier eclipse detection of the 3.934 micron line of Si IX by Kuhn and collaborators. While the signal-to-noise is too poor to measure coronal fields in this line with current meter class telescopes, it is a strong candidate for coronal magnetometry studies using the ATST. The ATST will extend this fundamental and uniquely powerful investigation of coronal magnetic properties to both higher sensitivities and resolutions. In addition, the ATST will complement the full-disk coronal capabilities that are expected to be available with the Frequency Agile Solar Radio (FASR) telescope— a recommendation of the Decadal Survey.

Until the ATST is online and providing direct measurements of coronal magnetic fields, field extrapolation is still the primary way to model topology and evolution of coronal magnetic fields in non-eruptive (coronal holes, network field, quiet active regions) and eruptive (active regions, flares, CMEs) solar features. Recent studies clearly indicate the need for non-linear force-free (NLFF) field extrapolation. Currently, SOLIS is the instrument that routinely provides the full-disk vector magnetograms necessary for NLFF extrapolation.

#### 2.7 The Solar-Stellar Connection

The stars offer a range in physical parameter space—rotation rate, mass, convection zone depth, metallicity, and so forth-that is unavailable with the Sun alone. Thus, stellar studies enable the investigation of the broad astrophysical applicability of models developed purely in a solar context. The relatively large aperture of the McMath-Pierce telescope, combined with its availability for utilization at night, led NSO to establish an innovative program in the study of the stellar counterparts of solar activity using high-resolution spectroscopy. Among the unique results of this program was the first ever measurements of a portion of the magnetic flux cycle in a solar-type star that exhibited a solar-like cycle in its Ca II H and K variations. Budgetary pressures forced the elimination of the productive NSO stellar synoptic program at the McMath-Pierce in the late 1990s. The SOLIS integrated sunlight spectrometer (ISS) is continuing Sun-as-a-star studies through daily observations in a variety of key spectral diagnostics such as the chromospheric Ca II H and K features. Recent spectra from the ISS confirm its suitability for the observation at high resolution of the aforementioned chromospheric diagnostics as well as photospheric diagnostics of convection (in the form of line bisectors where the characteristic "C-shape" is readily detected with the ISS). These spectra will be compared to analogous spectra obtained for solar-type stars in order to gain further insights on the nature and origin of spectral variability in the Sun and stars.

An active nighttime program of solar system investigations, supported primarily by NASA grants, continues at the McMath-Pierce complex. In addition, preliminary discussions have begun with the University of Florida concerning the establishment of a long-term program of Doppler spectroscopic observations of extrasolar planetary systems during 100 or more nights per year. This project would utilize a significant fraction of the available nights at the McMath-Pierce telescope. These kinds of long-term investigations serve as prototypes of the programs that could be initiated at the 4-m ATST on behalf of the community. NSO scientists, along with collaborators in the community, recently completed a survey of the chromospheric activity in the solar-type stars in the solar-age and solarmetallicity cluster M67. The implementation of a long-term program to detect solar-like cycles in the Sun-like stars in this cluster is being explored. Finally, NSO scientists are actively participating in a NASA-supported NASA Astrobiology Institute (NAI) program, in collaboration with the NOAO and the University of Arizona at its Life and PLanets Center (LaPLACE). NSO participation involves the characterization of brightness variations in solar-type stars spanning an evolutionary range of ages. Recent work in this area involving the 80-100 Myr old Pleiades open cluster has revealed ~1% shortterm variability in the brightness of young solar-type stars, i.e., 10 times the level of irradiance variability seen in the Sun today. These sorts of variations form an important input into the development of the evolution of young planetary atmospheres.

Recently, researchers at Aarhus University, Denmark have revived the concept of a Stellar Oscillation Network Group (SONG) project. In analogy to GONG, SONG would construct a number of small observing stations around the world to observe stellar oscillations with long, nearly continuous time series. These data would be used to infer the internal properties of the stars and refine evolutionary tracks in the HR diagram. NSO is considering participation in SONG at some level. The scientific staff and facilities of the NSO include expertise and capabilities that are relevant to the frontier topics in contemporary astrophysical research that will be addressed by the SONG project. It is clear that asteroseismology is a natural extension of the NSO/GONG efforts in helioseismology.

## **3 CURRENT AND FUTURE TOOLS FOR SOLAR PHYSICS**

The support needed to permit the solar community to address the science topics discussed in Section 2 and to teach the next generation of solar physicists, requires that first-class solar facilities remain available on a continuous basis. Thus NSO has developed a plan with the flexibility to transition from current facility operations to the period when new facilities are in place. The sections that follow discuss current facilities and plans for developing new capabilities.

#### 3.1 Current NSO Support for Users

Improved instrumentation, especially adaptive optics, has kept NSO's current major telescopes at the leading edge of solar physics. They remain extremely productive and are among the most useful solar telescopes in the world. Although the major NSO telescopes are four or more decades old, they still play a key role in support of U.S. and international solar research. The NSO telescope upgrade and instrument development program is guided by the scientific and technical imperatives for a new ATST. Consequently, telescope and instrument upgrades and operations are reviewed and supported on the basis that they serve as necessary preludes to the ATST initiative, while concurrently serving the needs of the scientific community. Both as a necessary prelude to the ATST and as indispensable facilities for current research in solar physics, NSO operation of the Dunn Solar Telescope and the McMath-Pierce Solar Telescope will continue until the ATST is commissioned.

The earliest that ATST construction can start is FY2010. Until the ATST is online, the solar community will rely on the DST for high-resolution spectropolarimetry and the McMP for high-resolution spectropolarimetry and imaging infrared observations beyond two microns. The NSO is upgrading existing operating and data handling systems in order to continue operations at the DST and McMP until a smooth transition to the ATST can be effected. The upgrades are being performed with ATST requirements in mind and in such a way as to test ATST concepts such as instrument and data interfaces and software architecture. The successful completion of the German GREGOR telescope and the New Jersey Institute of Technology New Solar Telescope, both of which are 1.6-m aperture, all reflecting, open telescopes, could offer additional observing capability that would ease the transition into the ATST era. Both will have limited public access for U.S. astronomers. The development of a large European Advanced Solar Telescope (EAST), following ATST by several years, will provide extended high-resolution coverage of magnetic fields, and offers the possibility of future cost sharing of instrument development.

#### 3.1.1 Dunn Solar Telescope (DST)

The 76-cm Richard B. Dunn Solar Telescope, located on Sacramento Peak, is a diffraction-limited solar telescope with strong user demand and excellent scientific output. It has two identical AO systems— well matched to the seeing conditions at the DST—that feed two different instrument ports. These ports accommodate a variety of diffraction-limited, facility-class instrumentation, including the Diffraction-Limited Spectro-Polarimeter (DLSP), and the Spectro-Polarimeter for Infrared and Optical Regions (SPINOR), the Interferometric BIdimensional Spectrometer (IBIS), the Facility Infrared Spectrograph (FIRS), the Rapid Oscillations of the Solar Atmosphere (ROSA) imaging system, and a high-speed speckle system. This has made the DST the most powerful facility available in terms of post-focus instrumentation.

In addition to supporting the solar community and the science discussed in Section 2, the DST supports observations that will drive ATST high-resolution requirements at visible and near-infrared wavelengths, and refine ATST science goals. The DST also supports the development of future technologies such as multi-conjugate AO (MCAO). The first successful on-sky MCAO experiment was recently performed at the DST. The DST supports the U.S. and international high-resolution and

polarimetry communities and is often used in collaboration with space missions to develop global pictures of magnetic field evolution. While competing European telescopes have emerged, they have not supplanted the need for the DST. Many Europeans still compete for time on the DST and provide instruments, such as IBIS (Italy) and ROSA (Northern Ireland, U.K.), that are available to all users. The 1-m Swedish Solar Telescope (SST) is providing high-resolution imaging and polarimetry with a geographic separation of seven hours from the DST. The geographic separation enables collaborations that extend the ability to follow magnetic evolution over longer periods, substantially enhancing the probability of observing the build-up and triggering of solar activity events. The DST will continue to play the major role in supporting high-resolution spectropolarimetry and the development of instruments needed for progress in this important field. These instruments will be the backbone of the ATST.

The NSO instrumentation program is focused on the development of enabling technologies that will be central to the ATST and a strong program of understanding solar magnetic variability. The primary areas of instrumental initiatives at NSO are high-resolution vector polarimetry in the visible and near-IR. Instrument development and scientific applications in these areas rely on the unique capabilities of the DST.

#### Adaptive Optics and Wavefront Sensing

High-resolution observations of the Sun are essential in solving many of the outstanding problems of solar astronomy. The current high-resolution solar telescopes are in the 1-m class. Without AO, the resolution of these telescopes is limited to about 1 arcsec (long exposure) because the Fried parameter (roughly speaking, the largest aperture telescope that would have diffraction-limited seeing) of a good daytime site is about 10 cm. AO is necessary to obtain full benefit from existing telescopes and is critical to the operation of the ATST.

The high-order AO development was brought to a successful conclusion. The project, carried out in primary partnership with the New Jersey Institute of Technology, has resulted in two fully operational AO systems at the 76-cm Dunn Solar Telescope at Sacramento Peak. A similar system was deployed at Big Bear Solar Observatory (BBSO). The NSF sponsored this project within the Major Research Instrumentation (MRI) program with substantial matching funds from the participating partner organizations, which include the NSO, the NJIT, the Kiepenheuer Institute in Germany, and the Air Force Research Laboratory. A follow-on effort to develop a scaled up system (349 actuators compared to the 97 actuators for the current system) for the BBSO New Solar Telescope is underway jointly between NJIT and NSO.

The current AO systems and the development of the new BBSO system, serve as proofs-of-concept for a scalable AO design for the much larger 4-m ATST. The DST systems are serving as test beds for the development of the ATST AO system. For example, the project is testing reconstruction algorithms needed for the ATST AO, where the pupil on the deformable mirror will rotate with respect to the wavefront sensor.

Another important aspect of this project is the development of AO data-reduction techniques and tools. The interpretation of AO data for an extended object like the Sun is challenging. The AO point spread function, and temporal and spatial variations thereof, must be understood in order to be able to interpret high-resolution imaging and spectroscopic data of solar fine structure. The performance limitations of solar AO systems also have to be understood. AO technology and AO data-reduction tools have been developed by a graduate student and in collaboration with the Center for Adaptive Optics (CfAO) and researchers at the Herzberg Institute in Canada. Work on interpreting AO-corrected images using the point spread functions derived from the wavefront sensor signals continues.

With the completion and deployment of the high-order AO systems, technical efforts of the AO project are now focused on the development of multi-conjugate adaptive optics. The Sun is an ideal object for

the development of MCAO because solar structure provides the "multiple guide stars" needed to determine the wavefront information in different parts of the field of view. During FY2004, the loop was successfully closed on the MCAO system for the first time, and the extension of the corrected field by the MCAO system in comparison to AO was demonstrated. The NSO system is one of the first successful on-sky MCAO experiments (the Kiepenheuer MCAO system being the other). Additional MCAO work will focus on evaluating and improving the system performance and making comparisons with model predictions. The major challenge is to develop and implement efficient control algorithms and find optimum and practical positions for the deformable mirrors. More wavefront sensor subfields also may have to be added. The solar MCAO experience will be very valuable to the entire astronomical community. The NSO's main goal, however, is to develop MCAO technology for the ATST.

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

The Diffraction-Limited Spectro-Polarimeter is 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 is now available for users. An online data reduction tool will be available within the next year or two. The raw data from the DLSP will be calibrated and a Stokes inversion will be performed on the fly. There are plans to make the reduced data available via the Virtual Solar Observatory.

The DLSP has been used to implement a "solar queue observing mode" at the DST. Pre-defined 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.

#### Facility Infrared Spectropolarimeter (FIRS)

This is a collaborative project between the National Solar Observatory 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. 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), a vital feature for studying dynamic solar phenomena such as flares. The high-order Echelle grating allows for simultaneous multi-wavelength observations and thus 3-D vector polarimetry. The detector is a  $1K \times 1K$  IR camera synced to a liquid crystal modulator. FIRS should be commissioned as a fully supported user instrument in 2009.

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

SPINOR is a joint HAO/NSO program to replace existing advanced Stokes polarimeter (ASP) at the Dunn Solar Telescope with a much more capable system. The ASP has been the premier solar research spectropolarimeter for the last decade. Its ability to explore new spectral lines and to observe in multiple lines simultaneously is still unique. The ASP wavelength range, was restricted to the visible, limiting its ability to sample new solar diagnostics, and its hardware is becoming out-dated and difficult to maintain. 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

computer equipment. Software control of SPINOR is being brought into the DST camera control and data handling systems as opposed to the stand-alone ASP.

SPINOR, along with IBIS, are the primary instrument for joint observations with Hinode and they augment capabilities for research spectropolarimetry at the DST and extend the lifetime of state-of-theart research spectropolarimetry at the DST for another decade.

#### Interferometric BIdimensional 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 the High Altitude Observatory, the Arcetri group has recently 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 DST. A new, faster and more sensitive camera will be integrated in a joint effort between NSO and the Arcetri group.

## **Replacements and Upgrades**

#### **Critical Hardware**

Given the finite time frame for DST operations, replacement and upgrades of hardware and software are limited to the necessary minimum. The Critical hardware upgrade (CHU) is aimed at reducing unscheduled downtime by replacing obsolete and unreliable hardware, such as the vintage 1970s CAMAC, with modern hardware. Critical hardware is defined as follows: hardware elements that fail repeatedly, and/or, hardware elements that cannot be repaired or replaced without significant downtime or re-engineering. Significant downtime (total) is defined as more than two weeks per year. These upgrades will be limited to supporting existing capabilities rather than offering enhanced capabilities.

#### Storage Area Network (SAN) Upgrade

The high data volumes produced by existing and new instrumentation such as IBIS, SPINOR, FIRS, and ROSA, an instrument to measure Rapid Oscillations in the Solar Atmosphere, require an expansion in data storage and handling capabilities at the DST. The DST data handling system (0.5 TB) is currently near its maximum capacity. The IBIS camera upgrade alone will include the integration of IBIS into the DST data handling system; this will push storage requirements and bandwidth well beyond the current capacity. Furthermore, the standard storage media, which is used to transfer data to users, is DLT tape. The DST DLT tape drives are obsolete, downtime is increasing, and DST users have expressed a strong preference for using hard drives as storage media. Hence, the data handling system will be expanded to 4 TB of storage and the existing DLT storage media will be replaced with removable hard drives.

NSO will continue to vigorously pursue the opportunities presented by this high-resolution, diffractionlimited imaging, with a goal of testing models of magnetoconvection and solar magnetism while refining ATST science objectives and ensuring the growth of the expertise needed to fully exploit ATST capabilities. The advent of high-order AO has increased the demand for DST time, and has given ground-based solar astronomy the excitement shared by space missions.

When ATST is complete, the high resolution capabilities of the DST will be surpassed, and NSO will cease operations and either close the DST or, preferably, find a group or groups interested in exploiting the DST for their own uses.

#### 3.1.2 McMath-Pierce Solar Telescope (McMP)

The McMath-Pierce Solar Telescope on Kitt Peak is the largest unobstructed-aperture optical telescope in the world. It is capable of panchromatic, flux-limiting studies of the Sun. In particular, it is the only

solar telescope in the world on which investigations in the relatively unexplored infrared domain beyond 2.5 microns are routinely accomplished. A new low-order AO system provides diffractionlimited imaging and spectroscopy at these infrared wavelengths. Coupled with the InSb-based detector of the NSO Array Camera (NAC), the McMP is producing the best mid-infrared solar observations ever achieved.

Infrared polarimetry and infrared imaging developed at NSO have been combined with the McMath-Pierce Telescope to reveal a ubiquitous presence of weak fields associated with turbulent convection at the solar surface that could play an important role in solar magnetic flux loss and heating of the outer solar atmosphere. Other observations with these systems have measured chromospheric magnetic fields and may provide the opportunity to directly observe coronal magnetic fields. The NAC will be used to test the theory that outlines how MHD waves decouple when propagating through the region where the plasma beta equals unity, the so-called magnetic transition region.

Much of the infrared spectrum is still barely explored, especially in flares, sunspots, and the corona. The McMath-Pierce telescope and the NAC have begun to address these questions with observations of a powerful X1.8 flare in the infrared He I line at 1083 nm, and observations of the CO lines at 2330 nm at the solar limb. The NAC will conduct spectropolarimetry of atomic lines near 4 microns. Particular lines from Si I and Fe I will be used to probe the photospheric magnetic fields, and Ca I and Mg I lines will be used to probe the chromosphere; these lines will provide magnetic sensitivity not possible with spectral lines in the visible or near-infrared. Weak magnetic fields and small changes in the magnetic fields with time will be examined in the quiet Sun and in sunspots and solar active regions. During this extended minimum, the NAC is being applied to granulation contrast studies in the infrared. The data provide invaluable input for testing models of the thermal structure of the quiet Sun. Finally, the cool solar temperature minimum will be probed with a variety of molecular lines including CN, CO and H<sub>2</sub>O. Further studies will be used to develop techniques and science questions that will continue to refine the ATST IR capabilities.

A grant from the NSF Advanced Technology Instrumentation (ATI) program is funding the development of a state-of-the-art all-reflective image slicer integral field unit. The Advanced Image Slicer (AIS) Integral Field Unit (IFU) is the first instrument of its kind for a solar telescope. The IFU is intended for AO-corrected infrared observations with the McMath-Pierce vertical spectrograph. D. Ren (California State University, Northridge) and C. Keller (Utrecht University) are co-investigators on this project that will divide a 6.25" × 8" 2-D field into 25 slices to produce a 200" long slit with a width of 0.25" 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  $\sim 1.2 \text{ m} \times 0.3 \text{ m} \times 0.3 \text{ m}$  box that mounts in the optical beam between the current AO system and spectrograph slit. The unit enables simultaneous sampling of the AO-corrected field at the McMath-Pierce for 3-D spectroscopy and polarimetry. Reformating the AO-corrected image into a linear array of slits results in greatly enhanced throughput for spectroscopy and polarimetry at high spatial and high temporal resolution. The IFU is now a facility instrument at the McMath-Pierce Solar Telescope on Kitt Peak. The future 4-m aperture ATST will also require IFUs for its suite of instruments. Thus, this effort is the first step in developing IFUs for the ATST and gaining experience in their use for forefront solar research.

The Fourier Transform Spectrometer (FTS), located at the McMP Facility, is a unique national resource in wide demand by atmospheric physicists and chemists, as well as astronomers. The FTS is a highly stable, Michelson interferometer that is able to simultaneously achieve high spectral resolution, excellent signal-to-noise ratio, and wide bandpass. The FTS is thus able to produce high-quality measurements of line positions, strengths, and widths. The McMath-Pierce FTS is a multi-disciplinary facility that is utilized for research programs in laboratory spectroscopy, atmospheric sciences, and solar physics. The FTS produces widely-used infrared solar atlases and is the only facility that completely resolves atomic and molecular lines at wavelengths out to 20 microns. The McMath-Pierce facility has been designated as an official complementary site for the Network for the Detection of Stratospheric Change (NDSC). The Earth atmospheric measurements that are made at this facility are included in the NDSC archive. A consortium has formed that has supported the upgrade of the FTS and will help support its use.

#### NSO Array Camera (NAC)

Because the McMath-Pierce does not have an entrance window, it has access to the solar infrared spectrum beyond 2.5 microns. NSO has focused its in-house instrumentation program on a large-format IR camera, the NSO Array Camera, which observes wavelengths from 1 to 5 microns. The NAC represents a significant improvement over previous NSO IR cameras. New types of scientific observations, including flare emission and rapid flows associated with an X1.8 flare, limb emission and chromospheric dynamics observed with CO absorption lines, and high-resolution AO-corrected imaging observations of granulation at 2000 nm have been made. The NAC is being used to make sensitive magnetic field measurements in sunspot umbra, studies of molecular line formation, and polarimetric observations from 3 to 5 microns. Moreover, studies of flows in prominences and quiet photosphere as seen in the IR are being performed. In addition to these PI-driven studies, NSO is exploring using the NAC for regular, highly sensitive, vector magnetograms of solar active regions in synoptic or campaign-mode observing runs.

Implementing and demonstrating the scientific value of a fast, large-format infrared camera is an important component of NSO's preparation for the IR-capable ATST. The operation of a large-format, advanced IR instrument at the McMath-Pierce solar telescope facility offers the most advanced research capability in the mid-IR for solar physics in the world today.

#### 3.1.3 Global Oscillation Network Group (GONG)

The Global Oscillation Network Group program is an international, community-based program that studies the internal structure and dynamics of the Sun by means of helioseismology—the measurement of resonating acoustic waves that penetrate throughout the solar interior—using a six-station, world-circling network that provides nearly continuous observations of the Sun's five-minute oscillations. The instruments obtain 2.5-arcsecond pixel velocity, intensity, and magnetic-flux images of the Sun every minute, with an approximately 90% duty cycle, enabling continuous measurement of local and global helioseismic probes from just below the visible surface to nearly the center of the Sun. The high-cadence, high-sensitivity magnetograms, and near-real-time seismic images of the farside of the Sun are now available.

GONG's science goals are to study the steady and time-varying temperature, composition, and rotation of the solar interior; to characterize the subsurface properties of the solar cycle on large and small scales; to explore the nature of individual active regions; to obtain images of the far side of the Sun to support a space weather predictive capability; and to provide continuous high-time-cadence and coverage, low-noise and precise magnetograms to support non-helioseismic studies such as the formation of coronal holes and coronal mass ejections, extrapolating the temporally well-sampled photospheric field, and examining the inferred coronal field's evolution. Results to date have substantially advanced the knowledge of solar internal structure from the core to the surface, and measurements are now being taken of significant structural variations and flows through the solar magnetic activity cycle, in addition to variations on shorter time scales. An example of the cycle-related variations is the sub-surface evolution of the torsional oscillation, an east-west oriented band of plasma that is moving slightly faster than the surface rotational velocity and that is spatially correlated with the surface activity. GONG observations have revealed that the torsional oscillation is not confined to the surface, but instead extends downward through the convection zone, and can be seen to rise to the surface as the cycle progresses. On shorter time scales, GONG has revealed the presence of twisting tornado-like motions below large active regions that produce many X-class flares. The temporal

variation of the amplitude of the twisting motion appears to predict the onset of activity, and this is now being evaluated for space weather predictive capability.

In addition to helioseismology science products, GONG is now providing an unprecedented and unique dataset to the solar physics community in the form of high-cadence (one per minute) full-disk longitudinal magnetograms that are continually obtained around the clock. Ten-minute averages of these images are returned to Tucson in near-real time, and extrapolations of the surface field into the corona are automatically generated and placed on the Internet on an hourly basis. This new dataset is being used by NASA missions, such as STEREO and Hinode, and is being incorporated into solar wind models for space weather. The continual high cadence of the observations has also revealed flare-related changes in the magnetic field, the presence of a rapidly varying horizontal component to the magnetic field, and curious anisotropies in the behavior of the *p* modes near sunspots.

NSF, through the NSO, has made a large investment in GONG to upgrade to a higher resolution capable of subsurface imaging, imaging of the far side of the Sun, and to greatly increase the resolution of solar velocity and magnetic structures below the solar surface. Such data are critical to understanding the generation of solar magnetic fields. A substantial fraction of the helioseismic investigators use GONG as a primary data source. When available, the supplemental data from space missions helps confirm GONG results and vice versa. Having two instruments enhances the reliability of deducing subsurface features. To assume GONG can be replaced by a limited duration space mission such as SDO is unwise for several reasons, including potential failure, degradation of detectors, no confirmation of results, and lack of continuity between mission, to name a few. To assume that helioseismology is no longer of use or important is like saying that the need to study stars and stellar systems is no longer necessary because enough is known. Given the value of GONG to the space weather community, NSO is seeking operational funding. Recently the U.S. Air Force provided funds to add an H-alpha capability to GONG as a precursor to providing operational funding. However, there is no guarantee that this funding will be provided.

The Senior Review recommendations linked the decommissioning of GONG to the availability of the Solar Dynamics Observatory. NSO will carefully monitor the progress of that mission to understand the potential timing of such a decommissioning in order to develop a back-up plan should outside funding not materialize. NSO will develop options for potential consideration by the NSF and continue to negotiate with NSF regarding additional support for this impressive scientific bang-for-the-buck program. Finally, the helioseismology community is providing views on the overall progress in the field of helioseismology for discussion purposes for the upcoming Decadal Survey.

#### 3.1.4 Synoptic Optical Long-Term Investigations of the Sun (SOLIS)

SOLIS is a project to make optical measurements of processes on the Sun, the study of which requires well-calibrated, sustained observations over a long time period (25 years). SOLIS replaces several antiquated synoptic facilities. The major and unique SOLIS instrument is a 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 rapidly being made available on the Internet. Researchers have reported excellent results from using high-quality VSM data. The other SOLIS instruments are a full-disk patrol (FDP) imager and an integrated sunlight spectrometer (ISS). The ISS is operating daily on Kitt Peak and the reduced data is available to the community. The FDP is now being completed in Tucson prior to its move to Kitt Peak late in 2009 or early in 2010. All of the SOLIS instruments have produced good data.

Both the VSM and ISS are in extended commissioning phases 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. 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 same strategy governed the science achieved by the VSM's highly-successful predecessor, the NSO Kitt Peak Vacuum Telescope and the ISS' predecessor synoptic programs using the Evans and McMath-Pierce facilities. The archives of these earlier programs are still in heavy use and each has produced distinguished science results.

Current emphasis is on completion and stable operation of SOLIS. A large number of unique full-disk vector magnetic field observations have been accumulated since September 2003. Their calibration and inversion to produce vector magnetograms was recently improved and they are now being made available on the web. It will take some time to process the entire data set. SOLIS VSM observations have shown a wealth of interesting new phenomena. In addition to the full disk line-of-sight and full disk vector magnetograms, quick-look and detailed vector magnetograms of selected active regions are available online.

Currently SOLIS activities include the calibration of new cameras for the VSM and FDP instruments. Once the instrumental polarization signals have been minimized for the VSM Stokes profile spectra, research activities will follow two key paths defined by spatial scale, that is, active region and global scales. The VSM vector data will be employed to give the magnetic field context for FDP observations of sunspots, filaments, flares, and coronal mass ejections. Besides magnetic field inversions of active region data for better parameterization of pre- and post-flare and coronal mass ejection events, the global magnetic field configuration is of great interest. The global field analysis will include the comparison of active region helicity between the hemispheres and during the solar cycle with the planned creation of synoptic magnetic helicity maps.

#### Summary of SOLIS Instrument Status

<u>Vector Spectromagnetograph (VSM)</u>: The SOLIS VSM instrument has been operating since August 2003. Initially, the VSM operated at a temporary site in Tucson until it was installed at Kitt Peak in April 2004. In early 2006, the degradation of the VSM 630.2 nm vector modulator required its replacement. This opportunity allowed for a more efficient 854.2 nm modulator and a fresh 630.2 nm longitudinal modulator to be installed. Chromospheric vector capability is under active investigation with an option that appears to be entirely feasible and low cost. In addition, a new camera system has been tested and will be installed in the fall of 2009.

<u>Integrated Sunlight Spectrometer (ISS)</u>: In the summer of 2006, new feed optics were installed for the Integrated Sunlight Spectrometer to reduce the image size illuminating the fiber that connects to the ISS. With the new feed optics, the ISS is no longer under sampling the solar disk. The pointing of the feed optics was adjusted during installation to co-align with the pointing of the VSM. The nominal ISS synoptic program began in December 2006. ISS data have been successfully cross-calibrated with both McMath-Pierce spectrograph data and with Evans Solar Facility spectrograph data. This allows the ISS to extend existing data sets that go back three solar cycles.

<u>Full-Disk Patrol (FDP)</u>: 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. Similar observations are available from other sources; therefore, completion of this instrument for the SOLIS three-instrument suite was the last to be scheduled. Currently, the FDP is in final testing before deployment.

#### **SOLIS Data Products**

Numerous data products are currently available from SOLIS, with more expected within the next year. Area-scans, full-disk photospheric, vector magnetograms, and chromospheric line-of-sight magnetograms are recorded daily as part of the VSM nominal observing program. The quality of the

VSM data products is significantly better relative to similar data produced with the previous Kitt Peak synoptic facility. Since August 2003, the VSM has recorded full-disk photospheric vector magnetograms at least weekly and, since November 2006, area-scans of active regions daily. Fully calibrated and inverted full disk and active region data are now available online and quick-look vector FITS-formatted files and JPEG images are also available daily. A typical observing day includes three full-disk photospheric vector magnetograms. Carrington rotation and daily synoptic maps are also available from the photospheric magnetograms and coronal-hole estimate images.

In addition to the VSM, calibrated SOLIS ISS spectra and parameter time series data are available publicly. Ca II H and K and He I 1083.0 nm spectra recorded by the ISS are now available daily as both FITS-formatted data and JPEG image files. In addition, various Ca II K-line parameter time series data are available as text-formatted data and JPEG image files. The remainder of the nominally observed ISS spectral-band data is expected to be available this year.

#### Instrument Upgrades and Hardware Replacement

The original vendor for the SOLIS VSM cameras defaulted on its contract, and the project was forced to install interim cameras that were slower, noisier, and had lower resolution than originally planned. This prevented the VSM from achieving its design performance. Fortunately, new cameras have recently become available with characteristics very similar to the original design. Three cameras (one spare) have been purchased from Sarnoff Corp. and modified to better meet the VSM scientific requirements. Work on a new data acquisition system (DAS) that is compatible with the high-speed Sarnoff cameras has been completed and the system underwent extensive testing over several months. The new camera system will be installed as time and weather permits during the fall of 2009.

There is great community interest in obtaining chromospheric vector magnetic field measurements. This will require a new polarization modulator package to replace the current line-of-site magnetic field measurement. Due to current observational scheduling with support of Hinode and STEREO, it is anticipated that this task should be undertaken during the first quarter of FY2010, in time to support the Solar Dynamics Observatory.

The VSM has had its ferroelectric liquid crystal (FLC) modulators replaced in the recent past, spring 2006, due to unacceptable changes across its field of view. Fortunately, now it appears that the life expectancy of the current technology has more than doubled. The existing modulator is expected to last through 2010. A possible long-term solution could be the replacement of existing FLCs with new technology that has recently demonstrated an operational lifetime of over 10 years. A vendor has been contacted to supply a unit during the summer of 2009 for extensive testing of efficiency, field of view effects, and scatter.

Replacing the current processing machines with more reliable hardware is still a high priority. In addition, the Storage Area Network (SAN) servers are currently without a spare. The function of these machines is critical to the operation of SOLIS and a phased replacement or upgrade is part of the long-range operational plan.

There are several Solaris machines among the many Linux machines within SOLIS. In general, it is desirable to make the machines and software as uniform as possible. This would improve maintenance and allow the machines to function in a more uniform way within SOLIS. Therefore, phasing out the existing Solaris machines over the next few years is being considered.

Finally, a synoptic program of daily, high-precision observations of the Sun as performed by SOLIS cannot meet its principal objectives without the secure storage of the accumulated data in a library. Therefore, we will be adding high capacity DLTs along with a tape library for storage to the SOLIS program.

#### 3.1.5 Evans Solar Facility (ESF)

The Evans Solar Facility provides a 40-cm coronagraph as well as a 30-cm coelostat. The Evans coronagraph is the most thoroughly instrumented in the world. The Air Force group at Sacramento Peak provides support for and is the primary user of the ESF 40-cm coronagraph. The coelostat is used in the NSO Ca II K-line monitoring program. This program will be discontinued once the cross-calibration with the SOLIS ISS has the opportunity to see the rise in chromospheric emission of the current solar cycle. SOLIS and ISOON have replaced the spectroheliogram capability of the ESF with full-disk imaging. The Air Force group provides funding for a part-time observer and provides NSO with funds for minimal maintenance. The High Altitude Observatory is developing a instrument for the ESF for measuring prominence magnetic fields and will provide support for its operation.

#### 3.1.6 Digital Library

In addition to its dedicated telescopes, the NSO operates a Digital Library that provides synoptic data sets over the Internet to the research community. Since the inception of the Digital Library in May 1998, more than 17 million science data files have been distributed to about 9,000 unique computers. These figures exclude any NSO or NOAO staff members. The holdings of the NSO Digital Library are currently stored on a set of RAID5 disk arrays and are searchable via a Web-based interface to a relational database. A higher-capacity storage system was installed in August 2003. This system, named *solarch* (for SOLIS, or solar archive), also holds the Digital Library is fully supported by non-NSO funds, and is an important component of the Virtual Solar Observatory.

#### 3.2 New Capabilities

The introduction of novel, post-focus instrumentation and adaptive optics has greatly enhanced the capabilities of the solar telescopes of NSO, thereby enabling whole new areas of scientific inquiry, especially in high-resolution and infrared observations of the Sun. These new results, combined with improved modeling, have shown that advances in spatial, temporal, and spectral resolution are required to accurately measure fine-scale, rapidly changing solar phenomena and to test the advances in our theoretical understanding. Increasing the number of photons collected over the short evolutionary times of solar features is needed for making accurate polarimetric observations. Meeting these challenges requires a new, large-aperture solar telescope.

#### 3.2.1 Advanced Technology Solar Telescope (ATST)

NSO is working with the solar community to develop the next generation solar telescope that will enable observations of fundamental astrophysical processes at their intrinsic scales. The major new ground-based project in solar physics is the development of the 4-m Advanced Technology Solar Telescope. A complete description of science goals and project information can be found at *atst.nso.edu/*.

The ATST was first proposed to NSF as a design and development project in 2001. Review of the proposal showed that the community had developed an excellent science case for ATST and the design and development (D&D) phase was funded. In late 2003, the ATST project submitted a construction proposal to NSF. After another highly successful review, it was determined that ATST should be the first project to follow the newly developing MREFC guidelines, which were being established to meet congressional concerns. NSF conducted an ATST cost review, which resulted in ATST entering the MREFC "readiness" phase. In the fall of 2006, a successful preliminary design review was held, and it was determined that ATST was ready to move into the next phase. At the August 2007 meeting of the National Science Board (NSB), it was recommended that the NSF should consider submitting ATST for funding, moving it from readiness into the approval phase. In May of 2009, NSF conducted a Final

Design Review (FDR) of the ATST. The review panel recommended that ATST is now ready for construction. NSF and the ATST project are now finalizing the Environmental Impact Statement (EIS) for the proposed construction site on Maui in anticipation of a positive Record of Decision (ROD) and NSB approval to begin construction.

#### ATST Science Working Group and Science Requirements

The ATST Project Scientist, Science Working Group (SWG), and in-house science team have carefully laid out the ATST science goals and developed instrument specifications required to meet these goals. The SWG (see Table 3.2-1) has both U.S. and international members who report to and advise the Project Scientist and Project Director. Under the leadership of the Project Scientist, the SWG and inhouse science team produced a Science Requirements Document (SRD) (#SPEC-0001) and contributed to the science write-up for the ATST construction proposal. The SWG recommended the primary and alternate sites for the ATST based on the site survey data.

Table 3.2-1. ATST Science Working Group						
Thomas R. Ayres	University of Colorado, CASA					
Thomas E. Berger (Chair)	Lockheed Martin, Solar & Astrophysics Laboratory					
Tim Brown	Las Cumbres Observatory					
Mats Carlsson	University of Oslo, Norway					
Gianna Cauzzi	Arcetri Observatory, Italy					
Manuel Collados-Vera	Instituto de Astrofisica de Canarias, Spain					
Craig DeForest	Southwest Research Institute					
Lyndsay Fletcher	University of Glasgow, United Kingdom					
G. Allen Gary	NASA Marshall Space Flight Center					
Sarah Gibson	High Altitude Observatory					
Leon Golub	Harvard-Smithsonian Center for Astrophysics					
Donald E. Jennings	NASA Goddard Space Flight Center					
Philip G. Judge	High Altitude Observatory					
Christoph U. Keller	Utrecht University					
Jeffrey R. Kuhn	University of Hawai`i, Institute for Astronomy					
Haosheng Lin	University of Hawai`i, Institute for Astronomy					
Dana Longcope	Montana State University					
Thomas R. Rimmele	NSO					
Luis Bellot Rubio	Instituto de Astrofisica de Andalucia, Spain					
Michael Sigwarth	Kiepenheuer Institut für Sonnenphysik, Germany					
Hector Socas-Navarro	Instituto de Astrofisica, Spain					
Robert F. Stein	Michigan State University					
Yoshinori Suematsu	National Astronomical Observatory of Japan					
Haimin Wang	New Jersey Institute of Technology/Big Bear Solar Observatory					

#### ATST Project Engineering and Design Progress

The ATST project accomplished several major milestones during this past year, including several successful system level design reviews, a successful final design review, and completion of a supplemental EIS on the road through Haleakalā National Park. The ATST project team continues to draw from a broad range of resources, which include members of the NSO staff, individuals from other organizations, and Co-PI teams that review instrumentation, operations, and design issues. As we near construction, several positions will be added to the project team.

#### NATIONAL SOLAR OBSERVATORY

#### **Construction Phase Planning**

Construction phase management and systems engineering efforts are focused on requirements for the construction phase including the integration, testing, and commissioning phase. These efforts are in addition to management and systems engineering efforts that support the design phase tasks. The project has considered a range of possible subcontracting options during the construction phase and developed these options with interface requirements and project organization in mind. The interface control document (ICD) system and the work breakdown structure (WBS) have been refined to cover the entire period through the construction phase. As in the design phase, the WBS is consistent with the subsystems, has an accounting number system that matches both the WBS and ICD organization, and includes the detailed plans and schedules for the project through the construction phase and into early operations. Current lead engineers and team members assigned to each of the major WBS design elements are shown in Table 3.2-2.

Funds have been budgeted to each of the major WBS elements for both design and construction phases, and design-to-cost "targets" were established for each WBS element. A conservative design scenario was used, without contingency, to establish these targets. It included estimates and design evaluation efforts from industry and partners. Contingency, based upon risks and feedback from industry after the conceptual design review (CoDR), is held centrally in the project management WBS to help focus each engineering manager on design-to-cost targets that were established early.

TABLE 3.2-2. ATST Engineering Responsibilities					
Systems Engineering	Eric Hansen				
	Rob Hubbard				
Telescope Assembly	Mark Warner				
Telescope Mount	Mark Warner				
M1 Assembly	Eric Hansen				
M2 Assembly	Eric Hansen				
Feed Optics	Eric Hansen				
Thermal Systems	LeEllen Phelps				
Stray and Scattered Light Control	Rob Hubbard				
Wavefront Correction	Thomas Rimmele				
	Steve Hegwer				
	Kit Richards				
Instrument Systems	Jeremy Wagner				
	Rob Hubbard				
High-Level Controls and Software	Bret Goodrich				
	Steve Wampler				
Enclosure	Mark Warner				
	LeEllen Phelps				
Support Facilities (includes infrastructure items)	Jeff Barr				

#### **Current Design Activities**

Current design activities include finalizing and tolerancing the instrument feed to the coudé lab; updates to the telescope structure and enclosure thermal design; including vents and liquid cooling systems, thermal design and analysis for the interface to the coudé lab; and performance up-dates based upon the Haleakalā site testing data. The current design is shown in Figure 3.2-1. The design includes the simplified one-level coudé instrument area and feed arrangement. The feed for instrumentation associated with this is more compact and simpler to direct to multiple instrument stations.

Preliminary instrument design efforts and other activities have continued with the Co-PI teams and partners. The following efforts are underway:

• High Altitude Observatory (Visible Light Polarimeter Design; Near IR Polarimeter Contributions).

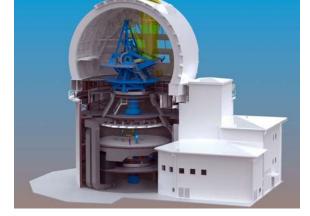


Figure 3.2-1. Current ATST facility design.

- University of Hawai'i (Near IR Polarimeter Design (Lead).
- New Jersey Institute of Technology (Tunable IR Filter Design).
- Lockheed Martin (Visible Broadband Imager Contributions).
- NASA Marshall Space Flight Center (Visible Tunable Filter/Polarimeter Design working with NSO and KIS).
- Kiepenheuer Institut für Sonnenphysik (Visible Tunable Filter (lead) working with NSO and NASA).

#### **ATST Management Activities**

Current management activities include planning for various potential scenarios for transition from design and development into construction. Currently there are no D&D funds allocated by NSF for FY2010 under the assumption that construction funding will be made available. If construction funding is delayed beyond October 1, 2009, it will be necessary to obtain additional bridge funding to keep the project moving ahead toward construction.

The overall top-level schedule is shown in Figure 3.2-2. It assumes that construction will begin in FY2010.

#### ATST Site

Following the selection of Haleakalā as the preferred site for ATST, preparations began to characterize the site and obtain the necessary permits for construction. Environmental permitting for Haleakalā requires an Environmental Impact Statement (EIS) as mandated by federal and state statutes. In May 2005, NSO contracted with Maui-based KC Environmental, Inc. to prepare the EIS. This process began with Notices of Intent and announcements published in the Federal Register.

In July 2005, three formal public scoping meetings were held on Maui to obtain community input on the issues that should be addressed in the EIS. The EIS process is planned to conclude with a Record of Decision by mid 2008. A number of informal meetings with concerned members of the public have been held to offer further opportunity for public input since the July 2005 scoping meetings. A draft EIS was released in 2006. In 2008, an agreement was reached with the National Park Service to include the Park road in a supplement to the draft EIS. The supplemental draft EIS was released to the public in May 2009 for comment.

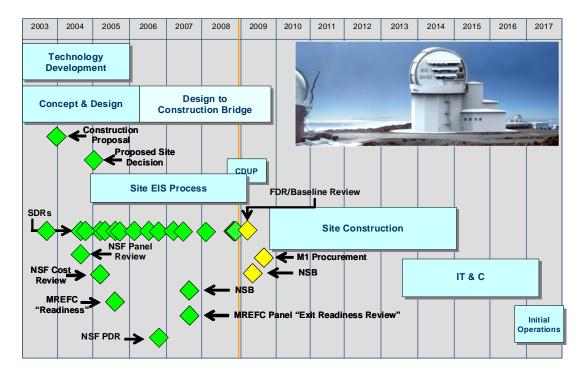


Figure 3.2-2. ATST top-level schedule.

In addition, a series of meetings to support the requirements of Section 106 of the National Historic Preservation Act (NHPA) are underway. Participants in the meetings included the NSF, the Project, Native Hawaiians, and other interested parties. An initial informal meeting was held on Maui in January 2006, followed by two formal consultation meetings held in March and April 2006. The Draft EIS document was released for public review and comment in September 2006. Additional NHPA Section 106 meetings were held on Maui in June and August 2008.

#### Plans

During 2010, it is anticipated that the ATST project will transition from design to construction phase. In the near-term, preliminary design efforts, site infrastructure and EIS process, and review of the construction proposal will be the principal project planning activities. Near-term design efforts are



Figure 3.2-3. Renderings of the ATST at the proposed primary (left) and alternate (right) sites on Haleakalā.

concentrating on refinement of the thermal control design for the enclosure, detailed optical feeds to instruments, more complete instrument concepts, system-error budgeting, and performance modeling using the latest Haleakalā site data. Risk management analysis continues and is being fed back into the project budgets (e.g., contingency), schedules (e.g., schedule contingency) and planning (e.g., in-process spares, integration, testing, and commissioning (IT&C) planning and staffing). Responses and actions resulting from the FDR will be planned and executed.

#### **Project Planning**

The engineer responsible for each WBS has developed detailed plans, including schedules and budgets, for the construction phase. The systems engineering team and project manager have integrated these details into the overall project schedule. Emphasis will be on near-term planning, but longer-term plans through the construction phase are essential for keeping the end-project goals in mind.

During the D&D phase, detailed plans have begun for transitioning to operations that will enable life cycle planning during the design process and help prepare the National Solar Observatory for the operational phase of ATST.

#### **Construction Phase**

Current planning, based on an FY2010 construction start, has calendar year 2017 targeted for obtaining the first scientific data with an ATST instrument. To maintain the overall schedule, the construction funding must begin in FY2010. During the first two years of construction, immediate site work, as well as manufacture of the primary mirror blank and completion of the final fabrication designs, will be crucial. Construction of main components such as the enclosure and telescope structure should also be well underway. There will be a year-for-year slip in this schedule if the start of construction funding is delayed further.

#### Funding

In FY2010, adequate construction funding is needed in order to transition the project team from D&D to the construction phase, and to establish commitments on many of the major subcontracts. The project team will transition fully from D&D funding to construction funding when the latter becomes available. This is anticipated to occur at at the beginning of FY2010. The construction funding requirements are based on the budget described in the original construction proposal and as revised following recommendations of the NSF-conducted Cost Review in March 2005, the Preliminary Design Review (PDR) Committee in October 2006, and the Final Design Review (FDR) Committee in May 2009.

The 2005 cost review resulted in the identification of six main areas that affect the construction proposal budget: (1) delayed start, (2) consequences of site selection, (3) preliminary design effort, (4) specific NSF Cost Review Panel recommendations (e.g., in-process spares), (5) Major Research Equipment Facilities Construction (MREFC) requirements, and (6) commodity cost increases.

Based on the panel's recommendations, the costs associated with each of these six areas were reviewed and the cost estimates revised accordingly. During the re-costing exercise, the project team reassessed each WBS element in detail. After all elements were examined and re-costed individually, the team reviewed the overall distribution of costs and contingencies to further balance the program and maintain the overall contingency as recommended by the review panel.

The PDR committee's recommendations resulted in a few revised costs as well. The largest change was associated with the factors used to address inflation. These factors were revised according to recommendations from the committee and guidance from the NSF. The latest Office of Management and Budget (OMB) factors for construction were applied to the construction project and the cost estimates were revised accordingly. The other major change resulted from separate NSF guidance regarding the funding profile and the limited funds potentially available for starting the project. The funding profiles proposed in the construction proposal, cost review, PDR, and FDR were based on technically driven schedules.

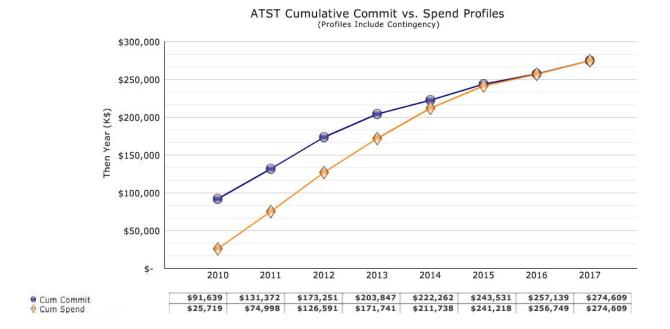
The estimate of required funds is given in Table 3.2-3, assuming no advanced purchase of the primary mirror. Inflation and an overall 25% contingency on base costs are included. Figure 3.2-4 shows the time-phased funding profile for construction.

#### Budget for Design and Development (D&D) Phase Completion

To maintain the project team, support the on-going EIS process, and perform recommended risk mitigation studies with industry, NSO requested additional funding to the projected ATST FY2009 budget. NSF provided an additional \$1.4M, raising the total available in FY2009 to \$3.2M. The American Recovery and Reinvestment Act (ARRA) is providing an additional \$3.1M. These additional funds will be used to advance the instrument designs and progress the telescope and enclosure designs towards construction.

The design feasibility and analysis studies with industry are targeted toward identified risk areas (i.e., performance, cost, and schedule—critical path and near critical path items). The studies will allow the team to advance the designs further while supporting the refinement of the requirements, interfaces, and statements of work required for the later design completion contracts with industry. By conducting the studies now, we will place the project in a much stronger negotiating position with industry.

Table 3.2-3. ATST Construction Phase							
Title	Total Then Year U.S. Dollars (\$M)						
Project Management	24.65						
Systems Engineering	3.77						
Telescope Assembly	76.63						
Wavefront Correction	13.92						
Instrument Systems	30.94						
High-Level Controls and Software	9.09						
Enclosure	32.74						
Support Facilities and Buildings	38.34						
Remote Operations Building (ROB)	1.61						
Integration, Testing, & Commissioning	14.22						
Science Support	5.85						
Support Services	9.35						
Contingency (General & Schedule)	13.50						
Total	274.61						
	Title         Project Management         Systems Engineering         Telescope Assembly         Wavefront Correction         Instrument Systems         High-Level Controls and Software         Enclosure         Support Facilities and Buildings         Remote Operations Building (ROB)         Integration, Testing, & Commissioning         Science Support         Support Services         Contingency (General & Schedule)						



*Figure 3.2-4. Time-phased funding profile for ATST construction. These numbers were presented at the May 2009 Final Design Review and will likely change based on review committee recommendations.* 

#### 3.2.2 SOLIS Global Network

NSO is now seeking international (or other national) partners and, if successful, proposes to build two additional SOLIS Vector Spectromagnetograph (VSM) units in response to the desired capability outlined in the NAS/NRC decadal survey, "Astronomy and Astrophysics in the New Millennium" and endorsed by the NSF/AST Senior Review. These units will be placed at distant longitudes and operated to form a SOLIS network capable of much more complete coverage of transient solar activity.

The establishment of a three-site SOLIS VSM global network will enable synoptic, full-disk observations of the Sun on a nearly continuous 24/7 basis. This capability, in turn, will provide a powerful complement to current and forthcoming solar space missions, such as Hinode and the Solar Dynamics Observatory. A VSM network will further provide simultaneous, or near-simultaneous, contextual data in coordination with other international ground-based solar telescope facilities such as the ATST, GREGOR, the Swedish Vacuum Telescope, and others throughout the world. The full-disk vector capabilities and high sensitivity are an excellent complement to the high-cadence longitudinal magnetograms produced by the GONG network.

The core synoptic program for the single VSM is three full-disk vector magnetograms per observing day at roughly three hours apart. That cadence was set by the amount of time anticipated to do full inversions of full-disk vector magnetograms. Faster would be better from a science perspective. It takes about 20 minutes to make a full-disk vector observation, but that can be increased or decreased depending on the desired signal-to-noise ratio. A single active region can be observed every two minutes with good results by restricting the scan size. A SOLIS movie of the vector field at disk-center (prepared by C. Keller) reveals network fields changing on a time scale of minutes, presumably due to buffeting by granulation. Two additional sets of three full-disk vector magnetograms per site per day have the value of tripling the chance of observing transient activity such as flares and CMEs, and more rapid detection of their observational precursors. The identification and investigation of flare and CME

precursors are essential for accurate space-weather forecasting. Catching a major flare in a fast sequence of good vector magnetograms would answer many long-standing questions.

A VSM network will enable the study of magnetic field changes associated with transient activity such as flares and coronal mass ejections, in addition to documenting the long-term changes associated with the solar cycle. Furthermore, a three-site global VSM network will:

- have three times better chance of capturing rare events;
- produce improved potential for short-term activity forecasts;
- have the ability to detect and correct systematic data errors;
- be more robust against a single-site failure;
- provide improved constraints on theoretical models of activity;
- generate opportunities for international scientific collaboration; and
- stimulate stronger research programs on solar activity.

#### Structure of a SOLIS VSM Network

The basic structure envisioned consists of three VSM instruments distributed around the world at sites with longitudes that include the southwestern U.S., Europe/Africa (+8 hours) and western Australia/Asia (-8 hours). It should be noted, parenthetically, that the ATST site on Haleakalā is at a less favorable longitude for a three-site global network than candidate sites in the southwestern U.S., such as Big Bear Solar Observatory (BBSO) or the present site at Kitt Peak. The other desirable site characteristics include clear skies at least 60% of the time and good seeing during the course of a day.

The NSF Senior Review recommended that a SOLIS network be formed through funding contributions by international partners. The partners could build clones themselves or contract the NSO to construct replicas of the VSM. NSO's estimate of the cost to replicate the SOLIS VSM is approximately \$5.5M (full-cost accounting with an estimated 20% error) in FY2007 dollars. The VSM currently in operation on Kitt Peak will require some redesign in order to (1) update various electronic components, and (2) increase the ease of maintenance. Of course, building two identical VSM instruments in parallel would reduce the unit cost for each.

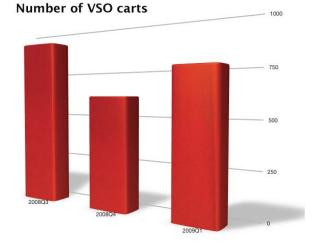
The NSO has found potential partners in Germany, Spain and Australia. Together with these potential partners, a proposal was submitted to NSF/ATM. While receiving excellent reviews, the proposal was not funded. NSO will continue to seek funding opportunities for a SOLIS network, perhaps through the special MRI-R<sup>2</sup> opportunity, depending on NSO eligibility as the lead institution.

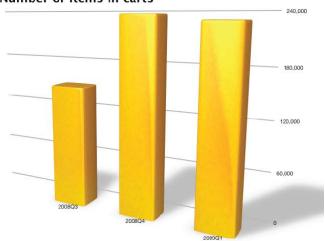
#### 3.2.3 Virtual Solar Observatory (VSO)

In order to leverage further the substantial national investment in solar physics, NSO is participating in the development of the Virtual Solar Observatory and the Collaborative Sun-Earth Connection (CoSEC). The VSO comprises a collaborative distributed solar-data archive and analysis system with access through the WWW. The system has been accessed approximately 80,000 times since Version 1.0 was released in December 2004. The current version, 1.4, provides access to 65 major solar data sets along with a shopping cart mechanism for users to store and retrieve their search results.

The overarching goal of the VSO is to facilitate correlative solar physics studies using disparate and distributed data sets. Necessary related objectives are to improve the state of data archiving in the solar physics community; to develop systems, both technical and managerial; to adaptively include existing data sets, thereby providing a simple and easy path for the addition of new sets; and eventually to provide analysis tools to facilitate data mining and content-based data searches. None of this is possible without community support and participation. Thus, the solar physics community is actively involved in the

#### NATIONAL SOLAR OBSERVATORY





Data in carts (Terabytes)

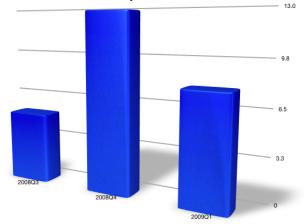
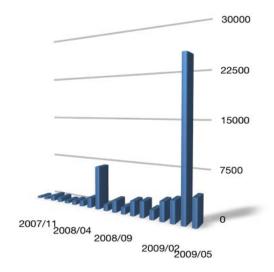


Figure 3.2-5. VSO usage trends, calendar year 2008 Q3 – 2009 Q1: (Above left) Number of data "carts" created by interaction with the VSO Web interface; (above right) number of data objects in VSO data "shopping" carts, the most direct measure of the number of distinct searches carried out by live users of the VSO Web interface; (left) total volume of data identified (and links provided) by VSO Web interface searches. We have at present no way of knowing how much of that data was downloaded as a result of a VSO search, since the data are obtained directly from the distributed data providers.



**Figure 3.2-5.** Monthly accesses of the Virtual Solar Observatory using the IDL VSO\_SEARCH function rather than the Web interface. (Figures for 2009 May represent only the first 15 days of the month.)

Number of items in carts

Observatory. None of the VSO funding comes from NSO; it is fully supported by NASA. For further information, see *vso.nso.edu/*.

In the time frame covered by this cooperative agreement, NSO should continue to be a central component of the VSO. In addition, the NSO archives should be observatory-wide with components at both sites. These components should link enhanced pipeline processing systems similar to those now available, such as ISOON and GONG++, massive storage systems based on the initial SOLIS system, an instrument-driven pipeline and PI data-capture systems at all NSO observing facilities, and a large-scale photographic digitization system. The details for this expansion have been discussed in the NSO Data Plan (see *www.nso.edu/general/docs/*).

The ATST Data Handling System (DHS) included in the construction proposal provides a common data transfer and storage service for all ATST facility instruments. The DHS supports four areas of instrument data requirements: transfer, storage, display for quality assurance, and retrieval. Data handling begins with the high-speed transfer of large data sets from one or more instruments. The data are organized and stored according to observation type and originating instrument, then integrated with observatory data such as experiment, investigator, and telescope status. Each observing program will have a unique identifier. Users requiring a real-time display of the data can request a quick-look display. The data set created by an experiment will be moved to temporary storage and then sent to the NSO data processing and archiving facilities for further reduction and dissemination.

Data that have been collected and temporarily stored at the summit will be transferred to processing facilities at the ATST Support Facility on Maui and to NSO Headquarters. The exact amount of storage and processing power to locate on Maui will be determined during construction and will depend on several factors, including data transfer costs, hardware costs, and personnel costs. Any extensive processing would occur at a data center located at NSO HQ that also supports other NSO programs. The ATST Support Facility on Maui, should at a minimum have sufficient capability to allow ATST staff stationed on Maui to reduce some of the data to further ensure quality and that the objectives of the observing run are being met as well as to conduct their own research.

An ATST data archive is not considered to be part of the baseline ATST construction. Science and engineering data produced by ATST will have a high enough value that they should be archived either permanently or for extended periods as determined by the NSO data policy for ATST. There will need to be a selection process to eliminate marginal data. Some (small) fraction of this can occur at the telescope before downloading off the mountain, but most will require at least some level of processing to determine the quality of the data. Ideally, we will store all (good) raw data along with their calibrations. Data that are reduced by NSO for community access would be stored for defined periods of time that take into account their usefulness as judged by downloads from the community. ATST data will become part of the NSO digital library and will share resources with other NSO programs. NSO can exploit the large amount of data center expertise that already exists within the NSO GONG and SOLIS programs. Data will be made available via FTP, the Web, and through the Virtual Solar Observatory

# 3.2.4 Planning for Beyond ATST

The next Astronomy decadal survey is now underway. It is presumed that the next Solar and Space Sciences survey will follow a few years later. The ATST will be in the latter part of the next decade, so the solar astronomy community must begin thinking about the continuing needs of its discipline. New instrumentation and upgrades for the ATST will cost in the millions of dollars. A few examples include MCAO, adaptive secondary, and new camera systems for the IR and visible. These systems will be sufficiently costly that considerable long-range planning will be required.

NSO will conduct workshops to consider theoretical progress and observational facilities needed to test and refine theory.

# 4 EDUCATION AND PUBLIC OUTREACH AND BROADENING PARTICIPATION

NSO has a comprehensive public affairs and educational outreach plan that includes graduate research and training, undergraduate research, teacher research and research-to-classroom experiences, public programs, media information, elements of distance (Internet) learning, and K-12 education. In late FY2008, NSO started a Broadening Participation initiative to expand among African American, Hispanic, and Native American populations awareness of the need for solar physics research and the potential for careers in the field. This will include expanded outreach through established education and professional venues and direct contacts with minority-serving schools.

NSO EPO goals are:

- To train the next generation of scientists and engineers through support for graduate students and postdoctoral fellows and close collaboration with universities and the ATST consortium.
- To develop K-12 teacher training and student training programs to advance knowledge of science and technology.
- To increase public understanding of the Sun, both as a star and as the driver of conditions on the Earth, as well as understanding of the related disciplines of optical engineering, electronics and computer sciences, as applied through the ATST and other NSO projects.
- To increase nationally the strength and breadth of the university community pursuing solar physics.
- To enhance the understanding and application of science and math education in our schools, colleges and the public at large, and among traditionally under-represented communities (Hispanic, Native American, African American, and women).

NSO has extensive experience in EPO at its Sunspot, NM, and Tucson, AZ, sites. It can also call on the experience of its colleagues within the broader Association of Universities for Research in Astronomy (AURA): National Optical Astronomy Observatory (NOAO), Gemini Observatory, Cerro Tololo Inter-American Observatory (CTIO), and Space Telescope Science Institute (STScI). It will also call on expertise from the University of Hawai'i Institute for Astronomy.

#### 4.1 Recruiting a New Generation

The future of solar physics hinges on the successful recruitment of a talented new generation of scientists by the universities and national research organizations. Since its formation as a national observatory in 1983, NSO has actively participated in the recruitment of the new generation by conducting annual programs that offer undergraduate, graduate students, and middle- and high-school teachers opportunities to participate in astronomical research (see Table 4.1-1). In recent years, NSO has also partnered with the Lunar and Planetary Laboratory at the University of Arizona to offer short (one week in duration), focused, summer schools to allow students to expand their knowledge horizons. These programs are successful in that many of the students who have had summer research positions at NSO continue to pursue research careers in solar physics or closely related fields.

Diversity of the solar physics workforce is a topic that deserves special attention. Diversity can only be ensured if the solar physics community fosters students who are traditionally at risk in the early career stages. Middle and high schools experience a high attrition rate of underrepresented minorities and women concentrating their studies in math and sciences. NSO is working towards diversifying the pool of college students studying astronomy and physics. This task is complex and must occur at all stages of apprenticeship: postdoctoral, graduate, undergraduate, and early education (high, middle and elementary school). As a first step, NSO has started sending EPO representatives to meetings of national societies of black, Hispanic, and Native American engineers and scientists, and in summer 2009, a graduate student from the Fisk-Vanderbilt Masters-to-PhD Bridge Program started a summer research internship at NSO/Tucson. NSO also has just hired a recent physics PhD recipient from Howard University to work on a project supported by a NASA SDO/Helioseismic Magnetic Imager (HMI) grant.

Та	Table 4.1-1. Number of Participants in NSO Educational Outreach Programs           (2003–2009)								
Year	Graduate (SRA)	Undergrad (SRA)	Undergrad (REU)	Teachers (RET)	Postdoctoral Fellows				
2009	3		6	2	6				
2008	3	1	6	0	6				
2007	5		6	4	7				
2006	4		7	4	5				
2005	9		8	4	5				
2004	6	1	6	4	3				
2003	7		8	3	4				

NSO has been successful with its inclusion of women in its program as more than half of the research undergraduates in recent years are female (see Table 4.2-1 for the gender and minority breakdown of REU statistics for the past five years). Enrollment of women in graduate science programs has risen drastically in the last decade, in part due to programs that foster girls' confidence in their scientific and mathematical abilities. In an isolated example of such a program, NSO recently participated in the development of a publication to be used as supplementary middle school education material to encourage more young women to pursue science careers (see Sally Ride Science, *www.SallyRideScience.com*, "The Inside Story of the Sun," 2007). In an effort to attract students from underrepresented areas into summer research internships, our mailing list includes colleges from the Historically Black College List generated by the NSF and a list of American Indian Science and

Engineering Society Affiliates. As can be seen in Table 4.2-1, racial minority enrollment in NSO REU programs has been small, and it is our goal to increase these numbers by participating in more directed recruitment and involvement in the Partnerships in Astronomy & Astrophysics Research and Education (PAARE) program.

The recent NSF program that appointed three new solar physics faculty at institutions will greatly aid and ensure the health of solar physics in the U.S. The positions, partially funded by NSF, were awarded to: the Institute for Astrophysics (IfA) at the University of Hawai`i, the Lunar and Planetary Laboratory (LPL) at the University of Arizona, and the University of Colorado. In 2007, the strengthened solar physics group at LPL successfully recruited a solar physics graduate student who participated as an REU with NSO and has been working with scientists at NSO. This illustrates the fruitful collaboration between NSO and LPL, as NSO scientists are available to advise PhD students and interact informally with the University of Arizona academic community in many regards. Figure 4.1-1 is a schematic to illustrate NSO's programmatic contributions to the educational pipeline.

Even with the success of NSO's Education and Public Outreach, cultural changes demand that NSO grow with the times. NSO will continue to update and modernize its EPO programs. Priorities will include:

- Increasing NSO's on-line presence in response to an ever-increasing use of the World Wide Web as a source of public information.
- Mentoring and advising more Ph.D. and post-doctoral students, especially U.S. nationals in areas directly relevant to ATST instrumentation calibration and science.

• Tailoring our student recruitment techniques to ensure diversity within the new generation of solar astronomers.

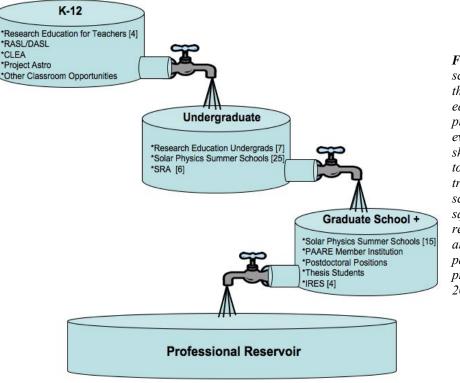


Figure 4.1-1. A schematic illustrates how the components of NSO education and outreach programs form a pipeline eventually providing skilled human resources to the professionally trained reservoir of scientists. Numbers in square brackets represent the average annual number of participants in the program from 2003-2009.

#### 4.2 Higher Education

Annually, NSO provides undergraduate and graduate students with the opportunity to engage in astronomical research at the Sunspot, New Mexico or the Tucson, Arizona site. Seven or eight undergraduate students work at NSO through the NSF Research Experience for Undergraduates (REU) program for ten to twelve weeks in the summer. These internships have been offered at NSO since the early 1980s. The summer research assistantship program (SRA) provides opportunities for graduate students to work on a specific research project in close collaboration with a scientific staff member of NSO.

NSO is pleased to be a formal partner with three institutions applying for funding through the NSF 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 Astronomical Sciences Division (AST)-supported facilities, projects or faculty members at research institutions including private observatories." This is an exciting opportunity for NSO scientists to mentor students from Vanderbilt and Fisk Universities; California State University, Northridge (CSUN), and New Mexico State University (NMSU).

In 2006, 2007, and 2008 NSO partnered with LPL at the University of Arizona to present a Solar Physics Summer School. The summer school consists of undergraduate and graduate students attending a week-long program featuring lectures on the most exciting contemporary solar physics research. Both summer schools have been held at NSO Sunspot with approximately 35–50 attendees from all over the world. NSO will participate in the program this summer (2009) and in 2010. In addition to graduate

student participation in the NSO/LPL summer school, NSO participated in a new summer research opportunity in 2007, 2008, and 2009, the International Research Experience for (Graduate) Students, or IRES. The program took place in Bangalore, India, under the auspices of the Indian Institute of Astrophysics. The program has been renewed and will continue for an additional three years.

Many alumni from NSO educational programs (roughly 50%) have continued their education to become active solar researchers. NSO aims to provide as many research opportunities as possible for students, because it agrees with Galileo's statement, "In questions of science, the authority of a thousand is not worth the humble reasoning of a single individual." The successful mentoring of one student may result in immeasurable gains to the field of solar physics and astronomy.

Table 4.2-1. NSO REU Statistics (2003-2008)									
	2008	2007	2006	2005	2004	2003	Total	% of Total	
Male	4	2	1	5	2	5	19	47.5%	
Female	2	4	6	3	4	2	21	52.5%	
Minorities	0	1	0	0	0	1	2	5.0%	

#### 4.3 Mentoring of Postdoctoral Fellows and Thesis Students

Most NSO postdoctoral fellows come to the observatory on grants held by individual NSO scientists, not on the NSO base budget. One major exception has been the ATST program, which has hosted regular ATST fellowships. All postdocs have a scientific staff mentor who consults on and guides their work. The mentor provides supervision as well as research guidance on a regular basis. Since many of the postdocs at NSO are directly involved in observations, the mentor also provides training on instrumentation and observing methods. The mentors as well as senior NSO management staff also provide professional guidance that includes discussions about and reinforcement of principles of scientific research ethics.

In addition to the assigned mentor, NSO postdoctoral fellows and thesis students interact with other members of the science staff, often forming collaborations that provide the benefit of a broader range of experiences. We hold regular staff seminars and informal science exchanges to further broaden exposure to all aspects of solar physics. Visiting scientists regularly give seminars and interact with the NSO staff and postdocs, providing the opportunity to make connections throughout the solar community. At NSO/Tucson, co-located with the NOAO on the University of Arizona campus, NSO postdocs are exposed to the entire range of contemporary research in astrophysics through seminars and colloquia in this active segment of the astronomy community. In addition, NSO encourages and provides resources for our postdoctoral fellows to attend and present their research at professional meetings.

We work closely with our postdocs on creating their resume and in finding opportunities to enter the permanent solar workforce. This process has been very successful; almost all of our postdoctoral fellows doing solar research have found positions in solar physics or closely related fields. Several of the postdocs over the past 10 years have worked at NSO in instrumentation and have taken jobs in industry or in developing instruments in other fields.

Frequent contact is an important part of mentoring, particularly with postdoctoral fellows who have limited experience. The GONG program holds bi-weekly individual meetings between the program scientist and each scientific staff member, as well as a bi-weekly science round table which is attended by all of the GONG scientists. Individual meeting frequency is higher for postdocs, with a weekly

cadence. In addition, new postdoctoral hires are provided with a reading list, and telecoms are held to discuss questions prior to the start of their employment.

As part of this proposal, NSO will establish a more formal career counseling program involving senior scientific staff, and will implement a program for tracking the career paths of our postdoctoral fellows. NSO scientists regularly prepare grant proposals for instrumentation and research support that provide the opportunity to train postdocs by including them in the proposal development and preparation. All of NSO's postdocs are encouraged to mentor undergraduate and graduate student participants in our annual Research Experiences for Undergraduates (REU) program and Summer Research Assistantship (SRA) program for graduate students. They receive advice from their mentor as well as NSO science, management, and administrative staff on best practices gleaned from many years of conducting these programs. These programs involve students from many different backgrounds and locations throughout the U.S. and the world, providing postdocs with experience in dealing with diverse groups.

#### 4.4 Programs for Science Teachers

NSO participates in the NSF-funded Research Experience for Teachers (RET) program, which offers middle and high school teachers an opportunity to apply physics, engineering, and mathematical methods to research problems with the understanding that these experiences will be incorporated in their classroom lessons. Participants in the RET program spend the summer either in Sunspot or Tucson.

In the past five years, NSO has participated in the Teacher Leaders in Research Based Science Education (TLRBSE) program developed by NOAO. This is an NSF-funded program that enhances middle and high school teachers' ability to teach science by providing them with a hands-on research experience for two weeks in the summer when they attend a workshop at NOAO Tucson. The RET and TLRBSE programs ultimately enrich the classroom experiences of K-12 students as their teachers have a hands-on knowledge of solar physics research problems and can convey their knowledge and enthusiasm from a personal point of view. NSO plans to continue its commitment to the RET program, but will not actively participate in the TLRBSE program in the future as this program will be paired more exclusively with NOAO scientific mentors. However, a solar physics option for study, and the use of the McMath-Pierce Solar Telescope, will remain included in the TLRBSE program.

#### 4.5 K-12 Classroom Research Activities

Two educational modules were developed by NSO to be used in the classroom at middle- and highschool levels. The Researching Active Solar Longitudes (RASL) project is geared towards improving students' computer and analytical skills in addition to becoming familiar with fundamental solar science. The Data and Activities for Solar Learning (DASL) project provides classroom experience for middle or high school students to study the properties of the Sun's magnetic cycle.

Project CLEA (Contemporary Laboratory Experiences in Astronomy) develops laboratory exercises that illustrate modern astronomical techniques using digital data and color images. They are suitable for high school and college classes at all levels, but come with defaults set for use in introductory astronomy classes for non-science majors. Each CLEA laboratory exercise includes a dedicated computer program, a student manual, and a technical guide for the instructor.

Project ASTRO is a national program that improves the teaching of astronomy and physical science by linking professional and amateur astronomers with local educators. Each astronomer is matched with an educator in a one-on-one partnership and commits to visiting the educator's students at least four times during the school year. NSO staff participate in the annual Project ASTRO two-day workshop hosted by NOAO and engage in mentoring throughout New Mexico and Arizona.

RASL, DASL, Project CLEA and Project ASTRO can all be accessed through the NSO education and public outreach link at *eo.nso.edu/*.

NSO is a strong participant in the Southwest Consortium of Observatories for Public Education (SCOPE). SCOPE is a consortium of research institutions in the Southwest that promotes public awareness of astronomy through access and education. This valuable collaboration results in excellent interaction among the public and educational outreach staff of these groups and includes cooperative promotion, visitor center display sharing, and the ability to leverage limited funding into additional outreach opportunities. NSO will produce materials that reflect the new capabilities of the ATST to describe solar astronomy and the effects of the Sun on the Earth for dissemination by SCOPE.

#### 4.6 Visitor Centers

The NSO Astronomy and Visitor Center at Sacramento Peak is host to over 15,000 visitors per year. A wide range of interactive education displays at the Visitor Center provide hands-on experience with astronomical and terrestrial phenomena, interactive demonstrations on the properties of light and how telescopes work, recent science results from both ground-based and space-based solar and astrophysical experiments, and access to interactive Web-based pages.

The Kitt Peak Visitor Center also attracts more than 40,000 public visitors annually. Exhibits adjacent to the gift shop include a large model of the McMath-Pierce telescope, a live feed for the solar image, and a hands-on display about spectroscopy and its solar science applications. Daily tours of the McMath-Pierce Solar Telescope are available.

Because the Sunspot and Kitt Peak Visitor Centers are located in the Southwest, a large proportion of visitors are Hispanic and Native American. NSO provides tours in both Spanish and English.

#### 4.7 Internet Resources and Public Web Pages

As the public becomes more Internet-savvy, organizations need to respond by continually updating their presence on the Web. The NSO Web site provides information to the public on solar physics and astronomy in general. A particularly successful interactive feature is the "Ask Mr. Sunspot" forum which provides a foundation for anyone on the Web to indulge in their scientific curiosity and ask specific questions. The Ask Mr. Sunspot feature is being revamped to streamline past answers into a comprehensive set and to write new tutorials about the Sun and ATST. NSO staff respond to these questions individually.

Near-real-time solar images are also available from NSO instruments on the following Web pages *nsosp.nso.edu/data/latest\_solar\_images.html, solis.nso.edu/*, and *gong.nso.edu/*.

The Virtual Solar Observatory (VSO) is a cornerstone to ensuring that NSO data are accessible to all scientists internationally. Currently, data from GONG and SOLIS are routinely archived and available through the VSO portals.

#### 4.8 Future EPO Plans

NSO and its partners, including the University of Hawai'i Institute for Astronomy (IfA), are developing the 4-m Advanced Technology Solar Telescope to serve the national and the world solar physics communities for several decades. The scale of the project and its planned lifespan imply that the ATST partners also need to ensure an adequate supply of skilled technicians, engineers, and scientists to operate the facility, as well as ensuring public awareness of the need for solar studies. This requires that the ATST partners start now to encourage local students to follow academic studies that preserve employment options as the ATST is built and then becomes operational.

As an initial step, the ATST project, the Center for Adaptive Optics (CfAO), and the Maui Economic Development Board (MEDB) are proposing to establish an ATST liaison position within the current CfAO/MEDB program. This position would be filled with a local professional who will develop contacts and program options incorporating ATST technical and scientific objectives related to current programs at Maui Community College (MCC), CfAO's Akamai fellowships, and programs of the Space Grant Consortium at MCC. Some of the initial programs could include participation of CfAO/Akamai interns in on-going ATST efforts to develop adaptive optics systems for solar physics. Also, students in the developing MCC electro/optics program could be incorporated into the on-going components of the ATST instrumentation program located at the IfA facility on Maui. In addition, ways of incorporating existing NSO-developed or sponsored computer-based activities into MCC's current astronomy and physics classes can be examined and developed. These include Researching Active Solar Longitudes and Data and Activities for Solar Learning (RASL/DASL) and the Contemporary Laboratory Exercises in Astronomy (CLEA).

The design, construction, and operations of the ATST also include leading-edge mechanical, electrical, optical, and computer engineering. Just as solar science was translated into the exercises above, NSO anticipates that lessons from the design of the ATST can be developed into classroom exercises with real-world applications for students in technical and science courses.

In order to enhance the opportunity for students to participate in the technical and science programs at MCC, NSO would propose to begin working with the local high schools and downward through the K-12 programs. These would include classroom enrichment activities for use during after-school programs and intersession breaks (i.e., fall and spring). These would be developed in consultation with the public school system, Maui Community College, the Maui Digital Bus project, and the Alaka`ina Foundation (sponsor of the Digital Bus). Planned enrichment activities include components of Magnetic Carpet Ride, Goldilocks Star, and Sizing Up the Solar System.

The ATST program can be a catalyst for developing existing and new education and human resources outreach on Maui. Programs developed can then continue to be exported throughout the state of Hawai`i and the nation as a whole. The promise of the ATST offers a unique and exciting opportunity to enhance and develop "Spirit, Education, and Employment" within the local and the greater community.

#### 4.9 Broadening Participation

In accordance with the AURA action plan to respond constructively to the NSF goal of broadening the participation of underrepresented groups, the NSO has appointed a Diversity Advocate and adopted a set of near-term and long-term goals in this vital area. AURA and established a Workforce and Diversity Committee that includes each AURA center's Diversity Advocate as a permanent member. The reader is referred to the AURA Web site for an overview of the meaning of "broadening participation" and its action plan. The NSO goals are guided by input received from our oversight committees that also take into account our resource constraints in effectively addressing this area of national concern. Despite limited resources, the NSO has and will continue to make important contributions to broadening participation in the science, technology, engineering and mathematics (STEM) workforce. Our near-term and long-term goals are given in the following:

#### Near-term goals:

1. Expand recruitment efforts of underrepresented groups through broader advertising venues for NSO job opportunities.

2. Participate in STEM-related society meetings, either national or regional, serving underrepresented communities such as the National Society of Black Physicsts (NSBP), National Society of Hispanic Physicists (NSHP), Society for the Advancement of Chicanos an Native Americans in Science

(SACNAS) and American Indian Science and Engineering Society (AISES).

3. Add a non-tenured scientific staff member from an underrepresented group to the NSO Scientific Personnel Committee.

4. Continue PAARE student participation in the NSO as funded by the Fisk/Vanderbilt PAARE proposal, as well as graduate student participation in the NSO through the Fisk/Vanderbilt Masters-to-PhD Bridge program. Expand this beyond the scientific staff to include our engineering and technical staff as mentors.

5. Identify more mentors among the engineering and technical staff in addition to the scientific staff.

#### Long(er)-term goals:

1. Increase the number of underrepresented students in the NSO REU program, ideally, with a supplement in our REU funding.

2. Expand the RET program effort by targeting teachers at minority-serving institutions, including getting funding for more RETs.

3. Increase the number of underrepresented minorities on the scientific and/or engineering/technical staff during the next 3 to 5 years.

4. Obtain student internships for engineering and computing at the NSO.

We are pleased to say that progress is already being made in these areas. In particular, a Fisk/Vanderbilt Masters-to-PhD Bridge program graduate student has joined the NSO this summer for work on GONG and SOLIS instrumentation, respectively. In addition, we have just hired an African-American who just received his PhD in physics from Howard University to carry out a project supported by a NASA HMI grant.

#### 4.10 Sunspot Solar System Model

The major EPO effort that NSO has under way is the Sunspot Solar System Model. It will be built on a scale of 1:250 million, centering on an 18-foot-diameter model (a radome) of the Sun at the Sunspot Astronomy and Visitor Center and having markers at planet locations along NM 6563, the Sunspot Scenic Byway leading to NSO, and in Cloudcroft and beyond. This is similar to the community solar system model in which scaled, painted models of the planets are placed at correct relative distances outward from a science museum or planetarium. Because NM 6563 is a narrow winding road with no safe turnouts at the correct locations, minimalist signs will be placed at the planet locations and the models will be at the Visitor Center where they can be compared with the size of the Sun. In addition, a four-color, legal-size brochure describing the solar system model will be distributed to area tourism information outlets, and small kiosks featuring parts of the model will be deployed at nearby cities from which the model could be a day trip or overnight trip.

# **5** IMPLEMENTATION

Continuing the effective support that NSO provides to the solar and space physics research community will require an evolution of NSO structure and its mode of operation phased with the construction of the ATST and development of a SOLIS synoptic network. Implementation of NSO's strategic, long-range plan by its staff, in collaboration with the community, provides this evolution and will play a fundamental role in maintaining U.S. preeminence in solar physics. Many of the major milestones in the NSO plan are keyed to obtaining ATST construction funding. As NSO facilities and programs evolve, the fundamental structure of the NSO will also evolve to ensure continued efficient and effective operations. As it undertakes the tasks outlined in its strategic plan, NSO will continue to form strong collaborations to enhance its long-term program and its impact on strengthening the solar physics community.

NSO has developed a long-range strategy that includes a logical and optimal transition from operations and support of the current national solar assets to the era in which several of the primary facilities are supplanted by the ATST. The increased complexity involved in ATST maintenance and operations will require combining the resources currently divided among operations of the Dunn Solar Telescope, McMath-Pierce Solar Telescope, Evans Solar Facility, and the Sunspot and Tucson sites to operate the ATST. Additional operations staff will also be needed. In parallel with ATST construction and development, resources will be required for the ongoing support and operation of a scientifically productive synoptic program, including support of the expansion of the SOLIS VSM to a three-site global network in collaboration with international partners. As the ATST approaches its operational phase, NSO will consolidate its staff at a single headquarters location and relocate staff, or hire locally, to support operations on Maui.

Development of a plan to implement the NSO strategy depends on several assumptions that, if incorrect, may necessitate flexibility. In particular, there are factors that would delay implementation of some facets of the plan. The major assumption in formulating the current plan is that ATST enters the MREFC queue and begins construction in FY2010. A FY2010 start would result in ATST commissioning in approximately 2016-2017. During the construction period, NSO will maintain a structure that minimizes the costs of providing ground-based facilities for the solar community, while freeing assets that permit NSO to begin ramping up for operations on Maui.

The NSO plan assumes the transfer of NSO resources to ATST as they are required to support construction and the ramp-up to operations. The plan provides for the support required for operating NSO major telescopes through 2013, with ramp-down of operations beginning in 2014, and completion when the ATST is operational. It also assumes that GONG can find an increasing amount of external support to maintain operations through 2011 and beyond. NSO will seek economies of scale between GONG and SOLIS operations and combine them into a single synoptic program.

#### 5.1 The Evolution of NSO

NSO's strategic plan consists of implementing three closely integrated areas: science, technology, and educational outreach. NSO assesses its planning in terms of users' needs, technology development, funding scenarios and opportunities, and the intellectual growth of its scientific staff. These four areas are closely linked. For example, the quality of NSO support to the user community relies on implementing the latest technologies, which, in turn, depends on available funds and the initiative and innovation of the scientific staff. The close interaction between staff scientists and the community drives the maximum utilization of existing facilities.

Over the past several years, NSO has restructured its program to free resources for the development of the ATST and ATST technologies, to complete SOLIS, and to upgrade GONG for high-resolution oscillation measurements, extending its ability to measure structures beneath the solar surface and to produce high-cadence, full-disk magnetograms 24 hours a day. Steps taken to free resources have included removing observational and technical support from several NSO facilities including the Evans Solar Facility, the Hilltop Solar Facility, and closing of the Kitt Peak Vacuum Telescope (KPVT). NSO has redirected a portion of its technical and scientific support from ongoing operations at the Dunn Solar Telescope (DST) and McMath-Pierce (McMP) Solar Telescope to ATST related technologies. This migration of personnel will accelerate as the ATST approaches commissioning. NSO has also adopted the philosophy that technology upgrades and new instrumentation at the DST and McMP must not only enhance user support, they also must lead into ATST technologies.

As the NSO roadmap (Figure 2 in the Executive Summary) unfolds, some of the critical-decision milestones include:

- Funding of the ATST construction phase proposal (2010).
- Decision on NSO headquarters location (2011–2012).
- Relocation of SOLIS to a superior synoptic site at a longitude favorable for a future three-site network (2013–2014).
- Commissioning of the ATST (2017).
- Divestment of older facilities (2015–2016).
- Consolidation of the NSO (2015–2016).

At each of these milestones, the value of existing facilities for solar astronomy must be weighed against freeing funds to complete high-priority programs in a timely fashion and against the availability of other non-NSO facilities to the solar community. NSO solicits input from users through the NSO Users' Committee and public meetings, such as the annual AAS/SPD business meeting; from the AURA Solar Observatory Council; and from NSF before making final decisions that broadly affect the community.

Much of NSO support for synoptic studies of the Sun has changed over the past few years. SOLIS data have supplanted the magnetograms, Dopplergrams, and spectral images that were obtained with the KPVT, and the spectroheliograms obtained at the Evans Solar Facility. GONG is now providing continual high-cadence, full-disk longitudinal magnetograms.

NSO's current operations, encompassing two major operational sites, Sacramento Peak in New Mexico and Tucson/Kitt Peak in Arizona, as well as several remote sites for the GONG network, address the needs of a diverse set of users in the solar community. The NSO maintains scientific staff at both of the major sites; this greatly enhances the scientific return from these national facilities. Close proximity of the staff to the telescopes has yielded a wealth of evolving capabilities, thereby maintaining the NSO at the forefront of solar research. Through its adaptive optics, infrared, and advanced instrumentation projects, the current NSO program is highly invested in the future and the implementation of the ATST.

Planning for ATST operations begins with the consideration of existing facilities and capabilities. NSO already has a fully staffed and operating observatory upon whose resources ATST operations will draw. In Sunspot, NM, and Tucson, AZ, NSO maintains the resources for supporting the operations of NSO-wide activities in computing, instrumentation, detector development, and administrative support. NSO currently has no operations at the selected ATST site on Haleakalā on Maui, Hawai'i. For the ATST to be located at this site, NSO will need to establish an infrastructure through either the development of its own facilities on Maui or through the purchase of support services from existing observatories. Most likely, some combination of the two will be required.

NSO and its director will be responsible for the operation of ATST and its integration into existing programs. Support for the operations of ATST will be allocated by the NSO director according to the

annual program plan, which is submitted to the NSF for review and approval. To involve the community in the operation of ATST, NSO proposes to establish an ATST Users' Committee that would be concerned with the telescope and its instrumentation and support infrastructure.

The ATST promises to push solar physics to the forefront of astrophysics by opening the exploration of new physical regimes that underlie solar magnetic activity and providing fundamental observational tests that challenge plasma and magnetic field theory. To provide the new talent needed to fully exploit these new capabilities, NSO wants to work closely with universities to increase the output of young solar physicists. As part of consolidation, NSO will seek a relationship with one or more universities that results in the establishment of faculty positions emphasizing experimental/observational solar physics and including a strong theoretical group.

In establishing a joint program, the target initiative of the NSO, namely, the enhancement of student participation in solar astrophysics and closely related fields (e.g., space physics) through teaching and student involvement in research at the undergraduate and graduate levels and increasing the participation of underrepresented minorities, is a primary criterion.

# 5.1.1 NSO Headquarters (HQ) Development

NSO plans call for consolidation of its Tucson and Sunspot staffs into an efficient organization to operate the ATST, conduct synoptic programs, operate a data reduction and distribution center, carry out forefront research by its staff and community, and to more effectively recruit new students into solar astronomy. Ideally, NSO's new HQ will be located on or near a university that has or is willing to build a strong solar faculty. The current two-site NSO configuration is the most efficient way to operate the multiple telescopes supported by NSO. Several cost studies have shown that consolidation while continuing to operate both sites would increase costs. As operations on the two NSO sites are ramped down, establishing a single HO with a remote operational site on Maui for the ATST will be the best configuration, allowing NSO to combine its scientific staff into a cohesive organization and provide an effective interface with the community. However, it is important to realize that, while providing scientific and organizational benefits, it most likely will increase costs. While Haleakalā is the best site for locating the ATST. Maui is an expensive place to maintain an operational staff—certainly more expensive than Sunspot or Tucson. The current cost-of-living adjustment on Maui is approximately 56% higher than Tucson. As a further illustration of the relative costs, the median home price in Maui as of April 2009 was \$504,000 compared to a median price of \$176,000 in Tucson. Also, an NSO HQ at or near a university could be more expensive in labor and building costs. NSO has attempted to structure its long-range budget estimates to account for these expenses. However, full ATST operations, synoptic operations, running a digital library and data distribution, continuing NSO's leadership in leading-edge instrumentation, and keeping a scientific staff to make this all happen, will require a substantial increment in the fiscal year that the ATST becomes operational. The projected budget, assuming a continued 3% increase from FY2008, and even with the closure or outsourcing of a large fraction of the helioseismology effort, is insufficient.

In anticipation of forming a new NSO HQ, NSO staff members have visited several universities that are either conducting solar research or have expressed interest in doing so. There appears to be strong interest in the university community for developing a relationship with NSO. The next step will be a request for information (RFI) to better understand the general interest and possibilities for relocation. This request will be released as soon as ATST construction funding begins. A solicitation for proposals will be released through AURA, Inc. when the construction and commissioning of the ATST is within five years of completion. A draft request for proposals and evaluation criteria has been developed and will be iterated with AURA and NSF over the next several months.

After the proposals are reviewed and a selection of the best site for NSO HQ is made, NSO will develop a schedule in consultation with the winning university or organization to move staff into the new HQ. The schedule will be tied to several factors. These include the ramping down of NSO

operations at current sites and divestiture or closure of those sites. This, in turn, is tied to construction and completion of the ATST. Other factors include whether the selected institution has an existing building or buildings that can accommodate NSO in a lease arrangement, or if new construction is required. In this latter case, consideration must be given to whether the institution proposes to construct the building and then lease it to NSO, or if the NSF needs to fund the construction.

NSO's transition to the ATST era with staff located on Maui for telescope operations and a new, yet-tobe determined headquarters location will require a one-time infusion of capital. This capital will be required to relocate employees and observatory equipment, and to demolish or modify infrastructure at NSO's current locations. This money is not accounted for in the current budgets or in any additional requests. As of yet, the following amounts are rough estimates, but they will be firmed up as planning for relocation and operations develops.

It is estimated that NSO will relocate approximately 25 to 30 employees to Maui of the ~46 needed to operate the ATST. This is estimated to cost between \$400K and \$500K. About 30 of the 49 employees that will be stationed at headquarters would move from existing sites at a cost of \$350K to \$450K. Additionally, there will be an amount of equipment, tools, vehicles, furniture, and other miscellaneous observatory items that will be shipped to Maui and the headquarters site at an estimated cost of \$500K.

At this time, the disposition of NSO's current sites is unknown. NSO will work towards finding new tenants or owners for the facilities; however, that may not be possible. Therefore, there may be requirements at all of NSO's sites for some amount of demolition or modifications to the infrastructure. The NSF plans to contract with an engineering firm to make a more accurate estimate of these costs. In the meantime, NSO has estimated that cost to range from \$4M to \$6M.

#### 5.1.2 Maui Operations

Ramp-up of operation on Maui needs to occur over a time frame encompassing ATST construction, with a majority of the operational staff in place during the latter part of the commissioning phase. During the early phase of construction, NSO would lease a limited amount of space from the University of Hawai`i to house construction engineers, a safety officer, and other necessary personnel. Funds to support space for the construction staff are included in the construction proposal.

As NSO operational staff are required, NSO will have to lease more space or build an operational building that can house approximately 30-35 personnel consisting of technical and science support for the telescope, administrative and computer support, and some lab and storage space. Another ~11 personnel would spend the majority of their time at the telescope and would not need permanent space at the remote operations center. NSO has discussed lease options with the University of Hawai`i and they have indicated a willingness to lease space, if available, to NSO on a cost-sharing basis. Current monthly leasing prices on Maui are approximately \$5 per square foot, so a leasing cost of between \$900,000 and \$980,000 per year is estimated, based on 15,000–16,000 square feet. Developing a new building would require a delta of approximately \$8M, based on current construction costs on Maui of \$400 per square foot and a building with about 14,000 square feet plus cost of the land. It is possible that a cost-sharing arrangement with the University of Hawai`i could reduce the leasing costs.

NSO personnel that are not paid for by the D&D proposal have participated in the ATST project from its inception. This has included developing, building, and deploying the site survey equipment; conducting the site survey; developing the science case and proposal; developing and demonstrating the effectiveness of solar adaptive optics, which is critical to ATST technology; participating in optical design; and working to develop partnerships. As ATST construction progresses toward completion, key NSO personnel and NSO base funding will be transferred to support the ATST on Maui, including administration, telescope operators and scientists for commissioning, contracting, outreach, establishment of a data center, and other functions as needed. These personnel will include both

transfers from current NSO facilities and new hires on Maui. While some NSO employees would be willing to transfer, others would inevitably seek other positions or retire.

NSO expects that some fraction of personnel needed in the construction phase will transfer into permanent NSO positions for Maui operations. Others will transfer from NSO's current operations, and some will be filled locally on Maui. NSO will endeavor to train native Hawaiians so they can fill technical and scientific jobs. In this respect, NSO plans to work closely with Maui Community College, the Institute for Astronomy, and the Center for Adaptive Optics.

#### 5.2 NSO Staffing

#### 5.2.1 Total Staff

The total NSO staff and how NSO envisions its evolution into the ATST era is shown in Table 5.2-1. The staff is responsible for operating current facilities, providing user support, developing the ATST and SOLIS, and conducting outreach programs. The current project team working on ATST along with current observational and technical staff operating the DST and McMP will migrate into many of the staff positions required to operate the ATST. Additional operational staff will be hired locally on Maui.

Assuming ATST construction begins in FY2010, a migration of key personnel from Sunspot and Tucson to ATST positions—some on Maui and some that would eventually be at the new NSO HQ—would begin in the 2014 time frame and be complete when the ATST is commissioned. Staffing in Table 5.2-1 for FY2016 assumes the additional resources described in Section 5.8 are made available.

A rough estimate is that  $\sim 60\%$  of NSO employees would transfer either to Maui or to NSO HQ, depending on the location of the latter. Many of the remaining employees are either tied to their current location or eligible for retirement.

A major key to implementing the NSO strategic plan is a robust scientific staff. The responsibilities of a scientific staff member are divided among observatory service, scientific research, and educational outreach, but the primary role of the NSO scientific staff is to provide scientific and instrumental innovation. By doing so, the scientific staff provides critical support and leadership to the solar community. Experience clearly confirms the AURA management view that maintaining a strong NSO scientific staff, with active research interests, is required in order to provide U.S. solar physicists with the best solar facilities in the world. NSO and affiliated staff are listed below, along with their primary area of expertise and key observatory responsibilities.

		09	10	11	12	13	14	15	16	17
NSO HQ	Director	2	2	2	2	2	2	2	2	2
	Science Staff	0	0	0	0	0	2	6	14	14
	Technical Staff						2	4	13	13
	Data Center						1	2	11	11
	Science Support						1	2	8	5
	Facilities							0	0	0
	Administrative Support						2	2	4	4
	Total HQ	2	2	2	2	2	10	18	52	49
ATST	Development	18								
	Construction		32	36	35	35	34	21	10	
	Operations					2	10	26	30	46
	ATST	18	32	36	35	37	44	47	40	46
Sunspot	Science Staff	4	4	4	4	3	2	0	0	0
•	DST Operations	3	3	3	3	3	3	2	0	0
	DST Technical Support	3	3	3	3	2	1	1	0	0
	Projects (controls, AO/MCAO, DLSP,									
	etc.)	7	7	7	8	8	2	1	0	0
	Technical Support Hilltop & Evans	1	1	1	0	0	0	0	0	0
	Facilities (maintenance, sewage,									
	roads, project support)	5	5	5	5	5	4	2	0	0
	Scientific Staff Support (secretarial,									
	library, computer)	4	4	4	4	4	3	1	0	0
	Administrative Support (site									
	management, purchasing, etc.)	5	5	5	5	5	4	1	0	0
	Sunspot	32	32	32	32	30	19	8	0	0
Tucson	Science Staff	4	3	3	3	3	3	1	0	0
	McMP Operations	2	2	2	2	2	2	1	0	0
	Projects (NAC, controls)	3.2	4	4	4	4	2	0	0	0
	Facilities (NOAO)	3	3	3	3	3	3	1	0	0
	Science Support (NOAO)	2	2	2	2	2	1	1	0	0
	Administrative Support (0.5 + NOAO)	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
	Tucson	14.7	14.5	14.5	14.5	14.5	11.5	4.5	0	0
SOLIS	Science Staff	2.8	4	4	4	4	4	4	0	0
	Technical	3.3	2	2	2	2	2	2	0	0
	Science Support	3	4	5	5	5	5	5	0	0
	SOLIS	9.1	10	11	11	11	11	11	0	0
GONG	Science Staff	6	5	4	4	3	3	1	0	0
	Telescope Operations	8	8	7	6	5	4	2	0	0
	Data Center Operations	8	7.3	7	6	4	3	2	0	0
	Facilities (NOAO)	3	3	3	2	2	2	1	0	0
	Science Support (NOAO)	2	2	2	1	1	1	1	0	0
	Administrative Support	1.5	1.5	1.5	1.5	1	1	0.5	0	0
	GONG	28.5	26.8	24.5	20.5	16.0	14.0	7.5	0.0	0.0
	Total FTEs	104.0	117.0	120.0	115.0	110.5	109.5	96.0	92.0	95.0

#### TABLE 5.2-1. ESTIMATED PERSONNEL EVOLUTION (FY 2009–2017 TIME FRAME)

#### 5.2.2 Sunspot-Based Scientific Staff

### NSO Staff

- David F. Elmore Development of ground-based spectrographs and filter-based polarimeters; new ATST instrumentation; exploring new spectro-polarimetric capabilities spectral regions, processing techniques, measurement calibration.
- Stephen L. Keil NSO Director; ATST PI; solar activity and variability; astronomical instrumentation; solar convection and magnetism; coronal waves; educational outreach.

# NATIONAL SOLAR OBSERVATORY

- 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.
- Friedrich Wöger Image reconstruction; adaptive optics; two-dimensional spectroscopy; spectropolarimety; ATST Data Scientist.

#### Grant-Supported Staff

- Alexandra Tritschler Solar fine structure; magnetism; Stokes polarimetry; ATST polarimetry.
- Jose Marino Adaptive optics; solar imaging.

#### Air Force Research Laboratory Staff at Sunspot

- Richard C. Altrock Coronal structure and dynamics; solar-cycle studies; Evans Solar Facility coronal photometer.
- K. S. Balasubramaniam Physics of the Sun; solar magnetic fields and activity evolution; eruptive solar activity; high-angular-resolution solar physics; Stokes polarimetry; space weather, spectroscopic and optical instrumentation
- Timothy A. Howard Space weather: its causes and affects; coronal mass ejections.
- Richard R. Radick Astronomical instrumentation; solar and stellar activity.
- S. James Tappin Space weather: Sun-Earth connection; solar energetic particles; coronal mass ejections.

#### Active Emeritus Staff (none of whom resides in Sunspot)

- Donald Neidig Solar activity and flare prediction.
- George Simon Convection.
- Jack Zirker Solar prominences.
- Jacques M. Beckers Solar/stellar physics; astronomical instrumentation and techniques; atmospheric seeing; large telescopes.
- Raymond Smartt Solar eclipses and coronal structure.

#### 5.2.2 Tucson-Based Scientific Staff

#### NSO Staff

- Olga Burtseva Local helioseismology; solar activity.
- Mark S. Giampapa NSO Deputy Director; stellar dynamos and magnetic activity; asteroseismology; Ch., Scientific Personnel Committee; Ch., NSO/KP Telescope Allocation Committee; SOLIS PI; NSO Diversity Advocate.
- Irene E. González Hernández Local helioseismology (seismic imaging and ring-diagram analysis).
- John W. Harvey Solar magnetic and velocity fields; helioseismology; instrumentation; SOLIS Project Scientist.
- SOLIS Data Scientist [Open] Solar MHD; polarimetry; space weather.
- Frank Hill Helioseismology; asteroseismology; fluid dynamics of the solar convection zone; the solar activity cycle; virtual observatories; GONG Program Scientist.
- Rachel Howe Helioseismology; the solar activity cycle; peak fitting.
- Shukur Kholikov Helioseismology; data analysis techniques; time-distance methods.
- John W. Leibacher Helioseismology; atmospheric dynamics; asteroseismology.
- SOLIS Staff Scientist [Open] Solar MHD; observational constraints for solar dynamo theory; instrumentation; SOLIS Program Scientist.

• Matthew J. Penn – Spectropolarimetry; near-IR instrumentation (ATST); solar atmosphere; solar oscillations; McMath-Pierce Solar Telescope Scientist; Co-Site Director, NSO REU/RET Program.

#### Grant-Supported Scientific Staff

- Michael Dulick Molecular spectroscopy; high-resolution Fourier transform spectrometry; study of molecules of astrophysical interest.
- John A. Eddy History of past solar behavior; influence of solar activity on terrestrial climate; interdisciplinary study of the interactive Sun-Earth system.
- Kiran Jain Helioseismology; solar cycle variation; ring-diagram analysis; sub-surface flows; irradiance reconstruction; empirical modeling; Sun-Earth connection.
- Brian Harker-Lundberg Solar activity; magnetism, polarimetry.
- Rudolph W. Komm Helioseismology; dynamics of the convection zone; solar activity and variability.
- Gordon J. D. Petrie Solar magnetic and velocity fields.
- William H. Sherry Formation and evolution of low-mass stars; evolution of magnetic activity of low-mass stars; extra solar planets.
- 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 magnetic fields; solar rotation; solar spectrum variability with time (Sun-as-a-Star); IR spectrum atlases.
- Harrison P. Jones Solar magnetism and activity; solar irradiance variation; solar feature identification.

#### 5.2.3 Future Science Staffing

NSO currently has 17 scientists on its permanent staff including the director. Of these, eight are tenured, one is tenure-track, and the remaining eight are non-tenured scientific staff. In addition, there are 11 NSO scientists supported on externally-funded projects, grants, contracts, and other soft money.

Table 5.2-2 shows the current estimate for science support of the various facilities. The scientists divide their time among various projects, user support, and research. Therefore, the amount of support they provide to facilities and the users of NSO facilities is approximate. Research time often involves collaborations that support outside users in reducing and analyzing data from a particular facility, and time on projects is generally aimed at enhancing the capabilities at one or more of the facilities. The table attempts to assign time charged to projects, telescope allocation activities, and various user support to the appropriate facility. The remaining scientific full-time equivalents (FTEs) are involved in modeling, educational outreach, and administrative functions.

TABLE 5.2-2. Scientific FTEs							
Facility	In-House	Soft \$ FTEs	Total				
R. B. Dunn Solar Telescope	1.60	0.50	2.10				
McMath-Pierce Solar Telescope	1.30	0.00	1.30				
McMath-Pierce FTS	0.00	1.00	1.00				
SOLIS	1.80	2.00	3.80				
GONG	6.90	3.00	9.90				
ATST	2.30	1.50	3.80				
Virtual Solar Observatory	0.20	0	0.20				
TOTALS	14.10	8.00	22.10				

The implementation of new capabilities such as adaptive optics, diffraction-limited polarimetry, largeformat IR cameras, and the high-resolution GONG, as well as the completion of new facilities such as SOLIS, SOLIS Global Network, and ATST, substantially enhance the quality and quantity of NSO data and observational capabilities. Taking advantage of the new facilities and capabilities will require increased scientific efforts, continued development of new instrumentation, enhancement of the NSO Digital Library, and the development of and linkage to the Virtual Solar Observatory. Given the recommendations of the Senior Review, this will require increased non-NSF support. The Air Force Research Laboratory has already stated their desire to maintain a solar staff collocated with NSO. GONG is actively seeking outside support.

A dedicated ATST scientific staff is required to optimize ATST scientific capabilities. Early on, scientists will participate in commissioning, testing, and acceptance. After final commissioning, the staff will be ready to provide expertise in all areas of ATST science operations. Particular areas of needed expertise for science and engineering include conventional and multi-conjugate adaptive optics; active optics; polarimetry in the visible, near-IR, and thermal IR, using both spectrographs and filters; image restoration through techniques such as phase diversity and speckle; and coronal observing techniques and analysis. Expertise in various areas where the ATST will provide breakthrough data, such as plasma-field interactions, magneto-convection, atmospheric heating, and origins of solar activity will be required. Because much of the ATST data will involve sophisticated processing and will be archived for public access, dedicated data scientists are required. Science staffing will come from members of the current NSO staff and from new ATST positions. Transferring the current in-house science positions that support the DST, McMP, and ATST to ATST operations provides approximately five FTEs. As part of the ATST construction proposal, NSO estimates that a minimum of eight, and preferably 10–11, scientific FTEs will be needed to support ATST operations and data processing. A vigorous ATST fellowship program could provide the additional manpower to scientifically support the ATST.

Once ATST construction funding is secured, NSO will finalize a staffing plan that will accommodate the transition from operating its current facilities to those needed in the ATST era. As NSO begins operating SOLIS, gains more experience with operating the high-resolution GONG, determines the level of support needed to sustain participation and leadership in the VSO, and refines the operational plan for ATST that was part of the ATST construction proposal, the required staffing levels can be accurately determined. Table 5.2-3 gives a current estimate of required science staffing that assumes a presence in helioseismology, but with most of the positions externally funded. Based on current experience, it also assumes that there will be partner- or grant-funded FTEs working with ATST and synoptic data.

TABLE 5.2-3. Scientific FTEs in the ATST Era							
Facility In-House Soft \$ FTEs Total							
ATST	13	6	19				
Synoptic	6	5	11				
TOTALS	19	11	30				

#### 5.3 Support for Users

#### 5.3.1 User Interaction and Feedback

NSO continues to serve a wide range of users from several disciplines with a remarkably broad range of pure and applied scientific research interests. From the basic structure of solar magnetic fields, to the forecasting of space weather, to the interior structure of the Sun, to the chemistry of the Earth's atmosphere—NSO provides critical observations and uses partnerships to leverage its resources. The NSO Users' Committee reflects these broad interests, from individual users that form the core of the

NSO scientific mission to agencies. They rely on solar data in fulfilling their mission. The committee members, their affiliations, and primary interests are listed in Table 5.3-1. The Users' Committee meets formally twice per year and informally as needed.

	Table 5.3-1. NSO Users' Committee							
Name	Institution	Primary Interest						
K. D. Leka, Ch.	NorthWest Research Associates	Solar Polarimetry						
Sarbani Basu	Yale University	Helioseismology						
Debi Prasad Choudhary	California State Univ., Northridge	Magnetic Fields; Solar Activity						
Craig DeForest	Southwest Research Institute	High-Resolution Imaging; Convection						
Donald E. Jennings	NASA Goddard Space Flight Ctr.	Thermal Infrared						
Richard R. Radick	Air Force Research Laboratory	Solar-Stellar; Space Weather						
Douglas M. Rabin	NASA Goddard Space Flight Ctr.	Polarimetry; Instrumentation; Mission Support						
Alysha Reinard	NOAA Space Environment Ctr.	Space Weather						
Edward J. Seykora	East Carolina University	Imaging; Atmospheric Properties						
Steven Tomczyk	High Altitude Observatory	Coronal Properties						
Thomas G. Barnes	NSF (ex-officio)	Program Director, NSO and NOAO						

NSO disseminates information to the community through several channels. These include the *NOAO/NSO Newsletter*, an up-to-date Web site, displays at AAS and AGU meetings, *SolarNews* (an online newsletter of the American Astronomical Society/Solar Physics Division (AAS/SPD), and through discussions and presentations at meetings of the SPD, AAS, and American Geophysical Union. NSO staff participate in and provide ground-based support for space missions such as TRACE, SOHO, Hinode, and in the SDO mission to be launched in 2009. NSO gives priority to principal investigators who apply for time and have collaborative observations with these missions.

NSO staff members actively participate in the governance and prize committees of the AAS and AAS/SPD, participated in the International Heliosphysical Year and are participating in the International Year of Astronomy, and serve on panels to review international solar facilities and programs.

NSO's users receive funding from diverse sources, including three NSF divisions (Astronomical Sciences, Atmospheric Sciences, and Chemistry), universities, NASA, and the U.S. Air Force. NSO, therefore, maintains contact with many agencies and makes presentations to, and is often represented on, advisory groups such as the NAS Management Operations Working Group for Solar Physics and NRC Committees on Solar and Space Physics and Solar-Terrestrial Research.

#### 5.3.2 Telescope Allocations and Usage

NSO telescopes are scheduled quarterly. To provide flexibility, responsiveness to users, and coordination with spacecraft and rocket experiments, site-specific but coordinated Telescope Time Allocation Committees (TACs) schedule time for NSO/Kitt Peak and NSO/Sacramento Peak. As the total number of hours scheduled is support-limited on most of the telescopes, typically, there is an adjustment or negotiation process (impractical in a nighttime context) for accepted proposals that results in a match between the days available and the days scheduled.

Most solar observations require coordinated data from several sources (space and ground), involve multi-instrument set-ups (e.g., simultaneous polarimetric, Doppler, and intensity imaging in several wavelengths using both spectrographs and narrow-band filters), and the target is often the evolution of activity on the Sun that covers scales from milliseconds to weeks. Thus, NSO tends to allocate telescope time in blocks of two or more weeks. Another significant difference is the greater importance of daily or periodic observations in solar and solar-stellar research. Several of NSO's telescopes,

including GONG, SOLIS, and the Evans Solar Facility, are primarily devoted to long-term, stable observations over the solar cycle. Such observations are critical to solar physics research programs as well as for the operational needs of NSO's partners, including the U.S. Air Force, NASA, and NOAA. Data from these programs are archived in the NSO Digital Library and are freely available over the Web.

Coordinated ground and space observations play an essential role in solar-terrestrial research. With the operation of the SOHO spacecraft and the TRACE missions, and now the Hinode spacecraft, NSO has placed priority on its non-synoptic observing time to support observers participating in these missions. The appropriate TAC, however, reviews all proposals based on scientific merit. Sub arcsecond seeing or solar activity is often an essential requirement for some types of solar observations. Therefore, NSO scheduling makes a provision for "bumping" proposals that may temporarily displace ongoing programs when there are exceptional conditions. Recently, a queue-based program was initiated at the Dunn Solar Telescope to enhance coordination with space missions and take advantage of good seeing opportunities.

During FY2008, NSO conducted 82 unique observing programs, of which 17 were thesis programs involving 23 graduate students. A total of 82 visiting telescope users represented 15 U.S. and 8 foreign academic institutions, and 14 U.S. and 5 foreign non-academic institutions. Table 5.3-2 lists the users by category.

Table 5.3-2. NSO Observing Programs by Typ (US and Foreign)	De	
12 Months Ended 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.

Table 5.3-2, however, represents only a small fraction of the users of NSO facilities and data during FY2008. A significant number of data files are regularly transferred from the FTP sites at NSO/Tucson and NSO/Sunspot. Figure 5.3-1shows the number of gigabyte of data that were downloaded from NSO FTP and WWW sites during FY2008. Much of the data are used to select targets for and to supplement spacecraft data, to help interpret data sets obtained from other ground-based observatories, to aid in space weather prediction, for climatology studies, as well as for individual research. NSO requests that users credit NSF and NSO for any use of the data in publications. Systematic literature searches reveal that NSO is informed of publications using NSO data somewhat less than 50% of the time.

#### 5.3.3 Support at the Telescopes

Solar observations often involve very complex set-ups and operational needs. The NSO provides trained observing personnel to help the users successfully complete their set-up and to operate the telescope. NSO provides real-time quick-look capabilities to ensure data collection is proceeding as planned and limited support for preliminary data reduction at the site. Host scientists are appointed as needed for visiting observers and often become highly involved in ensuring a successful observing program.

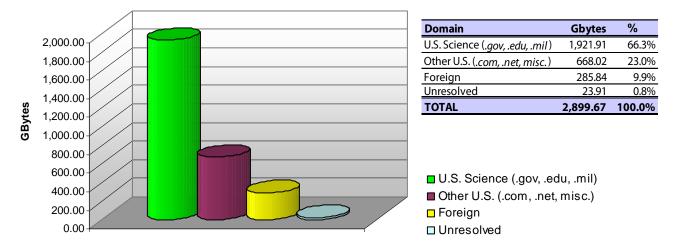


Figure 5.3-1. Amount of data downloaded from NSO FTP and WWW sites during FY2008.

#### 5.4 Community Partnerships and NSO Leadership Role

Through its operation of the majority of U.S. 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; 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 5.4-1 lists several ongoing joint projects and development efforts.

Table 5.4-1. 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 & Optical Regions (SPINOR)	HAO					
Rapid Oscillations in the Solar Atmosphere (ROSA) Instrument	Queen's University, Belfast					
Narrowband Filters and Polarimeters	Arcetri Observatory, U. Alabama, Kiepenheuer Inst.					
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					

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. A series of workshops on ATST science operations will begin this year to provide guidance for developing a sound plan for exploiting the full potential of the ATST.

#### 5.5 **Operational Partnerships**

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 5.5-1 is a summary of the current partnerships that provide operational support.

NSO's long-standing relationship with the U.S. Air Force space science group will continue into the ATST era. The Air Force Office of Scientific Research (AFOSR) has indicated 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. It has had discussions with many organizations and has 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 U.S. 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. NSO has formed a close working relationship with the University of Hawai'i for ATST operations and expects other partners to have some involvement in operations as well.

	Table 5.5-1. 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 (0.5 FTE)</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

GONG is actively seeking operational partnerships with members of the space environment community, including international partnerships for site operations and data processing.

#### 5.6 NSO Organization

NSO is currently managed in four major functional units, NSO/Sacramento Peak (NSO/SP), NSO/Tucson (NSO/T), NSO/GONG, and NSO/ATST. NSO conducts operations and projects with a combination of positions funded from its base NSF support, positions funded from projects and grants, and positions funded by its collocated partner organizations. In addition, NSO shares support personnel (e.g., shops, facilities maintenance, computing, and administration) with NOAO in Tucson and on Kitt Peak. Funds for these shared services, except for mountain support of NSO/Kitt Peak facilities by KPNO, are in the NSO budget and are shown on the NSO spending plan. However, these funds are currently committed to NOAO for shared services, which results in considerable cost savings. The NSO Director's office consists of two employees, the Director and an administrative manager, and receives financial and budget support from the NSO/SP facilities support and business manager. The Director currently resides at NSO/SP. The NSO Deputy Director, Mark Giampapa, serves as site director for Tucson and oversees operations there as well as serving as the SOLIS PI. His funding is included in the Tucson base budget. In addition, the NSO Director shares support personnel with NOAO for accounting, human resources, graphics, and educational outreach. Funds for the NOAO shared services are in the NSO budget and are shown in the NSO spending plan. Figure 5.6-1 shows the current, high-level organizational chart.

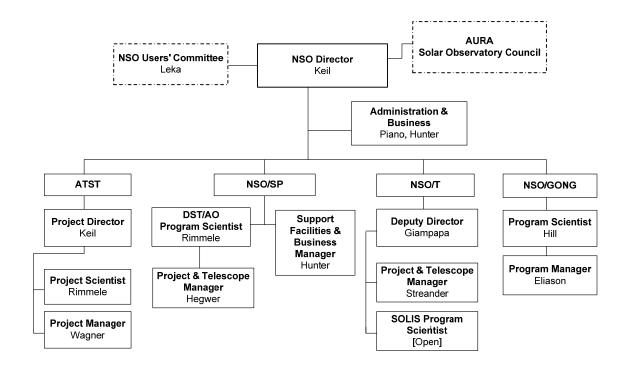


Figure 5.6-1. NSO high-level organizational chart.

NSO/SP primarily operates the Dunn Solar Telescope on Sacramento Peak as well as offices, computing, instrument development, and housing facilities for visitors and the resident scientific and technical staff. The DST program scientist, Thomas Rimmele, leads and oversees telescope operations and instrument projects and also serves as ATST project scientist. The DST project and telescope manager, Steve Hegwer, reports directly to him. Major projects at NSO/SP include development of adaptive optics and multi-conjugate adaptive optics, development of the DLSP and SPINOR, upgrading the data and control systems at the DST, and work on the ATST design. In addition, NSO/SP conducts experiments and smaller projects to improve near-IR cameras and spectroscopy, narrowband imaging in the visible and IR, and vector polarimetry techniques that can take advantage of high-resolution

facilities. Some support is also provided to Air Force- and HAO-funded programs at the Evans Solar Facility and Hilltop Facility, respectively. NSO/SP also has a facilities support and business manager, Rex Hunter, who is responsible for buildings and grounds, administration and business functions. The DST program scientist and the support facilities and business manager both report directly to the NSO Director.

NSO/T operates the McMath-Pierce Solar Telescope and SOLIS on Kitt Peak, offices in Tucson, and conducts projects at the Tucson facilities. The Deputy Director oversees Tucson programs and operations with Priscilla Piano as administrative manager. McMath-Pierce operations and projects are led by a telescope scientist, Matt Penn, who reports to the Deputy Director. A project and telescope manager, Kim Streander, and the SOLIS program scientist and SOLIS data scientist also report to the Deputy Director. NSO shares support personnel with Kitt Peak National Observatory (KPNO) on Kitt Peak and with the other NOAO divisions in Tucson. Major projects at NSO/T include completing SOLIS instrumentation, large-format IR camera development, and work on the ATST design. NSO/T also conducts experiments and minor projects to improve Stokes polarimetry techniques, imaging at the McMath-Pierce Solar Telescope, solar-stellar observation techniques, and speckle imaging techniques.

NSO/GONG, located in Tucson, operates and maintains the GONG network of six telescopes and collects, processes and provides data to users. GONG is led by a program scientist, Frank Hill. A program manager, Pat Eliason, is responsible for daily GONG operations and reports directly to the program scientist.

NSO/ATST is funded primarily by the ATST D&D proposal and planned funding to bridge the period leading up to the start of construction. The NSO Director currently serves as ATST Director. A project manager, Jeremy Wagner, and project scientist, Thomas Rimmele, report to the Director. The ATST staff reside in Tucson and at Sacramento Peak, allowing the team to interact with NSO staff and take advantage of lessons learned from current telescope operations and projects at both sites.

As NSO prepares for operations in the ATST era, the management structure will evolve as needed to provide the most efficient and cost effective structure. Once ATST construction funding is secured, NSO will begin reorganizing to support ATST operations. This will lead to the ramp down of current operations and divestments of current facilities as ATST reaches completion. In the ATST era, the NSO organizational structure will evolve to effectively support ATST, the synoptic program, an instrument program, and a data processing and distribution center. The exact structure will depend on partner contributions to ATST and synoptic programs.

# 5.7 Spending Plan

The NSO spending plan is summarized in Table 5.7-1 and detailed in Table 5.7-2. The plan covers a five-year period beginning in FY2009. The budget is summarized by functional units in Table 5.7-1 and shown in detail with each functional unit broken into work areas in Table 5.7-2.

The FY2009 spending plan is a revision of the FY2009 Annual Program Plan budget, based on the current allocation from NSF, the actual funds received from partners. The current FY2009 budget of \$10M is \$30K more than flat funding from FY2008. Meeting the FY2009 budget required expenditure of \$303K from the director's reserve (carry forward and indirects) to meet payroll and the freezing of several unfilled positions. The FY2009 budget fell approximately \$930K short of what was needed to fully conduct the NSO strategic program. In addition to the \$1.8M for ATST, NSO received another \$1.4M which was needed to continue the EIS process and prepare for the ATST Final Design Review.

Table 5.7-1. Five-Year Spending Summary									
	(Dollars in	Thousands)							
_	FY2009	FY2010	FY2011	FY2012	FY2013				
Director's Office	414	431	528	543	572				
HQ Operations	-	-	-	-	-				
Tucson Operations	1,306	1,489	1,610	1,584	1,495				
Sacramento Peak Operations	1,621	2,028	2,203	2,184	2,123				
ATST In-House Efforts	747	754	3,753	3,839	4,123				
GONG	2,526	2,654	1,496	1,464	1,521				
SOLIS	370	505	1,450	1,645	1,738				
Base Budget Program Totals	6,984	7,861	11,040	11,258	11,572				
General NOAO Support	961	960	1,000	1,030	1,087				
AURA Management Fee	255	279	300	422	432				
Base NSO Program	8,200	9,100	12,340	12,710	13,091				
ATST									
ATST D&D	1,800	-							
ATST Construction Proposal	TBD	TBD	TBD	TBD	TBD				
Total ATST Development	1,800	-	-	-	-				
Base NSO + ATST	10,000	9,100	12,340	12,710	13,091				

#### NATIONAL SOLAR OBSERVATORY

Development of the FY2010 plan was based on current guidance from NSF and the President's budget submission. The additional \$900K over the FY2009 budget partially covers the shortfall from last year, but further erodes the NSO base due to inflation. The FY2010 budget falls \$2.8M below the projected cooperative agreement amount. This delays NSO's ramp up of ATST and SOLIS operations. The FY2011 budget is based on the amount submitted as part of the cooperative agreement between AURA and NSF. The FY2012 – FY2013 budgets contains inflationary increases from FY2011 and reflect the evolution of ongoing programs towards eventual ATST operations. They were developed assuming continued transfer of in-house effort to the ramp-up of ATST, placing scientific emphasis on the high-resolution program at the DST, the IR program at the McMP, a ramp-up in SOLIS operations, taking advantage of synergisms between SOLIS and GONG data handling, and participation in the development of the VSO. The budgets also assume that NSO will continue to receive support from its partner organizations (shown as revenue in Table 5.7-2).

Although we allocate the base budget through functional areas, the actual budget is developed from the tasks in our work breakdown structure. Table 5.7-2 shows each of the functional areas broken down by work areas. Funding for the support received from NOAO is listed separately. Approximately 17% of the NOAO support goes to computer support, 33% to facilities in Tucson, 11% to educational outreach, and 39% to business services and human resources support. While the NSO base budget shown in Tables 5.6-1 and 5.7-2 allow NSO to conduct a robust program in solar physics, the fact that it has remained flat or slightly decreasing over the past several years has affected NSO's ability to fully fund ongoing programs that support the solar community while contributing to the ATST development effort.

#### Notes for Table 5.7-2:

(1) – Includes NSO personnel and direct-billed utilities only. Mountain support for maintenance, roads, etc. is included in the KPNO budget and not accounted for here. Estimates of this support range from \$200K-\$500K, depending on how mountain support is divided among the various telescopes and operations.

(2) – The educational outreach amounts contain funds from the REU and RET programs, and the NSO Visitor Center, which provides both public and educational outreach. The Visitor Center is basically self-sustaining; NSO uses the conference center, provides maintenance and budgets, and a small amount for contingencies. REU/RET funds are provided separately from the NSO base budget and are included in the revenue lines.

(3) – Revenue in Tucson includes \$62K from the REU/RET program in FY2009. Sac Peak revenue includes meal revenue [\$17K], housing revenue from rent [\$104K], funds received from the Air Force for operations [\$400K], earnings at the Visitor Center gift shop [\$50K], and funds from the REU/RET program [\$62K]. Funds received from the Air Force are variable due to DoD budget variations and are negotiated annually.

(4) – These numbers include NSO technical and scientific staff devoting time to the ATST science definition, the development of ATST technologies, and instruments. Its growth accounts for the reduction in scientific staff funding in the existing operating units as staff members devote increasing amounts of time to ATST.

# NATIONAL SOLAR OBSERVATORY

# Table 5.7-2. Detailed Five-Year Spending Plan (Dollars in Thousands)

	FY20	09	FY201	0	FY201	1	FY201	2	FY201	3
Director's Office	475				500		F 40			
Director's Office	475		455		528		543		572	
HQ Operations	(64)		(24)							
Programmed Indirects	(61)	· · · · -	(24)	424 -	-	500 <b>—</b>	-	E 4 2 -	-	570
Total Director's Office		414		431		528		543		572
Tucson Operations										
Scientific Staff	431		486		510		475		453	
Software Support	216		229		241		248		262	
Instrument Development NOAO/ETS Support	481 -		512 -		586 -		578 -		510 -	
Telescope Operations <sup>(1)</sup>	174		184		193		199		210	
Utilities on Kitt Peak <sup>(1)</sup>	74		78		81		84		60	
Educational Outreach <sup>(2)</sup>	62		62		62		62		62	
Revenue	(131)		(62)		(62)		(62)		(62)	
Total NSF Tucson	_	1,306		1,489		1,610		1,584		1,495
Sacramento Peak Operations										
Scientific Staff	337		388		408		370		291	
Scientific Support/Computing	225		263		277		287		253	
Instrument Development/Maintenance	517		665		749		721		685	
Telescope Operations	229		242		254		262		277	
Facilities	666		682		716		738		769	
Administrative Support	275		266		280		288		304	
Educational Outreach <sup>(2)</sup>	154		154		156		158		161	
Revenue <sup>(3)</sup>	(782)		(633)		(638)		(640)		(617)	
Total NSF SP		1,621	· · ·	2,028	<u> </u>	2,203	<u> </u>	2,184	<u> </u>	2,123
ATST In-House Efforts										
ATST Fellows	50		50		450		450		406	
ATST Maui Operations					450		549		635	
ATST Science Support	294		286		504		500		569	
Technology Development <sup>(4)</sup>	453		468		2,348		2,340		2,514	
Revenue	(50)		(50)		-				-	
Total ATST	. /	747		754		3,753		3,839		4,123
GONG										
Scientific Staff	836		922		968		997		1,006	
DMAC Operations	676		708		743		765		807	
Telescope Operations	855		955		1,003		933		976	
Administrative Support	182		202		212		218		231	
Revenue	(24)		(132)		(1,430)		(1,450)		(1,500)	
Total NSF GONG		2,526	<u> </u>	2,654	<u> </u>	1,496	<u> </u>	1,464		1,521
SOLIS										
Scientific Staff	95		223		700		771		823	
Operations	275		282		750		874		915	
Total SOLIS		370		505		1,450		1,645		1,738
NOAO Business/EO Support		961		960		1,000		1,030		1,087
AURA Management Fee		255		279		300		422		432
Total Base Program	-	8,200	-	9,100	-	12,340	-	12,710	-	13,091
ATST										
AST ATST D&D Proposal										
ATM ATST D&D Proposal										
ATST Bridge Funding		1,800		-						
ATST Construction Proposal (MREFC)		TBD		TBD		TBD		TBD		TBD
Total ATST	-	1,800	-	-	-	-	-	-	-	-
		10 000		0 100		12 3/0		12 710		13 001
Total NSO+ATST		10,000		9,100		12,340		12,710		13,091

#### 5.7.1 Final FY2009 Budget

The detailed breakdown of the NSO budget for FY2009 by work area and functional unit is shown in Table 5.7-3. This is a revision of the budget submitted in the Program Plan for FY2009 and reflects the latest guidance from NSF. The upper portion of the table shows the projected total NSO funding, including the ATST D&D effort, REU/RET support, revenue from meal service and housing, and partner funding, while the bottom portion removes revenue outside NSF/AST, showing the total NSF/AST funding for the combined NSO-ATST program. The revenue line labeled Programmed Indirects and Miscellaneous Revenues are funds from the director's reserve. The director's reserve consists mainly of funds from temporarily unfilled positions and indirects earned on externally funded projects. The portion of NOAO support going into outreach is shown in the Educational & Public Outreach line under the Director's Office.

	Discotorio						Tatal
	Director's	-					Total
	Office	Sunspot	Tucson	GONG	ATST	SOLIS	Budget
Director's Office	475				-		475
Scientific Staff		337	431	836	344	95	2,043
Scientific Support/Computing		225	216	676			1,117
Instrument Development/Maintenance		517	481	257	453		1,708
Telescope Operations		229	248	599		275	1,35 <sup>.</sup>
Facilities		666					66
Administrative Support		275		182			457
Educational & Public Outreach	109	154	62				324
NOAO Business Support	45	173	365	269	148		1,00
ATST					1,618		1,618
AURA Management Fee	255				34		29
Program Total	884	2,576	1,803	2,819	2,597	370	11,04
Revenues							
Programmed Indirects & Revenues	(61)	(149)	(69)	(24)			(30:
Housing Revenue		(104)					(104
Meal Revenue		(17)					(1)
NSF REU/RET Funding		(62)	(62)				(124
Air Force Support		(400)					(400
ATST Fellowship Support					(50)		(50
Visitor Center Revenue		(50)					(50
NSF Funds - ATST	823	1,794	1,672	2,795	2,547	370	10,000

Table 5.7-3.	FY2009 Budget	Allocations
(D	ollars in Thousand	's)

In the column labeled ATST, the \$344K shown for scientific staff and the \$453K shown for instrument development are NSO in-house contributions to the ATST project and are not paid out of the ATST D&D funding. They are salary and non-payroll transfers from the NSO operations budget and represent ongoing programs that will lead to ATST operations. The table shows revenue applied directly to the operations budget. It does not include soft money contracts and grants which vary from year to year.

Figure 5.7-1 shows the percentage breakdown for the total NSO program in FY2009. ATST is the dominant NSO program. Percentages shown for telescope operations, instrument development and maintenance, scientific support, and about 50% of the science staff and administration time provide direct support for users of the NSO facilities.

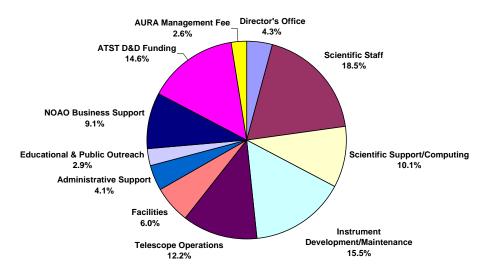


Figure 5.7-1. Budget breakdown by work areas in FY2009.

#### 5.7.2 FY2010 Budget

Table 5.7-4 shows NSO's planned FY 2010 allocations, conforming to the President's proposed budget of \$9,100K. It assumes no ATST D&D funding with the ATST project personnel moving on to construction funding. If NSO does not receive permission to spend construction funding at the beginning of FY2010, additional bridge funding will be needed to maintain the ATST project team.

The \$9,100K for NSO base operations is about \$2880K less that the \$11,980K planned for NSO operations in the cooperative agreement. The \$9,100K budget reflects the fact that NSO will not retain the majority of the ATST D&D funding wedge, which was intended in the cooperative agreement to be used for ramping up ATST operations, pursuing technologies that would enhance current science capabilities and ATST capabilities after it is commission (such as charge caching cameras and multi-conjugate adaptive optics), ramp up of the NSO Digital Library into a data center that can handle the increased data loads from SOLIS and ATST, and ramp up of SOLIS operations.

		ars in Thou	sanus)				
	Director's						Total
	Office	Sunspot	Tucson	GONG	ATST	SOLIS	Budget
Director's Office	455				-		455
Scientific Staff		388	486	922	336	223	2,355
Scientific Support/Computing		263	229	708			1,199
Instrument Development/Maintenance		665	512	-	468		1,645
Telescope Operations		242	184	955		282	1,663
Facilities		682					682
Administrative Support		266		202			468
Educational & Public Outreach	108	154	62				324
NOAO Business Support	16	144	462	307	-		930
ATST					-		-
AURA Management Fee	279				-		279
Program Total	859	2,805	1,935	3,094	804	505	10,001
Revenues							
Programmed Indirects & Revenues	(24)			(132)			(156)
Housing Revenue		(104)					(104)
Meal Revenue		(17)					(17)
NSF REU/RET Funding		(62)	(62)				(124)
Air Force Support		(400)					(400)
ATST Fellowship Support			0		(50)		(50)
Visitor Center Revenue		(50)			• •		(50)
NSF Funds - ATST	835	2,172	1,873	2,962	754	505	9,100

Table 5.7-4.	FY2010	Budget	Allocations
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(Dollars in Thousands)

#### 5.7.3 Strategic Needs and Infrastructure Improvements

NSO requests that its operations budget be increased by \$900K in FY2010 from the proposed amount, bringing it from \$9,100K to \$10,000K. At this level, NSO will be able to fill critical scientific positions for SOLIS that were frozen because of level funding in FY2009. NSO will also be able to fill a critical engineering position that provided both MCAO and DST support which was also frozen. In addition, NSO can begin to ramp up SOLIS scientific and operational support and begin building up scientific, postdoctoral, and operational support for ATST. It is important to begin this build-up for ATST as early as possible to ensure that NSO has the expertise to operate the ATST and handle the large volumes of ATST data that will be generated and made scientifically useful to the solar community.

With the ARRA funding that NSO will receive in FY2009, we will begin to address some of the longterm infrastructure issues that have long been deferred. These are needed to maintain safe operations and to make the facilities attractive to institutions that would be interested in assuming responsibility when those facilities are divested by NSO. Divesting the current facilities will be more cost effective than removing them. Some of the upgrades through ARRA funding include addressing data handling capabilities at the telescopes, upgrading obsolete electronics and control systems, addressing immediate safety issues such as the DST elevator and the McMP glycol system, and repairing the deteriorating road at Sac Peak.

In FY2010 through FY2016, we request an additional \$800K of infrastructure funds per year to upgrade our digital library into a data center that can handle the large data sets that will be produced by SOLIS once the final instrument is online, and prepare to handle the even larger data sets from ATST. With the advent of service mode (queue) observing at the DST and the addition of new high-speed, large-format CCD cameras, NSO would like to begin reducing and storing DST observing runs in an archive accessible via the Virtual Solar Observatory. Current storage and computing power is inadequate for handling these loads. Experience gained with the reduction and archiving of the SOLIS and DST data sets will carry over directly into ATST operations and give NSO the capability to reduce and distribute ATST data beginning with first light.

# 5.7.4 FY2011 – FY2013 Budgets

Tables 5.7-5 through 5.7-7 show preliminary detailed budgets for the out years based on the cooperative agreement proposal. They reflect cost for operation of current facilities and a steady shifting of scientific and project efforts to the ATST. The FY2011 budget continues support of current facilities that service the solar community. It ramps up ATST in-house support, SOLIS operational and scientific support, and allows for completion of the NAC project and continued MCAO development, and includes funds to begin exploring charge caching camera technology. If ATST construction does not start in FY2010, additional bridge funds would be needed to continue ATST design completion and risk reductions.

The FY2012 and FY2013 allocations assume inflationary increases in the base of 3%, and funding of the ATST construction through the MREFC. Additional NSO operational resources are transferred into ATST and SOLIS support.

#### Table 5.7-5. FY2011 Preliminary Budget

	(Dolla	rs in Thous	ands)				
	Director's						Total
	Office	Sunspot	Tucson	GONG	ATST	SOLIS	Budget
Director's Office	528				350		878
Scientific Staff		408	510	968	954	700	3,540
Scientific Support/Computing		277	241	743			1,261
Instrument Development/Maintenance		749	586	-	2,348		3,683
Telescope Operations		254	193	1,003		750	2,200
Facilities		716					716
Administrative Support		280		212			492
Educational & Public Outreach	113	156	62				331
NOAO Business Support	17	150	481	320			968
ATST					100		100
AURA Management Fee	300				-		300
Program Total	958	2,991	2,072	3,246	3,753	1,450	14,470
Revenues							
Programmed Indirects & Revenues				(1,430)			(1,430)
Housing Revenue		(100)					(100)
Meal Revenue		(16)					(16)
NSF REU/RET Funding		(62)	(62)				(124)
Air Force Support		(410)					(410)
Visitor Center Revenue		(50)					(50)
NSF Funds - ATST	958	2,353	2,010	1,816	3,753	1,450	12,340

#### Table 5.7-6. FY2012 Preliminary Budget

(Dollars in Thousands)

	Director's						Total
	Office	Sunspot	Tucson	GONG	ATST	SOLIS	Budget
Director's Office	543				359		902
Scientific Staff		370	475	997	950	771	3,563
Scientific Support/Computing		287	248	765			1,300
Instrument Development/Maintenance		721	578	-	2,340		3,639
Telescope Operations		262	199	933		874	2,267
Facilities		738					738
Administrative Support		288		218			506
Educational & Public Outreach	116	158	62				337
NOAO Business Support	18	155	496	330			997
ATST					190		190
AURA Management Fee	422				-		422
Program Total	1,098	2,979	2,058	3,243	3,839	1,645	14,862
Revenues							
Programmed Indirects & Revenues				(1,450)			(1,450)
Housing Revenue		(102)					(102)
Meal Revenue		(16)					(16)
NSF REU/RET Funding		(62)	(62)				(124)
Air Force Support		(410)					(410)
Visitor Center Revenue		(50)					(50)
NSF Funds - ATST	1,098	2,339	1,996	1,793	3,839	1,645	12,710

#### Table 5.7-7. FY2013 Preliminary Budget

100		20			aagot			
(Dollars in Thousands)								
	Director's Office	НQ	Sunspot	Tucson	GONG	ATST	SOLIS	Total Budget
Director's Office	572					379		951
Scientific Staff		-	291	453	1,006	975	823	3,547
Scientific Support/Computing		-	253	262	807			1,323
Instrument Development/Maintenance		-	685	510	-	2,514		3,709
Telescope Operations			277	210	976		915	2,379
Facilities		-	769					769
Administrative Support		-	304		231			536
Educational & Public Outreach	123		161	62				346
NOAO Business Support	18		163	495	348			1,024
ATST						255		255
AURA Management Fee	432					-		432
Program Total	1,145	-	2,903	1,991	3,369	4,123	1,738	15,270
Revenues								
Programmed Indirects & Revenues					(1,500)			(1,500)
Housing Revenue			(90)					(90)
Meal Revenue			(15)					(15)
NSF REU/RET Funding			(62)	(62)				(124)
Air Force Support			(400)					(400)
Visitor Center Revenue			(50)					(50)
NSF Funds - ATST	1,145	-	2,286	1,929	1,869	4,123	1,738	13,091

# **ACRONYM GLOSSARY**

AFRL	Air Force Research Laboratory
AISES	American Indian Science and Engineering Society
AO	Adaptive Optics
ATST	Advanced Technology Solar Telescope
ATM	Atmospheric Sciences (Division of NSF)
AURA	Association of Universities for Research in Astronomy, Inc.
BBSO	Big Bear Solar Observatory
CD-ROM	Compact Disk – Read Only Memory
CfAO	Center for Adaptive Optics
CLEA	Contemporary Laboratory Exercises in Astronomy
CMEs	Coronal Mass Ejections
CoDR	Conceptual Design Review
CoSEC	Collaborative Sun-Earth Connection
D&D	Design & Development
DASL	Data and Activities for Solar Learning
DLSP	Diffraction-Limited Spectro-Polarimeter
DLSI	Data Management and Analysis Center (GONG)
DoD	Department of Defense
DST	Dunn Solar Telescope
EGSO	European Grid of Solar Observations
EIS	Environmental Impact Statement
EPO	Educational and Public Outreach
ESF	Evans Solar Facility
ETS	Engineering and Technical Services (NOAO)
FDP	Full-Disk Patrol
FDR	Final Design Review
FOV	Field of View
FTEs	Full Time Equivalents
FTS	Fourier Transform Spectrometer
FY	Fiscal Year
GB	Giga Bytes
GONG	Global Oscillation Network Group
GSFC	Goddard Space Flight Center (NASA)
HAO	High Altitude Observatory
HMI	Helioseismic and Magnetic Imager
IBIS	Interferometric BIdimensional Spectrometer (Arcetri Observatory)
ICD	Interface Control Document
IDL	Interactive Data Language
IfA	Institute for Astronomy (University of Hawai`i)
IHY	International Heliophysical Year
IR	Infrared
	Improved Solar Observing Optical Network (now O-SPAN)
ISOON ISS	
	Integrated Sunlight Spectrometer
IT&C	Integration, Testing, & Commissioning
KPNO	Kitt Peak National Observatory
KPVT	Kitt Peak Vacuum Telescope
LAPLACE	Life and PLAnets Center (University of Arizona)

LRP	Long Range Plan
LTE	
	Local Thermodynamic Equilibrium
LWS McMP	Living With a Star McMath-Pierce
MCAO	Multi-Conjugate Adaptive Optics
MCAO	Maui Community College
MEDB	Maui Economic Development Board
MEDB	*
MKIR	Magnetohydrodynamic Mauna Kea Infrared
MREFC MRI	Major Research Equipment Facilities Construction (NSF)
NAC	Major Research Instrumentation (NSF)
NAC	NSO Array Camera
	NASA Astrobiology Institute
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NDSC	Network for the Detection of Stratospheric Change
NHPA	National Historic Preservation Act
NJIT	New Jersey Institute of Technology
NLFF	Non-Linear Force-Free
NLTE	Non-Local Thermodynamic Equilibrium
NOAA	National Oceanic and Atmospheric Administration
NOAO	National Optical Astronomy Observatory
NRC	National Research Council
NSBP	National Society of Black Physicists
NSHP	National Society of Hispanic Physicists
NSF	National Science Foundation
NSF/AST	National Science Foundation, Division of Astronomical Sciences
NSF/ATM	National Science Foundation, Division of Atmospheric Sciences
NSO NSO/SD	National Solar Observatory
NSO/SP	National Solar Observatory Sacramento Peak
NSO/T	National Solar Observatory Tucson
O-SPAN	Optical Solar Patrol Network (aka ISOON)
PAARE	Partnerships in Astronomy & Astrophysics Research and Education Public Affairs and Educational Outreach
PAEO	
PCA PDR	Principal Component Analysis Braliminary Dasign Payion
PSPT	Preliminary Design Review
	Precision Solar Photometric Telescope
RASL RET	Research in Active Solar Longitudes
REU	Research Experiences for Teachers
RISE/PSPT	Research Experiences for Undergraduates
RISE/PSP1 RMS	Radiative Inputs from Sun to Earth/Precision Solar Photometric Telescope Root-Mean-Square
ROD	Record of Decision
ROSA	
SACNAS	Rapid Oscillations in the Solar Atmosphere
SACNAS SCB	Society for the Advancement of Chicanos, Native Americans in Science Sequential Chromospheric Brightening
SCB	Southwest Consortium of Observatories for Public Education
SDOFE	Solar Dynamics Observatory
SFC	Space Flight Center (NASA)
SOC	Solar Observatory Council (AURA)
500	

SOHO	Solar and Heliospheric Observatory
SOI	Solar Oscillations Investigations (SOHO)
SOLIS	Synoptic Optical Long-term Investigations of the Sun
SONG	Stellar Oscillation Network Group
SOT	Solar Optical Telescope
SPINOR	Spectro-Polarimeter for Infrared and Optical Regions
SPD	Solar Physics Division (AAS)
SRA	Summer Research Assistant
SRD	Science Requirements Document
SST	Swedish Solar Telescope
SSWG	Site Survey Working Group (ATST)
STEM	Science, Technology, Engineering, and Mathematics
SWG	Science Working Group (ATST)
STEP	Summer Teacher Enrichment Program
TAC	Telescope Time Allocation Committee
TB	Tera Bytes
TCS	Telescope Control System
TLRBSE	Teacher Leaders in Research Based Science Education
TRACE	Transition Region and Coronal Explorer
UA	University of Arizona
UBF	Universal Birefringent Filter
USAF	United States Air Force
VCCS	Virtual Camera Control System (Dunn Solar Telescope)
VSM	Vector Spectromagnetograph
VSO	Virtual Solar Observatory
WBS	Work Breakdown Structure
WWW	World Wide Web