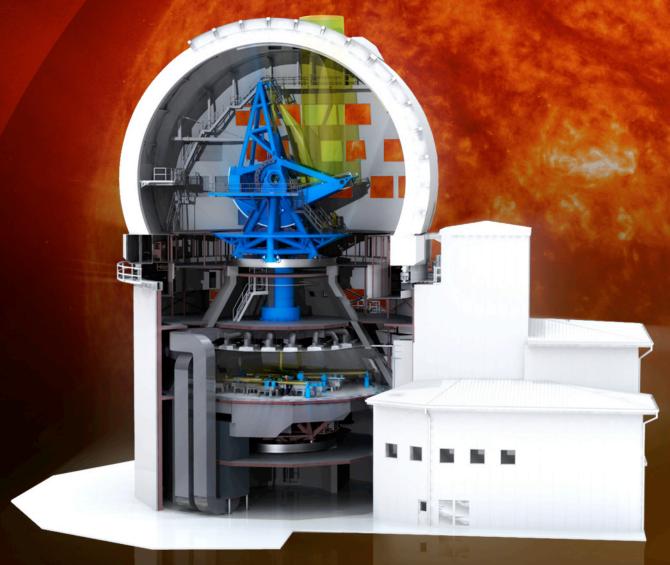






Long Range Plan **FY 2011-2015**









Submitted to the National Science Foundation under Cooperative Agreement No. 0946422

This report is also published on the NSO Web site: http://www.nso.edu

The National Solar Observatory is operated by the Association of Universities for Research in Astronomy, Inc. (AURA) under cooperative agreement with the National Science Foundation

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:

- o *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 buildup of solar activity.
- o *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.
- o *Explore the unknown* Explore fundamental plasma and magnetic field processes on the Sun in both their astrophysical and laboratory context.

TABLE OF CONTENTS

E	EXECUTIVE SUMMARY		
1	INTRODUCTION	5	
2	SCIENCE PROGRAM	7	
	2.1 Interior Structure and Dynamics	7	
	2.2 Origin of the Solar Activity Cycle and the Dynamo	8	
	2.3 Transient Eruptions: Flares and Coronal Mass Ejections (CMEs)	10	
	2.4 Origin of Variability in Solar Irradiance	12	
	2.5 Heating of the Outer Atmosphere and Origin of the Solar Wind		
	2.6 Surface and Atmosphere Structure and Dynamics	13	
	2.7 The Solar-Stellar Connection		
2	CURRENT AND FUTURE TOOLS FOR SOLAR PHYSICS	17	
J			
	3.1 Current NSO Support for Users		
	• • •		
	3.1.2 McMath-Pierce Solar Telescope (McMP)		
	3.1.3.1 Global Oscillation Network Group		
	3.1.3.2 Synoptic Optical Long-Term Investigations of the Sun (SOLIS)		
	3.1.3.3 Carrington Synoptic Maps		
	3.1.4 Evans Solar Facility (ESF)		
	3.1.5 Hilltop Upgrades		
	3.1.6 Digital Library		
	3.2 New Capabilities	30	
	3.2.1 Advanced Technology Solar Telescope (ATST)	30	
	3.2.2 SOLIS Chromospheric Vector Magnetogram Capability	37	
	3.2.3 SOLIS Global Network	38	
	3.2.4 Virtual Solar Observatory (VSO)	40	
	3.2.5 Planning for Beyond ATST	42	
4	EDUCATION AND PUBLIC OUTREACH AND BROADENING PARTICIPATIO	N43	
	4.1 Recruiting a New Generation	44	
	4.1.1 Existing Higher Education Program		
	4.1.2 Increasing the Diversity of NSO's Student Programs	45	
	4.1.3 Summer Schools	47	

4.1.4 Interactions with the University Community	47
4.1.5 Mentoring of Postdoctoral Fellows and Thesis Students	48
4.1.6 K-12	49
4.1.7 Public Outreach	50
4.1.8 Future	51
4.2 Broadening Participation and Increasing Staff Diversity	51
IMPLEMENTATION	
5.1 The Evolution of NSO	53
5.1.1 NSO Site Location Development	55
5.1.2 Maui Operations	56
5.2 NSO Staffing	57
5.2.1 Total Staff	57
5.2.2 Sunspot-Based Scientific and Key Management Staff	59
5.2.3 Tucson-Based Scientific and Key Management Staff	60
5.2.4 Future Science Staffing	61
5.3 Support for Users	62
5.3.1 User Interaction and Feedback	62
5.3.2 Telescope Allocations and Usage	63
5.3.3 Support at the Telescopes	64
5.4 Community Partnerships and NSO Leadership Role	64
5.5 Operational Partnerships	64
5.6 NSO Organization	66
5.6.1 Director's Office	66
5.6.2 NSO/Sacramento Peak	66
5.6.3 NSO Tucson and NSO Synoptic Program	67
5.6.4 NSO ATST	67
5.6.5 NSO Future Organization	67
5.7 Spending Plan	67
5.7.1 Final FY 2011 Budget	
5.7.2 FY 2012 Preliminary Budget	
5.7.3 ARRA Infrastructure Support	
5.7.4 FY 2011 Unfunded Infrastructure Improvement Requests	

This page intentionally left blank.

NSO EXECUTIVE SUMMARY

The National Solar Observatory is the primary provider of key ground-based solar facilities to the US 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. NSO facilities are used by the community in collaboration with space-based solar instruments to provide a complete picture of the Sun.

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, the Observatory Visiting Committee Report, 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 multiagency 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:

- Construct the Advanced Technology Solar Telescope. The ATST will be the premier groundbased 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 and its effects on space
 weather and the Earth's climate.
- Develop an NSO organizational 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. Participate in university partnerships that have been formed through programs such as the NSF Partnerships in Astronomy & Astrophysics Research and Education (PAARE) program and Fisk-Vanderbilt Masters-to-PhD 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 space weather community with the data needed to monitor, model, and understand solar activity and variability through the development and operation of enhanced and new observing capabilities (e.g., continual near-real-time GONG magnetograms and H-alpha imaging, SOLIS vector magnetic field maps, calibrated GONG farside images).
- 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 (VSO), 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 in strengthening their programs through participation in the NSO program of research, education, and the implementation of new scientific capabilities.

The NSO long-range road map is shown in Figure 1. It has been coordinated with the solar community, the NSO Users' Committee, and the AURA Solar Observatory Council (SOC). It has strong community buy in for the long-term future of ground-based solar physics. Ongoing and future NSO efforts are summarized in Figure 2 and explained in detail in the body of this plan. 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.

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 has entered the construction phase and is in the process of obtaining permits for building on Haleakalā.

The SOLIS vector spectromagnetograph (VSM) and the integrated spectrometer (ISS) 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 are available from the NSO Digital Library and are being used to support *Hinode*, the Solar TErrestrial RElations Observatory (STEREO), and soon the Solar Dynamics Observatory (SDO). NSO will explore partnerships for developing a network of SOLIS vector magnetographs.

GONG data have become an important tool for space weather in addition to its traditional role for investigating the solar interior. GONG farside images have helped improve models that predict the high-energy solar flux hitting the Earth's atmosphere. This result is helping to improve predictions of atmospheric neutral density and Ionospheric height, which are important for satellite drag and communications. The Air Force has provided GONG with support to implement an H-alpha imaging capability and is now providing funds for H-alpha operations.

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. Section 5 outlines the NSO plans for consolidation and for operations in the ATST era. Community workshops will help define modes of ATST science operations. The road map in Figure 1 summarizes the Observatory's strategic plan, showing when new NSO capabilities will become operational and when older, replaced facilities can be phased out. In previous long-range plans, the dates, which were based on ATST construction startup, slipped as the date to begin construction slipped. Now with construction funds in hand, the only remaining barriers to implementing the plan are obtaining the necessary building permits and any potential litigation that could slow construction. Phase-out of the Dunn Solar Telescope (DST) and McMath-Pierce Solar Telescope (McMP) are shown as occurring with the beginning of ATST operations. NSO will continue operating the Evans facility as long as support is provided by external sources.

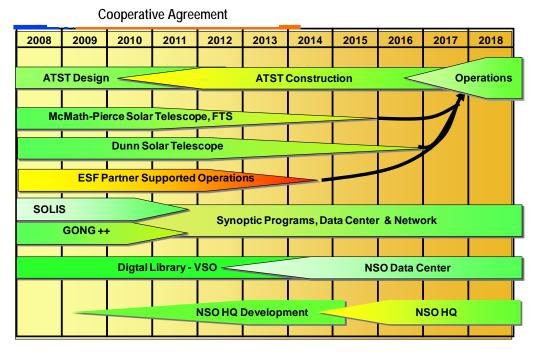


Figure 1. Strategic road map for NSO facilities.

NSO 2012-2016 Facility Planning

ATST

- Complete major ATST contracts
- o Complete building permitting process for Haleakalā (FY11)
- o Begin site construction (FY11/12)
- o Telescope completion (FY18)

• Dunn Solar Telescope

- o Continue development of multi-conjugate adaptive optics
- o Maintain and operate current instrument packages
- o Test bed for ATST instrument development
- o Conduct scientific operations for the solar community

McMath-Pierce Solar Telescope

- o Dedicate Advanced Image Slicer (AIS) and Integral Field Unit (IFU)
- Enhance control system to exploit NSO Array Camera (NAC) (1–5 microns) and thermal-IR
- o Conduct scientific operations for the solar community

• Synoptic Program

- Conduct joint GONG/SDO helioseismic measurements
- Air Force supported GONG space weather operations
- o Operate full suite of SOLIS instruments
- o Incorporate SOLIS data into Digital Library and Virtual Solar Observatory

Digital Library and Virtual Solar Observatory

- o Continue work on next release version; operation of NSO node
- o Continue strong collaboration with US and European institutions
- Start development of Data Center to incorporate ATST & Synoptic Data

NSO Directorate Site Development and Staff Consolidation

- o Negotiate with host site
- Develop site proposal as part of next cooperative agreement
- o Appoint a transition team
- Develop a transition plan for the selected site

Education and Outreach and Broadening Participation

- Continue strong graduate and undergraduate programs
- o Coordinate with Akamai Internship Program and UH Maui College
- o Increase outreach to underrepresented minorities

Figure 2. Planned and ongoing programs and projects at NSO.

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 FY 2011/2012.

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 violent explosions? Answers to these questions will help with 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 recent launch of SDO provide solar physicists with a wealth of space-based data. Striking new data and images from space missions continue to give solar physics high public visibility and have revealed a wealth of new phenomena and information about the complexity and dynamics of the corona and chromosphere. Groundbased 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), the Rapid Oscillation of the Solar Atmosphere high-speed cameras (ROSA) and the Diffraction-Limited Spectro-Polarimeter (DLSP) at the Dunn Solar Telescope reveal problems with MHD models for these phenomena. IBIS, SPINOR, ROSA 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. When the much more powerful Advanced Technology Solar Telescope 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 continues with advent of SDO in 2010. 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 FY 2010 Annual Progress Report and FY 2011 Annual Program Plan (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 NASA's Solar and Heliospheric Observatory/Solar Oscillations Investigations (SOHO/SOI) experiment, and 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.

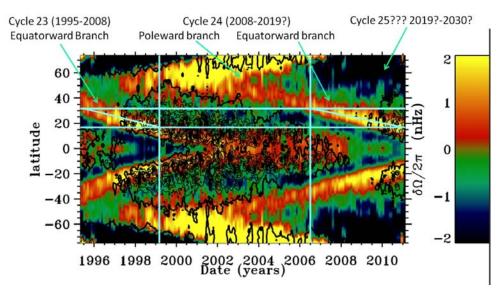


Figure 2.1-1. This image shows the torsional oscillation flow pattern at a depth of 7000 km below the solar surface using GONG and MDI data. The flow is similar to the jet stream in the atmospheres of Earth and Jupiter, and it migrates from the solar pole to the equator in 17 years. The flow is associated with the solar cycle; this picture shows the flow for cycles 23 and 24. The flow for cycle 24 is migrating more slowly than the cycle 23 flow; the 1.5-year difference is a likely cause of the current extended minimum. In addition, the flow for cycle 25 is now three years lat e in appearing, suggesting an even longer minimum between cycles 24 and 25.

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. These observations 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. Recent collaborative research by NSO and non-NSO scientists began addressing this issue using observations of kinetic vorticity and current helicity. There is preliminary evidence that weak magnetic fields are generated from small-scale non-helical dynamo process, while helicity properties of strong magnetic fields suggest their origin from deep-seated helical dynamo. Vector magnetic field measurements from the SOLIS will be instrumental in addressing this fundamental issue.

Recent minimum of solar activity—the deepest and longest of all minima in modern history of solar research—has provided a unique opportunity to study processes related to various solar features: small-scale and large-scale dynamo, formation of chromospheric filaments and isolated coronal holes and Moreton waves—flare/CME related dynamic phenomenon. Thus, the analysis of sunspot properties observed with the McMath-Pierce Solar Telescope suggests long-term changes in solar activity that may be responsible for unusually low solar activity in 2009/early 2010. And the formation of isolated coronal holes on remnants of dissipating active regions followed by transformation of toroidal (oriented East-West) to poloidal (oriented North-South) field indicates the need for deeper understanding of the relationship between solar features on different spatial and temporal scales.

Recent analysis of the infrared magnetic umbral measurements from the McMath-Pierce Solar Telescope show that the decreasing field strengths seen in sunspots during Cycle 23 have continued with the same trend through Cycle 24. A detailed analysis of the distribution of the magnetic field strengths suggests that Cycle 24 will have fewer sunspots than Cycle 23, as the magnetic fields weaken below an observed 1500 Gauss threshold which seems to be required to form a dark pore. If the trend continues through Cycle 25, virtually no sunspots will be expected to appear. Moreover, this trend agrees with recent observations of 10.7cm radio emission from the Sun, which is occurring at a higher rate than predicted by the sunspots visible on the solar surface. Finally, observations from GONG and the Evans Facility coronagraph suggest a weak Cycle 24, and see none of the expected precursors for Cycle 25 at all.

The concept of an extended solar cycle was proposed in 1988 based on the analysis of KPVT synoptic magnetograms. A recent study of magnetic bipoles using historic NSO data sets and magnetic observations from space-borne instrumentation (SOHO/MDI) indicates that a "wing" of a new solar

cycle may begin with ephemeral regions emerging at high latitudes shortly after maximum of a current cycle. GONG investigation of flow streams below the solar surface and migration of coronal streamers to solar poles, so called "rush-to-the-poles," support the concept although the exact mechanism responsible for the extended solar cycle needs further investigation. These long-term properties 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 Dunn Solar Telescope 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

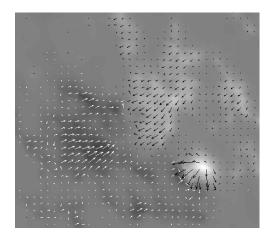


Figure 2.2-1. SOLIS vector magnetogram of Active Region NOAA AR 11272 Date 11/08/2011. In addition to full disk vector magnetograms, SOLIS can zoom in high-resolution mode on solar active regions.

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.

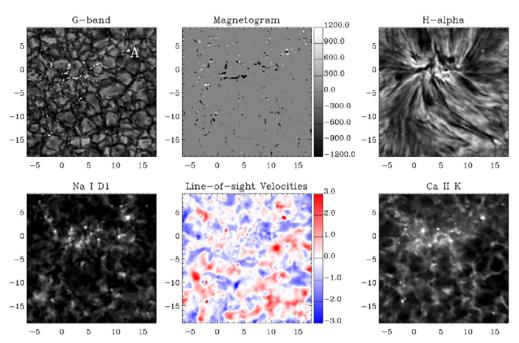
Observations with GONG and SOLIS show that the photospheric magnetic field in the "quiet Sun" has a ubiquitous and dynamic horizontal component that varies rapidly with time. This field could be a manifestation of changing magnetic connections between eruptions and evolution of small magnetic flux elements 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.

It is impossible to understand the solar dynamo without knowledge of the dynamics and flows below the surface. In the high- β 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 recent addition of 20 second cadence H-alpha images from GONG will greatly enhance this capability. The deployment of the final SOLIS instrument—the Full Disk Patrol (FDP)—will provide additional full-



Images from ROSA/IBIS obtained simultaneously at 14:06:21 UT. Color scales for the line-of-sight magnetogram and velocity maps indicate magnetic field strength (in Gauss) and Na I D $_1$ core velocity (in km s $^{-1}$), respectively. Artificial downdraft saturation is displayed in the velocity map to aid identification of MBP features. Axes are solar heliocentric coordinates in arcseconds. Downdrafts within Na I D $_1$ bright points exhibit speeds of up to 7 km s $^{-1}$.

disk images at a variety of wavelengths and at potentially higher spatial resolution (subject to seeing conditions). These images should be quite useful for monitoring at wavelengths that originate lower in the atmosphere below H-alpha. 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, GONG and the

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, GONG 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. 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. More recently, polarization studies at the DST and the McM/P using the full Stokes profiles of He 1083nm are being used to probe the details of the magnetic fields in the dark fibrils surrounding sunspots. Few such measurements exist, and these measurements are expected to provide valuable constraints on the static and dynamic models of the environment around sunspots, and will shed light on how the magnetic fields there are involved in flares and eruptions.

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, GONG, and 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 α telescope (ISOON) operating at NSO facilities. ISOON data, as well as the GONG H α capability, will continue to play a critical role in studies of flares and CMEs.

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 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 α , 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 are being 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 Transition Region and Coronal Explorer (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. 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. Similarly, the SDO/HMI (Helioseismic and Magnetic Imager) and AIA (Atmospheric Imaging Assembly) experiments will benefit greatly from simultaneous ground-based observations. Multi-wavelength observations of oscillations from GONG, HMI, and AIA will provide information on the behavior of the *p*-mode oscillations in the presence of magnetic fields; an essential step in understanding the subsurface structure of active regions as well as probing the solar atmosphere.

The infrared capability of the McMath-Pierce was used to probe the atmospheric dynamics with full-disk observations of solar p-modes using the CO molecular lines at 4667nm. The study explored the I-V phase spectrum revealed by the CO lines to (1) provide an independent measurement of the CO formation height, (2) measure a drop in p-mode power with height suggesting a conversion of p-mode power to higher or lower frequencies and (3) show that the solar atmosphere behaves non-adiabatically at about 400km, but that the conditions transform to adiabatic response about 600km into the solar atmosphere.

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. The SOLIS VSM can observe the Stokes I and V spectra in the chromosphere (and photosphere) on large spatial scales (though with moderate spatial and temporal resolutions). For example, together with SDO, the two instruments can be used to study large scale dynamics from the lower chromosphere to the corona. 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. The implementation of a chromosopheric vector field capability for the SOLIS VSM will enable more accurate field extrapolations into the corona.

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. The Ca II K parameter time series has revealed an apparent minimum in the solar cycle that occurred in the 2008 October-November time frame. In addition, the K line series appears to track the downward trend in irradiance during the unusually long solar minimum. 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). Sun-as-a-star observations of the CaII 854.2 nm line bisectors from SOLIS ISS and McMath/Pierce show a clear solar cycle variation with reduced bisector spans during solar maxima. Spatially resolved observations from VSM reveal a connection between bisectors, magnetic canopies, and magnetic shadows. The Ca II 852.nm line bisectors are a potential diagnostic for studying the relationship between activity and dynamics in other stars as well. 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.

A limited nighttime program of solar system investigations, supported primarily by NASA grants, continues at the McMath-Pierce complex. 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 solar-metallicity 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 using other nighttime telescope facilities, such as the new Discovery Channel Telescope at Lowell Observatory. A recent high spectral resolution investigation revealed a dispersion of rotation velocities in excess of the solar value that was also correlated with chromospheric Ca II strength. The possible existence of multiple cycles—perhaps arising from different dynamo processes—has been suggested from long-term observations of solar-type stars.

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% short-term 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.

Additional work in this area is focusing on the development of the neutral helium lines at 587.6 nm and 1083 nm as diagnostics of active region area coverages on Sun-like stars. The implementation of a joint IR and visible spectroscopic program using telescopes and instruments available through ESO and Max Planck, respectively, has been approved. Finally, NSO staff members, in collaboration with members of the community, are exploring innovative astrophysical applications of the ATST should nighttime operations be permitted at some future date following the verification of solar operations. The polarimetric capabilities of the ATST can be usefully applied in high sensitivity observations of phenomena ranging from circumstellar disks to extrasolar planetary atmospheres. The NSF, however, has thus far not approved nighttime utilization of the ATST nor has the NSO included the development of nighttime instrumentation in its Long Range Plans. The NSF has stated that they will consider proposals for nighttime science after the ATST has been verified for solar work. Any nighttime instrumentation would have to be provided outside the NSO budget.

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. In particular, the NSO already has collaborated with the community in recent proposal initiatives to obtain funding to establish one or more SONG nodes in the southwest US. 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.

Both asteroseismology and the study of spots on sun-like stars are active areas of investigation in the community, utilizing the enormously rich Kepler data base of ultra-high precision photometry. NSO staff members have participated in research using the Kepler data in asteroseismology. The prospect for joint spectroscopic and photometric observations is exciting since this approach may extend asteroseismological studies to higher modes.

The NSO development of students in solar physics continues through the REU program and with dissertation research through a joint program with the University of Arizona. Tom Schad is currently developing his dissertation involving the magnetic structure of chromospheric fibrils with joint observations from NSO/DST and McM/P. High-spatial resolution spectropolarimetry from the DST can be combined with higher signal-to-noise (but lower spatial resolution) spectropolarimetry from McM/P. Such a program uses state of the art instrumentation at both NSO facilities, and provides invaluable hands-on experience for the graduate student. With this work NSO hopes to help train the next generation of solar physics instrumentation specialists who will push the ATST capabilities farther than we can now imagine.

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 US and international solar research. The NSO telescope upgrade and instrument development program is guided by the scientific and technical imperatives for the 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 DST is playing a major role in developing the ATST instrumentation, polarization measurement and calibration, and in defining ATST operations.

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 has upgraded many of its 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 affected. Upgrades are 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 US astronomers. The possible development of a large European Advanced Solar Telescope (EAST), following ATST by several years, could 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), 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), and a high-cadence

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 performed in 2009 at the DST and further efforts are scheduled. The DST supports the US 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, UK), that are available to all users. The DST will continue to play the major role in supporting US 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.

3.1.1.1 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 NSO is continuing high-order AO development in primary partnership with the New Jersey Institute of Technology (NJIT). A 357 actuator system (compared to the 97 actuators for the current system) for the BBSO New Solar Telescope is being developed jointly between NSO and NJIT personnel. This effort is serving as a prototype for scaling up the current systems to meet ATST requirements (a 1900 actuator system). Two deformable mirror (DM) systems are undergoing detailed testing at the NSO optical laboratory facility at NSO, Sunspot. A thermal management system has been integrated into the DM that allows removing the solar energy absorbed during normal operations and maintaining the surface temperature at or close to ambient. This work is considered essential prototyping effort for the ATST adaptive optics system and involves a Akamai summer student and post-docs.

In addition to the high-order AO system development the AO project is 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. The NSO system is one of the first

successful on-sky MCAO experiments (the Kiepenheuer MCAO system being the other). Current MCAO work focuses 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. Close collaborations between NSO, NJIT and the Kiepenheuer Institute (KIS) exist. KIS has a permanent MCAO installed in their optical lab in Freiburg. The system will be installed at the 1.5m GREGOR on Tenerife in early 2012. It is planned that NSO members will participate in further lab testing and the subsequent on-sky tests on Tenerife. Dirk Schmidt, a grad student at KIS who is performing his thesis work with MCAO, will join the NSO MCAO team as post-doctoral researcher in late 2011 and become a focal point for joint NST/GREGOR/ATST MCAO development.

3.1.1.2 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. Software is available to calibrate the raw data from the DLSP and there are plans to make sets of 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.

3.1.1.3 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 more efficient 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 two detectors are a $1K \times 1K$ MgCdTe IR camera and a $2K \times 2K$ camera with Kodak CCD for the visible arm, both synced to a liquid crystal modulator. FIRS has been fully commissioned as a supported user instrument since 2009.

3.1.1.4 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 450 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 into the DST camera control and data handling systems has been completed and the instrument is fully commissioned as a user instrument.

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

3.1.1.5 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 (25 mA in the visible, and 45 mA in the infrared), high throughput, and consequently high cadence. In collaboration with NSO and the High Altitude Observatory, the Arcetri group has upgraded IBIS to a vector polarimeter. The wavelength range of IBIS extends from the 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. Two new identical Andor $1K \times 1K$ cameras have replaced the slower Princeton narrow-band and Dalsa wide-band cameras for improved data rates. IBIS has been integrated into the DST SAN.

3.1.1.6 Rapid Oscillations of the Solar Atmosphere (ROSA)

ROSA is a fast camera system developed and built by Queens University (QU) in Belfast, Northern Ireland. It consists of up to $7\,$ 1K \times 1K Andor cameras and a computer system capable of registering up to 30 frames per second. The computer system has an internal storage capacity of 20 Tb, enough for a few days of observations, even at the extremely high data rates the system is capable of. Typically the cameras are fed through some of NSO's wide band filters in the blue, while the red light is fed to IBIS. The DST observers have been instructed on operating ROSA and are capable of running the instrument without assistance from QU.

3.1.1.7 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 is currently 4 Tb for storage of daily observations, and 20 Tb for long-term (21 days or more) storage. A new 10 Gbs network switch has been purchased and has been installed on the observing table to allow instruments to write to the SAN at the sustained high data rates required by high-spatial resolution, high-cadence spectropolarimetry. Furthermore, the obsolete standard storage media, DLT tape, which was used to transfer data to users, has been completely replaced by removable hard drive with the eSATA transfer protocol for much higher throughput.

NSO will continue to vigorously pursue the opportunities presented by this high-resolution, diffraction-limited 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 second 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 low-order AO system provides diffraction-limited imaging and spectroscopy at these infrared wavelengths. Coupled with the InSb-based detector of the NSO Array Camera (NAC), the McMP is producing the highest signal-to-noise mid-infrared solar images and spectra ever achieved.

Synoptic observations from W.C. Livingston using the McMath-Pierce have shown a strange decrease in the sunspot magnetic field strength during solar cycles 23 and 24. If this decrease continues, it has enormous implications: a weak cycle 24 is one outcome, and an even weaker, or non-existant cycle 25 might also occur. No analogous observations have been made at any other facility, and this data set alone shows the enormous value of the McMath-Pierce and its infrared capability. Extension to this data set using imaging spectropolarimetry at 1565 nm with the new NAC system is currently being done.

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 dynamics. The NAC has been used to measure the changes in solar oscillations with height in the cool molecular gas of the temperature minimum, and these observations will shed light on the coupling of the magnetic fields with the solar oscillations.

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 new observations of a powerful X1.8 flare and the magnetic structure of the sunspot superpenumbra using the infrared He I line at 1083 nm, and new observations of the CO lines at 2330 nm and at 4667 nm. Full-disk scans of the Mn I line at 1526nm, which shows sensitivity to low magnetic fields with hyperfine structure, have been made for the first time at the McMath-Pierce. Further studies will be used to develop techniques and science questions that will continue to refine the ATST IR capabilities.

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; initial testing of the polarimetry optics required for these observations is underway in 2011. 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. Finally, the cool solar temperature minimum will be probed with a variety of molecular lines including CN, CO and H₂O.

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.

3.1.2.1 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 can observe 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. With a new dual-beam polarimetry bench, the NAC is being used for sensitive magnetic field measurements in sunspot umbra and in

chromospheric flow regions around sunspots, for studies of molecular line formation, and for 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, , and is working to cross-calibrate the 20 years of observations from W. C. Livingston (NSO) with new NAC measurements.

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 initial operation of a large-format, advanced IR instrument at the McMath-Pierce solar telescope facility will offer the most advanced research capability in the mid-IR for solar physics in the world today.

3.1.3 NSO Synoptic Program

In mid-2011, NSO merged the Global Oscillation Network (GONG) and Synoptic Optical Long-Term Investigations of the Sun (SOLIS) programs into the NSO Synoptic Program. The initial goals of this integration are to increase efficiency and lower the total overall cost of both projects. It is also expected that the integration will strengthen the use of the NSO synoptic data in the framework of Space Weather and Space Climate for both scientific research and operational forecasting applications. During these early stages of integration, many aspects of two projects still function independently and therefore are described separately.

3.1.3.1 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 $1K \times 1K$ 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. A new product, comprising $2K \times 2K$ H α intensity images obtained at a 20-second cadence, is 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; 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, solar wind modeling, and examining the inferred coronal field's evolution and to provide high-cadence $H\alpha$ intensity images in near-real time for flare and filament eruption studies and for space weather operations. 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. This has now been demonstrated to potentially be a very useful space weather predictive capability, and its development as an operational forecast tool is underway.

3.1.3.1.1 Data Products

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 at the Space Weather Prediction Center (SWPC), the Air Force Research Lab (AFRL), the Community Coordinated Modeling Center (CCMC), the Center for Integrated Space Weather Modeling (CISM), and the Space Weather Modeling Framework (SWMF). 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.

3.1.3.1.2 Instrument Upgrade and Hardware Replacement

At the beginning of 2011, GONG finished installing a new capability at each of the sites in the form of an H α observing system. This comprises a Daystar 0.4-Å H α interference filter and a 2K × 2K CCD camera. The resulting H α intensity images are acquired at each site with a one-minute cadence, and with the time of acquisition offset by 20 seconds at adjacent sites. Each image is processed and returned to Tucson within one minute of acquisition. Thus, GONG can provide high-cadence (20 second) images with a maximum latency of one minute for monitoring solar activity. This system was funded by the US Air Force Weather Agency (AFWA), and has resulted in a substantial amount of GONG operational support from AFWA. The completion of the H α system represents a major milestone in the evolution of GONG into a space weather data provider.

The next major upgrade to the GONG system will be in the area of the camera and Data Acquisition System (DAS). The current cameras were installed in 2001, when the original small-format rectangular-pixel CCDs were replaced with 1K X 1K square-pixel streaming media decoder (SMD) cameras. At that time the original NSO-designed DAS was replaced with a commercial unit produced by DNA Systems Inc.. This DAS is nearing the end of its lifetime, with components that are no longer in production. Today, a DAS system based on inexpensive PC hardware can be obtained at a cost that is less than 10% of the DNA system, and with higher performance and a longer lifetime. We have already upgraded the workstations at the GONG sites, and the new units will easily host the additional DAS hardware.

3.1.3.1.3 Other Considerations

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 help 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 Solar Dynamics Observatory (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 increasing value of GONG to the space weather community, the US Air Force Weather Agency provided funds to add an H α capability to GONG and is now providing operational funding. In fact, given the AFWA H α data use, and the magnetograms used by the NOAA Space Weather Prediction Center (SWPC) to forecast geomagnetic storms, GONG data is now playing an important role in national security.

The Senior Review recommendations linked the decommissioning of GONG to the availability of the Solar Dynamics Observatory. With the launch of SDO in February 2010 and the completion of SDO commissioning in June, the Senior Review recommendation would have resulted in the closure of GONG in June 2011. GONG, however, now has obtained outside operational support from the US Air Force Weather Agency, and is still pursuing additional support from NOAA focused on providing synoptic magnetograms as input to its solar wind modeling as well as the flare predictive capability of the subsurface vorticity measurements. In addition, the merging of GONG and SOLIS into the NSO Synoptic Program will increase efficiency and lower the total overall cost of both programs. Thus it remains for the NSF to determine if the 2006 Senior Review recommendations have been fulfilled.

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

To advance our understanding of long-term changes of solar activity, NSO designed and built a suite of instruments—the Synoptic Optical Long-term Investigations of the Sun (SOLIS). It has three main components: a vector spectromagnetograph (VSM) capable of observing the full disk vector and line-of-sight magnetograms, a full-disk patrol (FDP) imager, and an integrated sunlight spectrometer (ISS) for observing the high-resolution spectra of Sun-as-a-star. A prototype system is installed at Kitt Peak and the NSO Long Range Plan calls for a global network of two more VSMs to enable continuous solar observations. SOLIS instruments are designed to address three major questions: What causes the solar cycle? How is energy stored and released in the solar atmosphere? How do the solar radiative and non-radiative outputs vary in time?

The emphasis of the SOLIS program is on moderate to large spatial scale activity over the course of the solar 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 (KPVT) 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. SOLIS magnetic and helium observations by the VSM continue the historic synoptic data set from the NSO's Kitt Peak Vacuum Telescope facility collected during 1975–2003, and can be used to construct proxies characterizing solar irradiance, and to bridge and calibrate the data sets taken with the space-borne instruments such as SOHO/MDI and SDO/HMI.

Both the VSM and ISS are making regular observations that are available to the community via the Internet. They are gradually reaching their full potential for providing unique science results. In June 2011, the FDP was integrated into SOLIS at Kitt Peak. In early July 2011, it began taking regular data while still in testing mode. All of the SOLIS instruments are now producing high-quality data. The current emphasis is on completion and stable operation of SOLIS.

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 magnetic helicity synoptic maps. The ISS data are indispensible for studies of the solar irradiance and its changes over the solar cycle. The data will also be useful for a solar-stellar research.

3.1.3.2.1 Summary of SOLIS Instrument Status

Vector Spectromagnetograph (VSM). The SOLIS VSM instrument has been operating at Kitt Peak since 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 with higher special resolution was installed in the fall of 2009. Analysis software is being updated in order to improve the quality of the data products. Currently, SOLIS/VSM activities are focused on improving the data reduction of vector and line-of-sight magnetograms, including a better correction for the instrumental polarization, refining the determination of magnetic bias in weak fields, and investigating alternative inversion techniques for SOLIS VSM Stokes polarization measurments, with the goal of improving the speed of the inversion and the "quality" of the derived magnetic field parameters. It is expected that some of the planned improvements will allow us to provide users with the full Stokes spectra for each pixel of the image of the Sun as a level 2 data product. Currently, only the magnetic and thermodynamic parameters derived from the spectra are provided in that level of the data.

Integrated Sunlight Spectrometer (ISS). The ISS synoptic program began in December 2006 with observations taken in eight spectral bands centered at the CN band 388.40 nm, Ca II H (396.85 nm), CaII K (393.37 nm), C I 538.00, Mn I 539.41 nm, H α 656.30 nm, Ca II 854.19 nm, and He II 1083.02 nm. To expand a network of potential users, in 2010 the ISS daily synoptic program was modified to include Na I 589.6 nm (D line). The computation of the Ca K and H parameters has been revamped,

resulting in significant improvement in the quality of parameters derived from the K and H spectral line profiles.

ISS data have been successfully cross-calibrated with McMath-Pierce spectrograph data, and the calibration with Evans Solar Facility spectrograph data is underway. The cross-calibration will allow the ISS to extend existing data sets that go back three solar cycles. An extinction monitor has been assembled and is undergoing final alignment and testing. The monitor will provide information at five wavelengths on the atmospheric line-of-sight conditions which will be used to adjust exposure times. Future implementation of a telescope guider will improve the pointing of the ISS and improve the quality of the observations.

Full-Disk Patrol (FDP). The full-disk patrol imager is designed to take observations with high temporal cadence (about ten seconds) in several selected spectral lines including H α , Ca II K, He I 1083.0 nm, continuum (white light), and photospheric lines. It also has the capability of observing Doppler velocity maps. In June 2011, the FDP was integrated into SOLIS at Kitt Peak and is now taking observations in test mode. The data will be released to the public via the Internet after testing and calibration of the instrument are completed.

3.1.3.2.2 SOLIS Data Products

Current SOLIS data products include: daily full-disk vector and line-of-sight magnetograms in Fe I 630.2 nm, chromospheric line-of-sight magnetograms in Ca II 854.2 nm, full-disk images and derived maps of coronal holes in He I 1083.0 nm, and spectral observations of Sun-as-a-star in the wavelength range of 350–1100 nm. The core program requires the full-disk data, but area scans of a portion of the solar disk are also routinely observed. In addition to observations taken in the framework of the synoptic program, SOLIS can take observations in a PI-driven mode. Proposals for specific SOLIS observations are accepted on a quarterly basis from any qualified scientist including US-based or international researchers, postdocs and graduate students.

The quality of the VSM data products is significantly better relative to similar data produced with the previous Kitt Peak synoptic facility. Fully calibrated and inverted full-disk and active-region data are now available on line, and quick-look vector FITS-formatted files and JPEG images are also available daily. Selected VSM data have been compared with MDI, *Hinode*, and recently, HMI/SDO data. The comparison indicates generally good correlation between SOLIS and other instruments' data, although there are some disagreements that need further investigation. VSM magnetograms are superior in terms of their sensitivity and low noise level. Carrington rotation and daily synoptic maps are also available from the photospheric magnetograms and coronal-hole estimate images. Full-disk integrated magnetic flux and its imbalance are available through the end of 2009. More recent data will be released to the community once they are fully calibrated.

In addition to the VSM, calibrated SOLIS ISS spectra and parameter time series data are available publicly. Observations are made daily over about 0.5 nm in the spectral range centered on the wavelengths listed in Section 3.1.3.2.1. Spectra recorded by the ISS are now available daily as both FITS-formatted data and JPEG image files. Various Ca II K-line parameter time series data are also available as text-formatted data and JPEG image files. These parameters include, for example, total intensity in Ca II K-line integrated over 0.05 nm and 0.1 nm spectral intervals from 2006-present.

3.1.3.2.3 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 recently became available with characteristics very similar to the original design. Three cameras (one spare) were 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 was installed during the first two weeks of December 2009.

There is great community interest in obtaining chromospheric vector magnetic field measurements. This will require a new polarization modulator package that will replace the current line-of-site magnetic field measurement. The VSM had its ferroelectric liquid crystal (FLC) modulators replaced in spring 2006 due to unacceptable changes across the field of view. Fortunately, now it appears that the life expectancy of the current technology has more than doubled. The existing 6302 V modulator was expected to last through 2010; a recent failure of its thermal control system, however, inadvertently re-annealed the unit. The modulation efficiency thus has been restored to original design specifications but scattered light has increased. 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 recently loaned NSO a new generation modulator for extensive testing of efficiency, field-of-view effects, and scatter. If the unit meets scientific specifications, an achromatic modulator will be fabricated in late 2011 to replace the existing modulators. The instrument will then be able to take full Stokes vector data of the photospheric and chromospheric spectral lines.

Replacing the current processing machines with more reliable hardware is a high priority. In addition, the 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 more than a single 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.

3.1.3.3 Carrington Synoptic Maps

As one of the first integration steps in forming the NSO Synoptic Program, the production of GONG and SOLIS Carrington synoptic maps is being merged to standardize the numeric algorithms and the computer code. When this unification of the codes is completed, the (GONG and SOLIS) synoptic maps of different parameters will be produced by the same pipeline code.

Current work on the synoptic maps includes the installation of an automated pipeline to reduce the differences in the magnetic zero point between the six GONG instruments, the characterization of noise/errors for each pixel of the map, and the investigation and development of a better approach to fill the poorly-observed polar regions. With respect to the latter, an approach based on extrapolation of past trends in polar field behavior observed by GONG or SOLIS to fill the polar regions in GONG synoptic maps has been worked out. There also are plans to imbed the vector data for strong magnetic fields of active regions into the synoptic (radial field) maps. It is expected that such integrated synoptic maps would significantly improve modeling of solar magnetic fields in the corona and refine the forecasting of heliospheric magnetic fields and the solar wind. Addition of maps of the estimated errors/noise for each pixel of a synoptic map would enable modelers to provide a more realistic estimate of errors for their predictions.

In addition to photospheric synoptic maps, SOLIS is producing the chromospheric Carrington maps. Unlike photospheric synoptic charts, the chromospheric charts do not use radial correction for the observed magnetic fields. Work is underway to test the use of these maps in the derivation of coronal magnetic fields and solar wind properties.

3.1.4 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. SOLIS and ISOON have replaced the spectroheliogram capability of the ESF with full-disk imaging. The Air Force group also provides funding for a part-time observer and provides NSO with funds for minimal maintenance. The High Altitude Observatory has installed an instrument for the ESF for measuring prominence magnetic fields and is providing support for its operation.

3.1.5 Hilltop Upgrades

The hilltop lab facility has been upgraded to serve as primary optical lab facility at Sunspot for various ATST development efforts. These efforts include wavefront correction and instrumentation system development for the ATST. An existing solar light feed has been repaired and a clean room tent will be installed to provide a suitable environment for the expensive ATST optical systems, such as the DM and tip/tilt mirrors. The majority of the ATST wavefront correction team is now located at hilltop.

3.1.6 Digital Library

In addition to its dedicated telescopes, the NSO operates a Digital Library that provides synoptic datasets (daily solar images from SOLIS, FTS data, GONG data and a portion of the Sacramento Peak spectroheliograms) over the Internet to the research community. Additional data sets from ISOON, the DLSP, and the remainder of the NSO/SP spectroheliograms (being digitized at NJIT) will be added in the future. We will also be hosting some none-NSO data sets such as the Mt. Wilson Ca K synoptic maps and the AFRL ADAPT magnetic field forecasts.

Since the inception of the Digital Library in May 1998, more than 20 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 disk arrays and are

searchable via a Web-based interface to a relational database. The current storage systemcurrently has 100 TB of on-line storage. 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)

The 4-meter Advanced Technology Solar Telescope will be the most powerful solar telescope and the world's leading ground-based resource for studying solar magnetism, which controls the solar wind, flares, coronal mass ejections, and variability in the Sun's output.

The introduction of novel, post-focus instrumentation and adaptive optics has greatly enhanced the capabilities of NSO's solar telescopes, 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. A complete description of science goals and project information can be found at *atst.nso.edw*/.

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 was ready for construction. The NSB met in August 2009 and resolved: "that the National Science Board authorized the Director, at his discretion, to issue an 8 year award to the Association of Universities for Research in Astronomy for a not-to-exceed amount of \$297,928,000 for the construction of the Advanced Technology Solar Telescope (ATST). This award will be contingent upon the publication of a record of decision authorizing the commencement of construction." The

NSF finalized the Environmental Impact Statement (EIS) for the proposed construction site on Maui in December 2009 with a Record of Decision (ROD) authorizing the commencement of construction.

3.2.1.1 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) meets approximately once per year and has both US and international members who report to and advise the Project Scientist and Project Director. Under the leadership of the Project Scientist, the SWG and in-house science team produced a Science Requirements Document (SRD) (#SPEC-0001) and contributed to the science write-up for the ATST construction proposal.

Table 3.5	Table 3.2-1. ATST Science Working Group				
Thomas R. Ayres	University of Colorado, CASA				
Thomas E. Berger (Chair)	Lockheed Martin, Solar & Astrophysics Laboratory				
Mats Carlsson	University of Oslo, Norway				
Roberto Casini	High Altitude Observatory				
Gianna Cauzzi	Arcetri Observatory, Italy				
Craig DeForest	Southwest Research Institute				
Lyndsay Fletcher	University of Glasgow, United Kingdom				
G. Allen Gary	NASA Marshall Space Flight Center				
Neal Hurlburt	Lockheed Martin, Solar & Astrophysics Laboratory				
Donald E. Jennings	NASA Goddard Space Flight Center				
Philip G. Judge	High Altitude Observatory				
Jeffrey R. Kuhn	University of Hawai'i, Institute for Astronomy				
Haosheng Lin	University of Hawai'i, Institute for Astronomy				
Scott McIntosh	High Altitude Observatory				
Clare Parnell	University of St. Andrews, Scotland				
Jiong Qiu	Montana State University				
Thomas R. Rimmele	National Solar Observatory				
Luis Bellot Rubio	Instituto de Astrofisica de Andalucia, Spain				
Wolfgang Schmidt	Kiepenheuer Institute for Solar Physics				
Hector Socas-Navarro	Instituto de Astrofisica, Spain				
K.S. Balasubramaniam	AFOSR				
Yoshinori Suematsu	National Astronomical Observatory of Japan				
Haimin Wang	New Jersey Institute of Technology/Big Bear Solar Observatory				

3.2.1.2 ATST Project Engineering and Design Progress

In January 2010, the ATST project transitioned from design and development to the construction phase. At that time, efforts were concentrated on establishing contracts for the major sub-systems and long-lead items, detailed optical feeds to instruments, and system-error budgeting. The project staffing was ramped up per plan after funding authorization was received. The project has awarded contracts for the M1 Blank, architectural and engineering services related to the Support Facilities, Enclosure construction design, Telescope Mount Assembly, and Facilities Thermal System construction design, the M1 Cell Assembly, M1 Polishing and Top End Optics Assembly (see Table 3.2-3).

Preparations for construction in Hawai'i continue as the project continues to support the permitting process in Hawai'i. The State of Hawai'i Board of Land and Natural Resources approved the Conservation District Use Permit (CDUP) submitted by the University of Hawai'i at their December 6, 2010 meeting in Honolulu. A CDUP contested case hearing is expected to be resolved in the summer of 2011.

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. 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. As presented at the NSF conducted FDR, 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 was done in the design phase, the WBS is consistent with the subsystems, and each work package has an accounting number system that corresponds to the WBS and ICD organization.

Funds have been budgeted to each of the major work package for the construction phase. Contingency, based upon risk analysis presented at the NSF conducted FDR is held, and managed, centrally by project management.

Current Design Activities

The current ATST design is shown in Figure 3.2-1. The design includes the coudé instrument area and feed arrangement. 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 Spectro-Polarimeter.
- University of Hawai'i (Diffraction-Limited Near-IR Spectro-Polarimeter Design; Cryo IR Spectro-Polarimeter.
- NSO/ATST (Visible Broadband Imager).
- Kiepenheuer Institut für Sonnenphysik (Visible Tunable Filter).

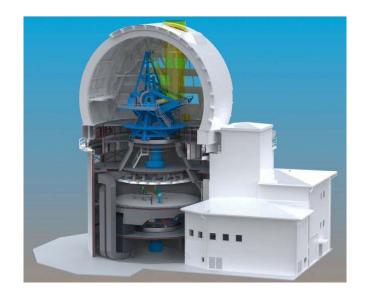


Figure 3.2-1. Current ATST facility design.

3.2.1.3 ATST Management Activities

Current management activities include support and preparation for the contested case hearings and lawsuits relating to the Conservation District Use Permit, National Pollutant Discharge Elimination System (NPDES) permitting, and an Environmental Assessment relating to modifications in the vehicle counts originally studied in the Final Environmental Impact Statement (FEIS). Negotiations are under way with the FAA (lay down areas), USAF (mirror coating facility) and the National Park

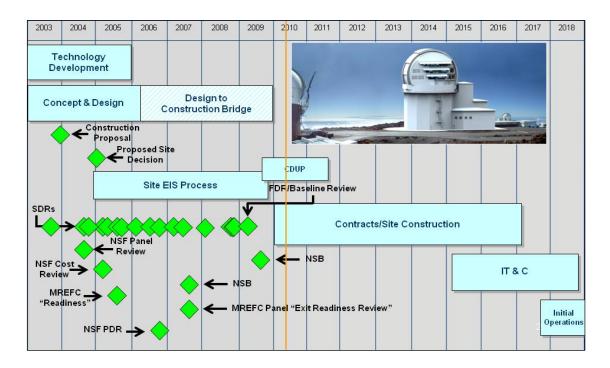


Figure 3.2-2. ATST top level schedule.

Service (Special Use Permit). We have also begun planning for implementation of the Habitat Conservation Plan and relocation of staff to Maui. The overall top-level schedule is shown in Figure 3.2-2.

3.2.1.4 ATST Site

Environmental permitting for ATST at the selected Haleakalā site required the preparation of an Environmental Impact Statement as defined by Federal and State of Hawai'i statutes. In 2005, the Maui-based firm of KC Environmental (KCE) was contracted to lead that effort. Following the published Notice of Intent (NOI), a series of scoping meetings were held on Maui to elicit early input from the public on the issues to be addressed in the EIS. As reported previously, the main concerns included: the impacts on Haleakalā as a cultural site to Native Hawaiians, impacts to the viewshed and viewplane, due to its required height and white color; the potential impact of ATST on biological resources, particularly the endangered Hawaiian petrel; and increased traffic on the Haleakalā National Park road during construction and operation. Comments from the public and concerned agencies were taken into account in the preparation of the Draft EIS (DEIS).

Following release of the 2006 DEIS, the public was given the required 45-day public comment period in which to submit written comments on the DEIS. Three public meetings were held on Maui during that period to allow the community to comment on the document, either verbally or by submitting written comments. The input received largely reinforced the concerns that had been identified previously. The adjacent Haleakalā National Park, in particular, raised concerns about the construction-related use of the 11-mile section of highway that runs through the Park and is maintained by them. (Access to the Haleakalā High Altitude Observatory Site (HO) is through the National Park.) The Park cited potential negative impact on Park visitor experience caused by the increased traffic and also by the visual presence of another nearby large observatory. The Park's comments pointed out the historic nature of

the Haleakalā highway itself and the potential for damage caused by construction traffic. The Federal Aviation Administration (FAA), who operates a repeater station on Haleakalā for air-to-ground communication, expressed concern about signal reduction caused by the proximity of the ATST structure to their antenna. A contract now is in place for modifications to the FAA tower to resolve the signal reduction issues. With regard to the endangered-species issue, the US Fish and Wildlife Service (USFWS) completed a Biological Opinion on the impact of ATST. In consultation with KCE and project engineers, a set of reasonable mitigation measures were established which resulted in a USFWS opinion that the ATST project is "not likely to adversely affect the Hawaiian petrel" or other species of concern. This finding was a significant positive development for the ATST EIS.

The Supplemental Draft Environmental Impact Statement (SDEIS) was published on May 8, 2009 and was prepared in response to public and agency comments of the DEIS published in September 2006. In a number of respects, the SDEIS was considerably revised from the DEIS; comments received warranted additional surveys and studies, which were completed after the DEIS was published. The SDEIS was substantially changed from the DEIS of September 2006. The public was again given a 45-day comment period with three public meetings held to allow further public comment.

Environmental permitting also involves satisfying the applicable provisions of the National Historic Preservation Act (NHPA). Section 106 of the NHPA provides the legal framework for addressing such issues as the Park's concern about the historic highway and the Native-Hawaiian community's concerns about the sacred nature of the Haleakalā summit. In conformance with NHPA, a number of meetings with the public and concerned agencies have been held; proposals for mitigation and minimization of cultural impact have been invited and received. A Programmatic Agreement with members of the community and various agencies was fully executed in September 2009. As the Lead Agency for the Proposed Action, the National Science Foundation is implementing the Programmatic Agreement, and significant progress has been made, especially with the formation of the Native Hawaiian Working Group (NHWG).

The Final EIS was completed in July 2009, and a Record of Decision was signed by the Director of the NSF on December 3, 2009. Following the release of the FEIS and the Record of Decision, the project, through the University of Hawai'i as the applicant, submitted the Conservation District Use Application (CDUA), as required by Hawaiian statute. The Board of Land & Natural Resources approved the application and granted the Conservation District Use Permit (CDUP) on December 2, 2010. A contested case has been filed and a hearing held on July 18-22, 2011.





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

3.2.1.5 Plans

The ATST project is focusing on a variety of near-term efforts. Many contracts for the major subsystems and long-lead items are in place and are shown in Table 3.2-3. Other areas of effort include detailed optical feeds to instruments, completion of instruments designs, 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).

Table 3.2-3. A	TST Major Sub-System Contracts in Place	
Work Package	Vendor	Award Date
Support and Operations Building Design	M3 Engineering	9/24/2009
Telescope Control System	Observatory Sciences, LTD	5/7/2010
DL-NiRSP Design	University of Hawai'i, Institute for Astronomy	5/12/2010
Cryo-NiRSP Design	University of Hawai'i, Institute for Astronomy	5/27/2010
Enclosure Design	AEC Engineering	5/28/2010
Facilities Thermal Systems	AEC Engineering	9/27/2010
ViSP Design	UCAR/High Altitude Observatory	10/7/2010
Telescope Mount Assembly	Ingersoll Machine Tools, Inc.	11/22/2010
Cultural Monitor Services	CKM Cultural Resources	1/27/2011
On-Island Services	KC Environmental	2/11/2011
Program Management Services	TRIAD Management Services	2/24/2011
M1 Cell Assembly	Advanced Mechanical and Optical Systems, SA (AMOS)	4/4/2011
M1 Mirror Blank	Schott North America Inc.	5/19/2011
M1 Polishing	University of Arizona/College of Optical Sciences	5/27/2011
Top End Optical Assembly	L3 Integrated Optics	5/27/2011
M5 Fast Tip Tilt Module	Physik Instrumente	6/27/2011

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 and IT&C are essential for keeping the end-project goals in mind.

During the initial construction phase, the detailed plans for transitioning to operations that were developed in the D&D phase are being refined and used to continue life-cycle planning and help prepare the National Solar Observatory for the operational phase of the ATST.

Current planning has calendar year 2018 targeted for obtaining the first scientific data with an ATST instrument. 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 will also be well underway.

Funding

Funding from the American Recovery and Reinvestment Act of 2009 was made available to the project at the level of \$146M, and from normal appropriations, an additional \$7M was awarded in FY 2009 and \$13M in FY 2010. Funding on the order of \$20M per FY through the run out of the project is planned, with the total funding equal to \$297.298M. Table 3.2-2 is shown in the NSF FY 2011 Budget Request to Congress.

Table	Table 3.2-2. Appropriated and Requested MREFC Funds for the Advanced Technology Solar Telescope									
	(Dollars in Millions)									
		FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	
	FY 2009	Estimate	Request	Estimate	Estimate	Estimate	Estimate	Estimate	Estimate	Total
Regular										
Appropriations	\$7.00	\$13.00	\$17.00	\$20.00	\$20.00	\$20.00	\$20.00	\$20.00	\$14.93	\$151.93
ARRA	146.00	-	-	-	-	-	-	-	-	146.00
TOTAL ATST	\$153.00	\$13.00	\$17.00	\$20.00	\$20.00	\$20.00	\$20.00	\$20.00	\$14.93	\$297.93

In January 2010, adequate construction funding was provided 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 transitioned at that time fully from D&D funding to construction funding. 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 Committee in October 2006, and the Final Design Review 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 FDR committee made recommendations regarding the potential impact of ARRA funds and the associated buy-American restrictions, as well as recommendations regarding schedule contingency and instrumentation management. The funding profiles proposed in the construction proposal, cost review, PDR and FDR were based on technically driven schedules.

The required funds are given in Table 3.2-3. Inflation and an overall 25.32% contingency on base costs are included. Figure 3.2-4 shows the time-phased funding profile for construction.

Table 3.2-3. ATST Construction Phase					
WBS Element	Title	Total Then-Year			
1.2.1	Project Management	30.92			
1.2.2	Systems Engineering	2.96			
1.2.3.1	Telescope Assembly	71.17			
1.2.3.2	Wavefront Correction	12.00			
1.2.3.3	Instrument Systems	22.35			
1.2.3.4	High-Level Controls and Software	6.92			
1.2.3.5	Enclosure	18.03			
1.2.3.6	Support Facilities and Buildings	43.22			
1.2.3.7	Remote Operations Building (ROB)	1.25			
1.2.4	Integration, Testing, & Commissioning	18.91			
1.2.5	Science Support	5.34			
1.2.8	Support Services	14.79			
1.4	Contingency (General & Schedule)	50.07			
	Total	297.93			
	Includes 25.32% contingency on base costs				

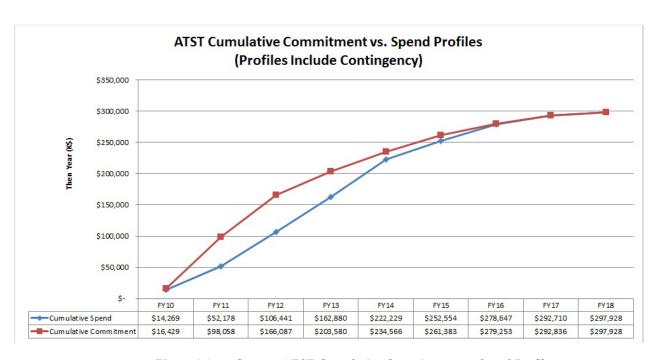


Figure 3.2-4. Current ATST Cumulative Commitment vs. Spend Profiles.

3.2.2 SOLIS Chromospheric Vector Magnetogram Capability

Successful launch of the Solar Dynamics Observatory has created a unique stream of photospheric vector magnetograms, enabling "around-the-clock" studies of magnetic evolution in flaring and CME-producing active regions. On the other hand, photospheric magnetograms have limitations in studies requiring extrapolation of fields into the corona and, perhaps, interplanetary space.

Chromospheric vector magnetograms are widely considered to be a much better option for such studies. Also, it is often difficult to infer true topology of horizontal magnetic fields in the chromosphere and above because photospheric magnetic fields (especially on small spatial scales) may close locally and not extend to the upper hemisphere. In that respect, chromospheric vector magnetograms may provide additional critical information not easily obtainable from photospheric observations. Chromospheric magnetography is an emerging new frontier in solar physics which has a potential to improve our understanding of the topology and the evolution of solar magnetic fields. On the other hand, many details on measurements, interpretation, and usability of chromospheric magnetograms await further exploration. SOLIS has a potential to lead the way in this emerging research field. The capability of producing chromospheric vector magnetograms is a future upgrade of the SOLIS modulator; this will significantly enhance the understanding of topological properties of solar magnetic fields in the solar upper atmosphere, and potentially, improve the utility of SOLIS data in space weather forecasting.

3.2.3 SOLIS Global Network

The NSO continues to seek 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." 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 solar space missions, such as *Hinode* and SDO. 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 photospheric 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. Observing 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:

- provide enhanced capabilities for capturing rare events;
- produce improved potential for short-term activity forecasts;
- provide a better uniformity and continuity in measuring vector magnetic fields;
- 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.

In addition, SOLIS' future capability of producing chromospheric vector magnetograms will complement SDO photospheric data and has a potential of significantly improving the understanding of topology of magnetic fields throughout the solar atmosphere. As a spectrograph-based magnetograph, SOLIS will be indispensible in calibrating and removing variations across field-of-view possibly existing in filter-based SDO/HMI magnetograms. Such variations are well-known to exist in MDI magnetograms.

3.2.3.1 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 US, 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 US, such as Big Bear Solar Observatory 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 FY 2007 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, and together with these potential partners, a proposal was submitted to the NSF/ATM. The proposal received excellent reviews but was not funded.

In September 2009, a joint proposal was submitted to a special NSF MRI-R² opportunity with the California State University, Northridge (CSUN) as the lead institution. The CSUN Vector Spectromagnetograph (CSUN-VSM) project aimed at building a state-of-the-art vector magnetograph based on the successful first version of the SOLIS NSO-VSM. Unfortunately, in January 2010, the proposal failed to make it to the next level of review.

Despite these set-backs, NSO will continue to actively pursue future funding opportunities for a SOLIS network.

3.2.4 Virtual Solar Observatory (VSO)

In order to further leverage the substantial national investment in solar physics, NSO is participating in the development of the Virtual Solar Observatory. The VSO comprises a collaborative distributed solar-data archive and analysis system with access through the WWW. The system has been accessed approximately 350,000 times since Version 1.0 was released in December 2004. The current version, 1.4, provides access to more than 80 major solar data sets along with a shopping cart mechanism for users to store and retrieve their search results.

The overarching scientific 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 planning and management of the Virtual Solar Observatory. None of the VSO funding comes from NSO; it is fully supported by NASA. For further information, see http://vso.nso.edu/doc. Recently, the major effort in the VSO has been the construction of remote mirror nodes for the data set produced by NASA's SDO mission. One of these nodes is now located at NSO.

With the completion of the SDO mirror nodes, VSO will resume the development of spatial searches. Currently, almost all of the data accessible through the VSO is in the form of full-disk solar images. A spatial search capability will allow the user to locate data in a specific area on the sun delineated by heliographic coordinates. The returned data could be either observations of a restricted area on the sun, or full-disk data covering the required Carrington longitudes. The spatial search capability requires information on the location of the observational instruments, since current NASA missions such as STEREO are not located near the Earth. In addition to the spatial search capability, the VSO will soon provide access to another 6-12 data sets that have requested to be included.

In the time frame covered by this Long Range Plan, NSO will 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/). First steps towards this integrated NSO data center are now being made with the merger of GONG and SOLIS into the NSO Synoptic Program. The first major development task of this combined effort is a unified approach to the construction of magnetic field synoptic maps for both GONG and SOLIS. This will then form the basis for developing the next generation of synoptic products, such as diachronic maps that better represent the global solar magnetic field at a given time.

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 the VSO, 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 VSO.

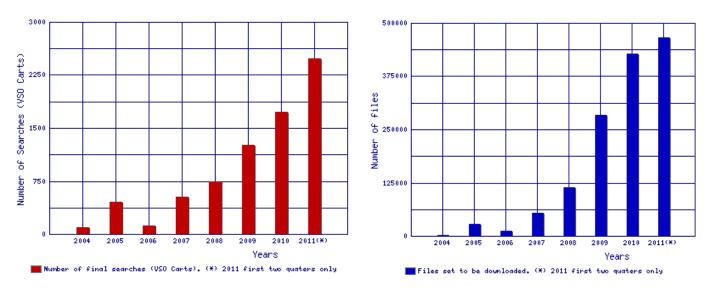


Figure 3.2-5. Top: Number of searches from the NSO node of the VSO as a function of year. Bottom: Number of files distributed from NSO via the VSO as a function of year. Currently, there are nine major VSO nodes: NSO, NASA/Goddard, Stanford University, Montana State University, Harvard-Smithsonian Center for Astrophysics, Royal Observatory of Belgium, Max Planck Institute, University of Central Lancashire and the Institut d'Astrophysique Spatiale.

3.2.5 Planning for Beyond ATST

The ATST will be completed 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.

Local helioseismology is providing information on the formation of active regions with high potential for determining when active region will produce flares and other forms of activity. It time to begin planning for the next generation of helioseismic instrumentation that provides better vertical and spatial coverage of emerging magnetic regions. This will require both multi-wavelength coverage and better spatial resolution.

NSO will continue to conduct its workshop series that consider theoretical progress and observational facilities needed to test and refine theory.

4 EDUCATION AND PUBLIC OUTREACH AND BROADENING PARTICIPATION

NSO conducts a vigorous public affairs and educational outreach program 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. NSO is developing a proposal to broaden participation in its outreach and staffing, as well as in science in general. Part of our initial aims are to increase awareness of the need for solar physics research and the potential for careers in the field among African American, Hispanic, Native American and Native Hawaiian populations as well as provide to levels K-12 general scientific material based on skills needed to understand aspects of our nearest star to help seed the path to higher education and jobs. This will include expanded outreach through established education and professional venues and direct contacts with minority-serving schools. As NSO moves into the ATST era, it plans to expand its outreach programs in several of the STEM areas through proposals and partnerships, including the establishment of effective outreach in Hawai'i by partnering with groups already involved in Hawaiian outreach programs. Section 4.2 presents a draft program that will be the subject of a proposal to NSF for some of the actions NSO plans to initiate as ATST is developed and into the era of ATST operations on Maui.

The primary NSO EPO objectives and goals are:

- To help train the next generation of scientists and engineers through support for undergraduate and graduate students, and postdoctoral fellows, and close collaboration with universities and the ATST consortium.
 - o Continue our successful REU program.
 - o Strengthen our Summer Research Assistantship for graduates program.
 - o Increase the number of thesis students working at NSO.
- To develop K-12 teacher training and student training programs to advance knowledge of science and technology.
 - o Strengthen our Research Experience for Teachers (RET) program.
 - o Make RET lesson plans available on the WWW.
 - o Develop solar classroom material that illustrates general math and physics.
- 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.
 - o Increase the relevance and content of our WWW outreach.
 - o Develop outreach materials for both classroom and public distribution.
 - o Complete our solar system model and the handout materials that accompany it.
- To increase nationally the strength and breadth of the university community pursuing solar physics.
 - Work closely with our ATST university partners and other groups to recruit and help diversify the community of scientist doing solar research.
 - o Establish close ties with additional universities to provide NSO thesis students.

- To enhance the understanding and application of science and math education in our schools, colleges and the public at large, and among traditionally underrepresented communities (Hispanic, Native American, African American, and women).
 - o Create models, display, and support packages for teachers using solar physics as examples of physical phenomena.
 - o Create ties with schools and universities serving underrepresented minority groups.

Current NSO EPO resources includes the ~1.0 FTE of scientific staff time (~\$115K), \$132K from NSF to support the REU/RET programs, one full-time EPO staffer (~\$90K), support for a visitors center and tours of \$50K, and part-time support from several members of the administrative and technical staff total approximately 0.5 FTEs (\$55K). In addition, NSO transfers \$108K to NOAO to participate in their EPO programs. The total resources going into EPO are thus approximately \$550K. NSO has generally asked one scientist at each of its sites to shepherd its REU and RET programs. Other outreach is conducted as time permits using time from both our science and support staff members. In addition, NSO provides funding to the NOAO Public Affairs and Educational Outreach (PAEO) group and participates in several of their programs. Thus the programs described below are conducted with time from both science and support staff from the observatories. In spite of these limitations, NSO has maintained an active outreach program with a great deal of success, especially in the area of bringing new personnel into solar physics.

4.1 Recruiting a New Generation of Scientists

The future of solar physics hinges on the successful recruitment of a talented new generation of scientists by the universities and national research organizations.

4.1.1 Existing Higher Education Program

Since its formation as a national observatory in 1983, NSO has actively participated in the recruitment of new generations of scientists 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).

Opportunities are provide at our Sunspot, New Mexico and our Tucson, Arizona sites. As we build-up staff in for ATST operations these programs will be extended to Maui. Six to eight undergraduate students work closely with NSO staff each year through the NSF Research Experience for Undergraduates (REU) program for ten to twelve weeks in the summer. During summer 2010, participants in the NSO program included five females and two males.

The NSO summer research assistantship (SRA) program provides opportunities for graduate students and additional opportunities for undergraduates to work at NSO. This program has been extremely effective in attracting graduate students into the field of solar physics with over 50% of the graduates going on to postdoctoral fellowships in solar research and over 80% staying in astronomy. Many of the current NSO staff and the science staff at other institutions have participated in this program.

Tab	Table 4.1-1. Number of Participants in NSO Educational Outreach Programs (2003–2010)						
Year	Graduate (SRA)	Undergrad (SRA)	Undergrad (REU)	Teachers (RET)	Postdoctoral Fellows		
2010	6*		7		5		
2009	6*		6	2	6		
2008	7*	1	6	0	6		
2007	9*		6	4	7		
2006	4		7	4	5		
2005	9		8	4	5		
2004	6	1	6	4	3		
2003	7		8	3	4		

^{*}Includes students participating in the 10-week IRES summer program (see Sec. 4.1.3)

4.1.2 Increasing the Diversity of NSO's Student Programs

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 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).

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 4.1-2, 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. NSO and ATST staff have begun exhibiting and recruiting at several venues designed to attract a broad range of students and teachers. NSO activities in FY 2010 included (chronologically):

- Exhibit at New Mexico Science Teachers Association convention, Ruidoso, NM (Oct. 2009).
- Exhibit at the annual national meeting of the Society for the Advancement of Chicanos and Native Americans in Science (SACNAS), Dallas (Oct. 2009).
- Exhibit at American Indian Science and Engineering Society (AISES) convention, Portland, including a presentation on the Sunspot Solar System model (Oct. 2009).
- Sun Balloon exhibit for the 40th anniversary of the Apollo 12 landing, New Mexico Museum of Space History (Nov. 2009).
- Exhibit at the American Geophysical Union in San Francisco (Dec. 2009).
- Participation in the AURA Diversity Summit in Tucson (Feb. 2010).
- Prepared to exhibit at the Feb. 2010 National Society of Black Physicists/National Society of Hispanic Physicists convention in Washington (canceled by NSBP).
- Participation in a Wavelength and Photosynthesis activity in a grades 9-12 astronomy workshop sponsored by the University of Hawai'i in Kihei, Maui (Mar. 2010).

- Sun Balloon exhibit to six science classes (about 200 students) at Ruidoso High School, Ruidoso, NM (Apr. 2010).
- Participation in three events at the AAS/Solar Physics Division Meeting in Miami: Exhibited at the meeting proper, talked with students and teachers at the education receptions, and participated in the AstroZone Exploration Station at the Miami/Dade Public Library the day before the conference (May 2010).
- At the May 2010 AAS/SPD meeting, NSO agreed to take the lead on local preparations for the EPO committee when SPD meets in Las Cruces in 2011.
- Sun Balloon exhibit at a star party at Brantley Lake State Park near Carlsbad, NM (Jun. 2010).
- Sun Balloon exhibit and displays at the University of Arizona "Sun Day" in Tucson; public talks about the Sun were presented by two NSO scientists and an NSO grad student (Jun. 2010).
- Sun Balloon exhibit and short presentations to about 150 teachers about NSO educator resources during the Scientifically Connected Communities event (SC²) held by New Mexico State University in Las Cruces (Jun. 2010).
- Sun Balloon exhibit at the Lunt Solar Observing Convention held in Tucson (Jun. 2010).
- NSO representation at two meetings of the Youth ACTION program being developed under the leadership of the U.S. Forest Service in Alamogordo. This represents an opportunity to attract a larger audience to Sunspot for a broader range of activities.
- Lecture presentations to approximately 400 K-8 students attending New Mexico Space Academy in Alamogordo and Las Cruces on six occasions (June-July 2010).
- Sun Balloon exhibit at "Sun Day" at the New Mexico Museum of Natural History in Albuquerque (Jul. 2010).
- Sun Balloon exhibit at the Cosmic Carnival, International Balloon Museum in Albuquerque (Aug. 2010).
- Lecture presentations on solar science and hosted public viewing on H-alpha and white-light telescopes just before a star party at Carlsbad Caverns National Park, NM (Aug. 2010).
- Exhibit and discussions on education materials at the annual Teacher Open House at the New Mexico Museum of Natural History, Albuquerque (Sept. 2010).
- Sun Balloon exhibit and discussions about solar science with about 200 K-6 students at La Promesa Charter School, Albuquerque (Sept. 2010).
- Joint organization and participation in the Akamai Workshop for engineering students, Maui (Nov. 2010).
- Participated with AURA in the National Indian Education Association national conference, San Diego (fall 2010).
- Planned participation in the joint National Society of Black Physicists/National Society of Hispanic Physicists (NSBP/NSHP) national conference, Austin, Texas (Sept.2011).
- Planned participation in the astronomy sessions at the Society for the Advancement of Chicanos and Native Americans in Science (SACNAS) national conference, San Jose (Oct. 2011).

NSO has established formal partnerships with two institutions that have successfully applied for 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 and New Mexico State University (NMSU). In summer 2009, Matthew Richardson, a graduate student in the Fisk-Vanderbilt Masters-to-PhD Bridge Program, started a summer research internship at NSO/Tucson with Frank Hill (NSO) and Keivan Stassun (Vanderbilt U.) as advisors. In August 2010, Matthew successfully completed and defended his Master's thesis on "Solar Flares: A Possible Driving Mechanism of High-Frequency Global Oscillations." Matthew has been admitted to the Vanderbilt PhD program in astronomy.

NSO has been successful with the inclusion of women in its program as more than half of the research undergraduates in recent years are female (see Table 4.1-2 for the gender and underrepresented minority breakdown of REU statistics for the past five years). Enrollment of women in graduate science programs has risen dramatically in the last decade, in part due to programs that foster girls' confidence in their scientific and mathematical abilities (see for example http://www.aps.org/programs/women/workshops/-gender-equity/upload/genderequity.pdf).

	TABLE 4.1-2. NSO REU Participant Statistics (2005 - 2010)						
Year	2010	2009	2008	2007	2006	2005	% Participants
Male	2	3	4	2	1	5	43
Female	5	3	2	4	6	3	57
Minority*	0	2	0	1	0	0	7.5

^{*}Includes only students from underrepresented minorities (Hispanic and African-American).

4.1.3 Summer Schools

For four years beginning in 2006, NSO partnered with the Lunar and Planetary Laboratory at the University of Arizona to present a Solar Physics Summer School. The summer school consisted of undergraduate and graduate students attending a week-long program featuring lectures on the most exciting contemporary solar physics research. These summer schools were held at NSO Sunspot with approximately 35–50 attendees from all over the world. Lectures at the summer school included some NSO and University of Arizona staff, but most came from outside organizations. The grant to the University of Arizona that paid for the program ended in 2010. NSO plans to seek new funding to continue this highly successful school in partnership with the University of Hawai'i and the Center for Adaptive Optics. NSO continues its strong participation in the International Research Experience for (Graduate) Students, or IRES. The program has been taking place in Bangalore, India since the summer of 2007 under the auspices of the Indian Institute of Astrophysics and will continue through the summer of 2012.

4.1.4 Interactions with the University Community

The NSF program that has resulted in four new solar physics faculty at four different universities will greatly aid and ensure the health of solar physics in the US. The positions, partially funded by NSF, were awarded to the Institute for Astronomy (IfA) at the University of Hawai'i, the Lunar and Planetary Laboratory (LPL) at the University of Arizona, the University of Colorado, and New Mexico State University (NMSU). As a result of this NSF initiative, three PhD students are working

on thesis projects in close collaboration with NSO. In 2007, the strengthened solar physics group at LPL successfully recruited a solar physics graduate student who participated as an REU program with NSO and is now working closely with scientists at NSO on his thesis. These new positions have helped foster closer ties between NSO and the university community.

Additional interactions with US universities that involve graduate students include a graduate student at NMSU who is working on his PhD with NMSU, US Air Force, and NSO support, and a University of Hawai'i Institute for Astronomy (UH/IfA) student who has been working on her PhD thesis based on a UH/IfA instrument located at NSO. She will defend her thesis in August 2011. All three of these thesis students previously participated in NSO REU or SRA programs.

NSO has collaborated with minority serving universities such as the California State University at Northridge and New Mexico State University in the formulation of MRI-R² proposals to enhance their research and educational programs.

4.1.5 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 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 scientific 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. The NSO and the University of Arizona Lunar and Planetary Lab jointly sponsor a "brown bag lunch" seminar series on topics primarily in solar and heliospheric physics in which all of the scientific staff, including postdocs, participate as speakers on a regular basis. 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 resumé 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 roundtable 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.

NSO is working to 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 scientific, 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 US and the world, providing postdocs with experience in dealing with diverse groups.

4.1.6 K-12

4.1.6.4 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.

4.1.6.5 K-12 Classroom Research Activities

Two educational modules were developed by NSO to be used in the classroom at middle- and high-school 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. In addition to providing and collating the data, NSO provides assistance in using the modules. Those wishing to incorporate this data set and activities will find that it addresses many of the national science standards. Both Project 2061 and the National Science Education Standards are referenced to provide validity for performing such investigations in the classroom. This resource is rich in scientific content standards as well as emphasizing scientific process standards.

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. NSO provides a module using GONG data that allows the student to measure solar rotation and learn about the difficulties of inferring three-dimensional information from two-dimensional projections.

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.

4.1.7 Public Outreach

4.1.7.1 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. The McMath-Pierce Facility also includes an educational exhibit referred to as the "Sunnel." The tunnel that leads from the entrance to the Main Observing Room features exhibits or displays that take the visitor from the center of the Sun to its outer atmosphere along the length of the "Sunnel."

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.

During FY 2010, NSO procured most of the major elements of the Sunspot Solar System Model. The planet models and two large graphics were installed, and the remainder of the work was completed November 2010. The New Mexico Department of Transportation (NMDOT) installed most of the

highway signs for the Sunspot Solar System Model during April and May 2011. Sunspot now has the largest solar system model in the West, the third largest in the US and the sixth largest in the world. Several designs are being adapted to be taken on the road to New Mexico schools and thus serve as a starting point for the Sun on Wheels, portable activities in ATST outreach. Podcast materials are being developed that will be available online. Designs and materials are being translated into Spanish to help attract Hispanic audiences. NSO is developing software to provide near-real time and other images to the National Air and Space Museum at NASM's invitation. These will be available to all museums.

4.1.7.2 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 that 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 members respond to these questions individually.

Near-real-time solar images are also available from NSO instruments on the following Web pages <code>nsosp.nso.edu/data/latest_solar_images.html</code>, <code>solis.nso.edu/</code>, and <code>gong.nso.edu/</code>.

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.

4.1.8 *Future*

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. Some of the priorities will include:

- Increasing NSO's online 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.
- Enhancing the content of our outreach modules and exhibits.
- Develop a proposal to expand NSO programs and community interaction.

4.2 Broadening Participation and Increasing Staff Diversity

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 has 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:

- Expand recruitment efforts of underrepresented groups through broader advertising venues for NSO job opportunities.
- Participate in STEM-related society meetings, either national or regional, serving underrepresented communities such as the National Society of Black Physicists (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).
- Add a scientific staff member from an underrepresented group to the NSO Scientific Personnel Committee.
- Continue PAARE student participation in the NSO as funded by the Fisk/Vanderbilt and NMSU PAARE proposals, as well as graduate student participation in the NSO through the Fisk/Vanderbilt Masters-to-PhD Bridge program. Respond to interest expressed by additional institutions to propose for a PAARE program with the NSO. Expand this beyond the scientific staff to include our engineering and technical staff as mentors.
- Identify more mentors among the engineering and technical staff in addition to the scientific staff.

Long(er)-term goals:

- Increase the number of underrepresented students in the NSO REU program, ideally, with a supplement to our REU funding.
- Expand the RET program effort by targeting teachers at underrepresented minority-serving institutions, including getting funding for more RETs.
- Increase the number of underrepresented minorities on the scientific and/or engineering/technical staff during the next three to five years.
- 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 joined the NSO in the summer of 2009 to work on GONG and SOLIS instrumentation, respectively, and as previously mentioned, he is now working on a Master's thesis on flare excitation of high- ℓ p-modes based on archived GONG data. In addition, we hired an African-American who received his PhD in physics in 2009 from Howard University; he spent two years working at NSO/Tucson on a project supported by a NASA HMI grant. One of our female scientific staff members (untenured) has been added to the NSO Scientific Personnel Committee. The NSO is also represented at selected science and engineering society meetings that serve underrepresented groups.

5 IMPLEMENTATION

NSO has partially reorganized its programs to accommodate the ATST construction effort. At Sunspot, some of the technical and scientific staff members that previously supported the Dunn Solar Telescope operation and projects have transferred to ATST construction. We have added a few ATST engineers in both Tucson and Sunspot. In addition, with the installation of the final SOLIS instruments and the fielding of a GONG H-alpha capability, we have implemented the reorganization of these two programs into a single Synoptic Program.

Implementation of NSO's strategic, long-range plan by its staff, in collaboration with the community, provides this evolution of NSO that will play a fundamental role in maintaining US preeminence in solar physics. As NSO undertakes the tasks outlined in its strategic plan, we will continue to form strong collaborations to enhance NSO's long-term program and its impact on strengthening the solar physics community.

The NSO long-range strategy 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 the combining of resources currently divided among operations in Sunspot and Tucson as well as additional operation staff. The ATST will produce a ten-fold or more increase in the data NSO needs to archive and, unlike for our current flagship telescopes, NSO plans to process ATST data and make it publically available.

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 ATST ramps up towards its operational phase, NSO will consolidate its staff at a single headquarters location and relocate staff, or hire locally, to support operations on Maui.

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, broadening participation, and the intellectual growth of its scientific staff. These five 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.

A few of the DST positions that transferred to ATST were refilled to sustain support of the community at the DST until ATST is commissioned. In addition, the DST is serving as a test bed for many of the ATST instruments and optical systems, including wave front correction. GONG has obtained support from the USAF to support its operations. This frees NSO funds for ramping up SOLIS operations and scientific support. Combining SOLIS and GONG operations into a single synoptic program allows NSO to achieve some economies of scale (data handling, technical support, science support) that will release resources to help ramp up to ATST operations.

As the NSO road map (Figure 1 in the Executive Summary) unfolds, some of the critical-decision milestones include:

- Starting on-site construction of ATST (2011-2012).
- Decision on and negotiations for NSO directorate site location (2011–2012).
- Development of a proposal to move to and operate the new NSO site (2013-2014).
- Relocation of SOLIS to a superior synoptic site at a longitude favorable for a future three-site network (2014-2015).
- Commissioning of the ATST (2018).
- Divestment of older facilities (2017–2018).
- Consolidation of the NSO (2015–2017).

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. In addition to helioseismic measurements, GONG is providing continuous high-cadence, full-disk longitudinal magnetograms and rapid cadence full-disk H-alpha images. 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 and its director will be responsible for the operation of ATST and its integration into existing programs. Agreements with national and international partners will also play a yet to be determined role in ATST operations. 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 will establish advisory committees 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 is working closely with universities to increase the output of young solar physicists. As part of consolidation, NSO will establish 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 groups, is a primary criterion.

5.1.1 NSO Site Location 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 site will be located on or near a university that has or is willing to build a strong solar faculty. As operations at the two NSO sites are ramped down, establishing a single directorate site 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.

It is important to realize, however, that providing these scientific and organizational benefits will most likely 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 on Maui is approximately 56% higher than Tucson. Also, an NSO directorate site 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 retaining a scientific staff to make this all happen, will require substantial increments in the fiscal years during which a new NSO directorate site is established and when the ATST becomes operational.

AURA received seven proposals in response to its solicitation for a new NSO directorate site. After review by an eight-person panel, two proposals were selected for further review and discussion. These are the University of Colorado in Boulder, and the University of Alabama in Huntsville. After selection of the best site for NSO is made — currently scheduled for Fall 2011 — AURA will develop a cost and schedule for consolidation that will be submitted to NSF as part of the next Cooperative Agreement. The schedule will be tied to several factors, including the ramp 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 the 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.

In addition to the budget ramp-up needed to operate, NSO's transition to the ATST era with staff relocated to Maui for telescope operations and to a new, yet-to-be determined, directorate 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 budget projections. It will come as a one-time request when costs are better known. Table 5.1-1 contains a rough estimate of these costs with an attempt to bracket the potential costs.

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. It is our understanding that NSF plans to contract with an engineering firm to make a more accurate estimate of these costs.

Table 5.1-1 Estimated Relocation and Closure Costs						
Staff Relocation		Low	High			
To Maui	Relocating 25-35 personnel @\$ 40,000/person	\$1,000,000	\$1,400,000			
To Headquarters	Relocating 50 personnel @ \$15,000/person	\$750,000	\$900,000			
Equipment to Maui	Vehicles, optics, instruments	\$500,000	\$550,000			
Equipment to HQ	Electronics, optics, machine tools, computers, data archives	\$500,000	\$550,000			
Closure Costs						
Deconstruction of Sac Peak						
Building Removal		\$4,500,000	\$6,500,000			
Ground Restoration		\$300,000	\$500,000			
Hazardous Material Cleanup	Mercury, oil and gas spillage	\$200,000	\$400,000			
Kitt Peak						
Mothball McMP		\$200,000	\$200,000			
Relocation of SOLIS		\$550,000	\$750,000			
	Total	\$8,500,000	\$11,750,000			

5.1.2 Maui Operations

Ramp-up of operations 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 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 staffing is required, NSO will have to obtain more space to accommodate approximately 30-35 personnel consisting of technical and science support for the telescope, administrative and computer support, and some laboratory and storage space. We refer to this additional space as a base-facility, or remote operations building (ROB). Approximately six additional personnel would spend most of their time at the telescope and would not need permanent space at the remote operations center. Establishing an operational capability from the ROB has been discussed to reduce travel to and from Haleakalā, but it is not funded in the construction budget.

As ATST construction progresses toward completion, key NSO personnel and NSO base funding will be transferred to support ATST operations 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 to fill technical and scientific jobs. In this respect, NSO plans to work closely with Maui Community College, the University of Hawai'i Institute for Astronomy, the Akamai Internship Program, 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 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 FY 2011, 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 2015 time frame and be complete when the ATST is commissioned. Staffing in Table 5.2-1 for FY 2017/2018 assumes the additional resources described in Section 5.7 are made available.

A rough estimate is that ~60-70% of NSO employees would transfer either to Maui or to NSO's new directorate site 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 US solar physicists with the best solar facilities in the world. NSO scientific and management staff, as well as affiliated scientific staff, are listed in Section 5.2.2 with respective primary areas of expertise and key observatory responsibilities.

		EV/10	EV/11	FV/10	E\/12	EV4.4	EV/1E	E\/1/	E\/17	EV/10
NOO 110	B	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18
NSO HQ	Director	2	2	2	2	2	2	3	3	3
	Scientific Staff	0	0	0	0	0	2	14	15	16
	Technical Staff					0	2	14	15	16
	Data Center					0	1	11	12	13
	Science Support					0	1	8	8	8
	Administrative Support					0	2	5	5	5
	Total HQ	2	2	2	2	2	10	55	58	61
ATST	Development									
	Construction	14	0	0	0	0	0	0	0	0
	Operations on Maui	4	30	36	38	44	50	59	47	37
	Operations/science at HQ	0	0	0	0	0	0	2	2	6
	ATST	18	30	36	38	44	50	61	49	43
Sunspot	Scientific Staff	4	4	4	4	4	4	3	2	0
	DST Operations	4	4	4	4	4	4	4	0	
	DST Technical Support	3	3	3	3	2	1	1	1	
	Projects (Controls, AO/MCAO, DLSP, etc.)	7	7	7	7	8	2	1	0	
	Technical Support (Hilltop & Evans)	1	1	1	0	0	0	0	0	
	Facilities (maintenance, sewage, roads, project	5	5	5	5	5	4	2	2	
	Scientific Staff Support (secretarial, library,	4	4	4	4	4	3	1	0	
	Administrative Support (site management,	5	5	5	5	5	4	1	1	
	Sunspot	33	33	33	32	32	22	13	6	
Tucson	Scientific Staff	4	3	3	3	3	3	1	0	
	McMP Operations	2	2	2	2	2	2	1	0	
	Projects (NAC, controls)	3.2	4	4	4	4	2	0	0	
	Facilities (NOAO)	3	3	3	3	3	3	1	0	
	Science Support (NOAO)	2	2	2	2	2	1	1	0	
	Administrative Support (0.5 + NOAO)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0	
	Tucson	14.7	14.5	14.5	14.5	14.5	11.5	4.5	0	
SOLIS	Scientific Staff	2.8	4	4	4	4	4	4	0	
JOLIJ	Technical Staff	3.3	2	2	2	2	2	2	0	
	Science Support	3.3	4	5	5	5	5	5	0	
	SOLIS	9.1	10	11	11	11	11	11	0	
GONG	Scientific Staff	6	5	4	4	3	3	1	0	
	Telescope Operations	8	8	7	6	5	4	2	0	
	Data Center Operations	8	7.3	7	6	4	3	2	0	
	Facilities (NOAO)	3	3	3	2	2	2	1	0	
	Science Support (NOAO)	2	2	2	1	1	1	1	0	
	Administrative Support	1.5	1.5	1.5	1.5	1	1	0.5	0	
	GONG	28.5	26.8	24.5	20.5	16	14	7.5	0.0	
	Total FTEs	105.3	116.3	121	119	120.5	121.5	151	136	106

5.2.2 Sunspot-Based Scientific and Key Management Staff

(*Grant-supported staff)

NSO Staff

Serena Criscuoli – DST instrumentation; solar magnetic fields and convection.

David F. Elmore – Ground-based spectrograph and filter-based polarimeter development; ATST Instrument Scientist.

Steven Hegwer – ATST Instrument Engineer, Optical design.

Rex G. Hunter –NSO budget management; ATST business support; Support Facilities and Business Manager.

Craig Gullixson – DST Technical and Project Manager.

Stephen L. Keil – NSO Director; ATST PI; solar variability; convection.

Alexei A. Pevtsov – Solar activity; coronal mass ejections; solar magnetic helicity; SOLIS Program Scientist.

Thomas R. Rimmele – Associate Director, ATST Project Scientist; Associate Director for ATST work packages at Sac Peak; Solar fine structure and fields; adaptive optics; instrumentation.

Han Uitenbroek –Atmospheric structure and dynamics; radiative transfer modeling of the solar atmosphere; DST Program Scientist; Ch., NSO/SP Telescope Allocation Committee; ATST Visible Broadband Imager.

Alexandra Tritschler – Solar fine structure; magnetism; Stokes polarimetry; ATST operations development.

Friedrich Wöger – ATST Data Handling Scientist; ATST Visible Broadband Imager PI; high-resolution convection; solar fine structure; magnetic fields.

Air Force Research Laboratory Staff at Sunspot

Richard C. Altrock – Coronal structure and dynamics.

Edward Cliver – Solar activity; flares, CMEs.

Richard R. Radick – Solar/stellar activity; adaptive optics.

S. James Tappin – Coronal mass ejections.

Postdoctoral Fellows

*James Lewis Fox – Spectropolarimetric studies of solar prominences

*Jose Marino – ATST wavefront correction; image restoration.

*Nina V. Karachik – Solar helicity and activity.

Thesis Students Using NSO Facilities and Data Thesis Students

Michael Kirk (New Mexico State University) – Flare prediction.

Sarah Jaeggli (University of Hawai'i) – Facility Infrared Spectrometer and solar polarimetry.

5.2.3 Tucson-Based Scientific and Key Management Staff

NSO Staff

Luca Bertello –Solar vector magnetic fields; helioseismology; SOLIS Data Scientist.

Mark S. Giampapa – NSO Deputy Director; stellar dynamos and magnetic activity; asteroseismology; astrobiology; Ch., NSO/KP Telescope Allocation Committee; Ch., Scientific Personnel Committee; SOLIS PI.

Irene E. González Hernández –Local helioseismology; helioseismic holography; ring diagrams; GONG Program Scientist.

Frank Hill - Associate Director, NSO Synoptic Program; solar oscillations; data management.

John W. Harvey – Solar magnetic and velocity fields; helioseismology; instrumentation; SOLIS Project Scientist.

Shukur Kholikov – Helioseismology; data analysis techniques; time-distance methods.

John W. Leibacher – Helioseismology; atmospheric dynamics.

George Luis – GONG Program Manager.

Matthew J. Penn – Solar atmosphere; solar oscillations; polarimetry; near-IR instrumentation; Co-Site Director, NSO REU/RET Program; McMath-Pierce Facility Scientist; ATST near-IR.

Anna Pietarila - Chromospheric dynamics and magnetism; spectropolarimetry.

Priscilla Piano – Administrative Manager: Director's office and Tucson site support; NSO grants and NSO/Tucson site budget management.

Kim V. Streander – Technical Program and Telescope Manager; SOLIS Program Manager; NSO Synoptic Program Manager.

Postdoctoral Fellows

*Olga Burtseva – Time-distance analysis; global helioseismology; leakage matrix.

Sanjay Gosain – Spectopolarimetry; solar magnetic fields; instrumentation.

*Brian J. Harker-Lundberg – Stokes spectropolarimetry of the photosphere; Stokes inversion techniques for inferring vector magnetic fields; automated tracking and classification of sunspot and active region structure; parallel processing computational techniques for data reduction.

Thesis Students

Matthew Richardson (Fisk University) – Helioseismology.

Thomas Schad (University of Arizona) – IR spectropolarimetry.

Grant-Supported Scientific Staff

- *Michael Dulick Molecular spectroscopy; high-resolution Fourier transform spectrometry.
- *Kiran Jain Helioseismology; solar cycle variations; ring-diagram analysis; sub-surface flows.
- *Rudolph W. Komm Helioseismology; dynamics of the convection zone.
- *Gordon J. D. Petrie Solar magnetism; helioseismology.
- *Sushanta C. Tripathy Helioseismology; solar activity.
- *Roberta M. Toussaint Helioseismology; image calibration and processing; data analysis techniques.

5.2.4 Future Science Staffing

In addition to the current 18 members of the NSF supported scientific staff and 11 grant supported scientific staff, NSO expects to add 4-5 more NSF supported scientific staff in the ATST era, bringing the total NSF supported scientific staff to ~22-23. Several of these will be on Maui at any given time. Of the NSF supported staff, eight are tenured, two are tenure-track, and the remaining eight are non-tenured scientific staff. Eleven NSO scientists are supported on externally-funded projects, grants, contracts, and other soft money.

A dedicated ATST scientific staff is required to optimize ATST scientific capabilities. Early on, scientists will participate in commissioning, testing, and acceptance efforts. 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 multiconjugate 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 construction to ATST operations provides approximately six or seven of the needed FTEs. As part of the ATST construction proposal, NSO estimates that a minimum of eight, and preferably 12–13, 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.

Now that ATST construction funding has commenced, NSO will finalize a staffing plan that will accommodate the transition from operating its current facilities to those needed in the ATST era. Once NSO has accumulated experience with the Synoptic Program, determines the level of support needed for an NSO Data Center that can handle ATST data and interface to the VSO, and refines the operational plan for ATST, the required staffing levels can be accurately determined. Table 5.2-2 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 5.2-2. 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 respective affiliations and primary interests are listed in Table 5.3-1. The Users' Committee meets formally once per year and informally as needed.

	Table 5.3-1. NSO User	s' Committee
Name	Institution	Primary Interest
Douglas C. Braun	NorthWest Research Associates	Helioseismology
Roberto Casini	High Altitude Observatory	Coronal Properties
Debi Prasad Choudhary	California State Univ. Northridge	Solar magnetism; Instrumentation
Craig DeForest	Southwest Research Institute	High-Resolution Imaging; Convection
Carl J. Henney	Air Force Research Laboratory	Space Weather
K.D. Leka	NorthWest Research Associates	Solar Polarimetry
Haosheng Lin	University of Hawai	Infrared Instruments, solar magnetic fields
James McAteer	New Mexico State University	High speed imaging, oscillations
Douglas Rabin, Chair	NASA Goddard	Polarimetry; Instrumentation; Mission Support
Alysha Reinard	NOAA Space Env. Center	Space Weather
Craig B. Foltz	NSF (ex-officio)	Program Director, NSO and ATST

NSO disseminates information to the community through several channels. These include the *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 SDO. 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, and serve on panels to review international solar facilities and programs.

NSO's users receive funding from diverse sources, including two NSF divisions (Astronomical Sciences, and Atmospheric and Geospace Sciences), universities, NASA, the US Air Force, and the Department of Commerce (NOAA). 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 from nighttime scheduling 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 US 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 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. A queue-based program is available at the Dunn Solar Telescope and at the Kitt Peak SOLIS Tower to enhance coordination with space missions and take advantage of good seeing opportunities.

During FY 2010, NSO conducted 68 unique observing programs, of which 16 were thesis programs involving 11 graduate students. A total of 61 visiting telescope users (26 US and 35 foreign) represented 9 US and 11 foreign academic institutions, and 3 US and 2 foreign non-academic institutions. Table 5.3-2 lists the users by category.

Table 5.3-2. Users of NSO Facilities by Category (FY 2010)							
		Visitors NSO Staff					
	US	US Non-US Total % Total					
PhDs	22	19	41	67%	13		
Graduate Students	3	16	19	31%	0		
Undergraduate Students	1	0	1	2%	0		
Other	0	0	0	0%	19		
Total Users	26	35	61	100%	32		

Table 5.3-2, however, represents only a small fraction of the users of NSO facilities and data during FY 2010. A significant number of data files are regularly transferred from the FTP sites at NSO/Tucson and NSO/Sunspot. In FY 2010, a total of 5,785 Gbytes of data where downloaded from NSO FTP and

WWW sites. Approximately 3,820 Gbytes went to US science sites, 1,102 Gbytes to other US sites, and 821 Gbytes to foreign sites. Helioseismology accounted for the bulk of the transfers (2,947 Gbytes).

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

Because 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 that 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.

5.4 Community Partnerships and NSO Leadership Role

Through its operation of the majority of US ground-based solar facilities and its ongoing synoptic programs, NSO is clearly important to the solar community. In turn, NSO must work closely with the solar community and provide leadership to strengthen solar research, renew solar facilities and to develop the next generation of solar instrumentation. Recent examples of NSO meeting this responsibility include the addition of rapid magnetograms and H-alpha images to GONG; development of solar adaptive optics and multi-conjugate adaptive optics for both NSO and university telescopes; development of infrared observing capabilities in collaboration with the University of Hawai'i, California State University-Northridge, and NASA; leading the development of SPINOR in collaboration with HAO, and participating in IBIS with Arcetri Observatory, and ROSA with Queens University Belfast. Table 5.4-1 lists several ongoing joint projects and development efforts.

NSO will continue to work closely with the ATST Science Working Group and the community to develop a sound operations 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 with 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 US Air Force space science group will continue into the ATST era. NSO the Air Force Weather Agency is providing funding to help operate GONG. 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 5.4-1. J	oint 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 CfA, 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, Cal State Northridge
Adaptive Optics, Multi-Conjugate AO	NJIT, Kiepenheuer Institute, AFRL
Diffraction-Limited Spectro-Polarimeter ((DLSP)	HAO
Spectropolarimeter for Infrared and Optical Regions (SPINOR)	HAO
Rapid Oscillations in the Solar Atmosphere (ROSA)	Queen's University, Belfast
Narrowband Filters and Polarimeters	Arcetri Observatory, Kiepenheuer Institute
Synoptic Solar Measurements	USAF/AFRL, NASA
Fourier Transform Spectrometer	NASA
IR Spectrograph and Cameras	U. Hawai'i, Cal State Northridge
Advanced Image Slicer & Integral Field Unit	Cal State Northridge
Virtual Solar Observatory	NASA, Stanford, Montana State, Harvard-SAO
H-alpha Imaging System (GONG)	Air Force Weather Agency (AFWA)/AFRL
Small Synoptic Second Solar Spectrum Telescope (S5T)	Utrecht University

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; 5 scientists, including 1 postdoc, stationed at NSO/SP; daily coronal emission line measurements; provides operational funding for SP: \$400K-Base and various amounts for instrument development. NSO/Tucson Farside ADAPT Project support (0.25 FTE).
Air Force Weather Agency	Funded the addition of an H-alpha capability for GONG. Providing ~750K/year for GONG/Synoptic Program operations.
NASA	 Funding for SOLIS Science Goals: Postdoctoral Research Associates (1.25 FTE); Instrument/Observing Specialist (0.5 FTE). McMath-Pierce: Support for Operation of the FTS (1.0 FTE); Upper Atmospheric Research; Solar-Stellar Research; Planetary Research. DST: Support for a Research Fellow for <i>Hinode</i> mission support (coordinated observations, science planning, mission operations, data analysis) (via Lockheed-Martin sub-award). GONG: 3.0 FTE Scientific Support; SDO/HMI Pipeline Development Support (0.7 FTE). Virtual Solar Observatory Development Support (0.75 FTE). Development of VSM advanced flux estimate map for next general model of the corona and solar wind (via SAIC sub-award). SHINE research support for 3 scientists at 0.17 FTE each. SDO/GONG White-light flare study support via UC-Berkeley SSL sub-award (0.11 FTE) Active Region Flaring Predictions using Helioseismology research support via UC-Boulder sub-award (0.33 FTE).

GONG is actively seeking additional operational partnerships with members of the space environment community, including international partnerships for site operations and data processing. SOLIS is continuing discussions for establishing a SOLIS network with Germany, Spain, and Australia.

5.6 NSO Organization

During the ATST construction phase, the challenges to NSO have shifted. In addition to transitioning personnel to ATST construction tasks, we have other personnel charging some of their time to ATST and some to the base program. Preventing the loss of essential personnel as we pursue a new NSO directorate site location will be a challenge. NSO will also use opportunities provided by reorganization to continue the pursuit of increased diversity and educational outreach. Because of these challenges and to achieve economy of scale in other areas, NSO is reorganizing parts of its management structure to accommodate immediate needs during the transition to construction and to begin an evolution toward the structure we anticipate NSO will need when ATST becomes operational. During this period, NSO needs to continue its strong support of the solar community while using current assets to develop ATST instruments to test ATST operational concepts, and to train personnel on the multi-instrument, high-data output expected with ATST.

5.6.1 Director's Office

The NSO Director's office consists of the Director, a Deputy Director responsible for overall Tucson operational support, and an Executive Administrative Manager; it also receives financial and budget support from the NSO/SP-ATST Facilities and Business Manager. The Director, Stephen Keil, currently resides at NSO/SP and also serves as the ATST Project Director. The NSO Deputy Director, Mark Giampapa, serves as site director for Tucson, interfacing with the NOAO for shared facilities, chairing the Scientific Personnel Committee, and supervising senior scientific personnel. His funding is included in the Tucson base budget, but should migrate to the director's office budget when the NSO moves to its new location. In addition, the NSO Director shares support personnel with NOAO for accounting, human resources, graphics, and educational outreach.

5.6.2 NSO/Sacramento Peak

NSO/SP operates the Dunn Solar Telescope on Sacramento Peak and provides some maintenance support for the Evans Solar Facility. NSO/SP is undertaking several ATST work packages during ATST construction. This has increased pressure on office space and housing. In addition to telescope support, the staff at SP supports an office building, library, computing, instrument development, and housing facilities for visitors and the resident scientific and technical staff. Thomas Rimmele is the Associate Director leading the ATST work packages at SP. Han Uitenbroek is now in the role of DST Program Scientist and he will continue to report to Thomas to ensure a seamless transition. Han leads and oversees telescope operations and instrument projects. Thomas also continues to serve as ATST Project Scientist. The previous DST Project and Telescope Manager, Steve Hegwer, has transitioned to ATST as Instrument Engineer. Craig Gullixson has replaced Hegwer at the DST and reports to Han Uitenbroek. Rex Hunter, who has been responsible for buildings and grounds, administration, and business functions, is taking on the additional role of business manager for the ATST project. He continues with the business management functions for NSO, but many of his prior duties at SP have been delegated to other personnel. We will hire replacements for some of the technical and engineering positions that transfer from supporting the DST and projects to ATST, but not all. With the reduction in technical staff, we have reduced the number of projects at the DST in order to concentrate on science operations with the newly completed suite of diffraction-limited instruments and support for testing of ATST instrument technologies.

5.6.3 NSO Tucson and NSO Synoptic Program

NSO 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 support from Priscilla Piano as Administrative Manager. McMath-Pierce operations and projects are led by a telescope scientist, Matt Penn, who reports to the Deputy Director. Kim Streander manages project and operational personnel for the McMP. Frank Hill has been appointed Associate Director for Synoptic Programs. Both the SOLIS Program Scientist (Alexei Pevtsov) and the GONG Program Scientist (Irene González Hernández) will report to Hill. Kim Streander will also serve as Program Manager for the Synoptic Program. George Luis will be instrument and operations manager and Sean McManus will manage the synoptic data center. Both positions report to Streander.

5.6.4 NSO ATST

NSO/ATST is now funded through both the NSF MREFC program and through funds from the American Recovery and Reinvestment Act (ARRA). The NSO Director currently serves as ATST Director. Interim Project Manager Mark Warner and Project Scientist Thomas Rimmele report to the Director. The ATST project staff reside in Tucson, at Sacramento Peak, and now in Hawai'i. This allows the ATST team to interact with NSO operations and projects. Lead engineers have responsibility for the various ATST work packages. As noted, some NSO personnel have transferred full time to ATST construction while others will work part time for the project.

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. Now that ATST construction funding is secured, NSO is planning for the reorganization that will be needed to support ATST operations. ATST commissioning will lead to the ramp down of current operations and divestment of current facilities. 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.

5.6.5 NSO Future Organization

During the ATST era, the NSO will reorganize to support ATST operations on Maui and maintain healthy synoptic and instrument programs. NSO will no longer operate the DST on Sacramento Peak and the McMP on Kitt Peak. NSO plans to consolidate its workforce at a location that provides an optimal management focus for the Advanced Technology Solar Telescope era, and can benefit the growth of the solar research community. NSO will also move part of its work force to Maui, in addition to new hires on Maui to operate the ATST.

5.7 Spending Plan

Table 5.7-1 summarizes a long-range funding profile for NSO based on preliminary targets provided by the NSF. NSF funding for the period FY11-FY14 is determined under the current Cooperative Agreement between the NSF and AURA. The FY11 figure shown is the amount that was in the President's budget released in February 2010 and is the amount to which NSO had developed its preliminary FY11 program. This amount was reduced from \$9.510M to \$9.1M. NSO reduced its spending accordingly by not filling several empty positions. The FY12 figure is what was in the President's submission to Congress. FY13-FY18 funds are approximate target figures provided by

NSF. FY15 and beyond will be negotiated in the next Cooperative Agreement. The spending figures shown are estimates in FY 2010 dollars of what NSO will need to operate the ATST and maintain a synoptic program and data center at its primary location.

Table 5.7-1. Long-Range Budget Estimates (Dollars in Thousands)								
	Current Cooperative Agreement				Next Cooperative Agreement			
Program	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18
Director's Office ¹	411	500	540	556	822	847	873	898
NSO Directorate Site Development/Operations ²	22	60	62	214	800	965	964	993
ATST Support at HQ	0	0	0	150	766	1,200	1,236	2,915
ATST Operations on Maui ³	0	0	0	1,300	1,500	1,822	5,356	6,897
ATST Administrative Support	0	0	0	0	240	400	412	600
Instrument Program/Maintenance	0	0	0	500	1,000	1,330	1,370	2,200
Data Center/Software/Computing	0	0	0	2,379	2,700	1,700	1,751	2,091
ATST EPO Program	0	0	0	394	400	412	424	550
In-House Efforts toward ATST Operations ⁴	90	120	391	534	1188	1618	0	0
Tucson/McMP	720	770	744	766	789	813	0	0
Synoptic Program ⁵	0	4,253	4,154	4,278	4,407	4,539	3,000	3,090
GONG	2,134	0	0	0	0	0	0	0
SOLIS	2,047	0	0	0	0	0	0	0
Sac Peak ⁶	2,817	2,811	2,886	2,872	2,837	1,772	983	0
NOAO Support	979	980	1,009	1,040	1,071	1,102	1,137	1,170
AURA Management Fee	290	296	305	407	480	480	494	596
Total	9,510	9,790	10,091	15,390	19,000	19,000	18,000	22,000

Actual Received 9,100 ????

Since additional funding (Air Force support, grants, etc.) are not known, those are not shown but we expect to receive continued support for synoptic programs from other agencies and will seek additional support for ATST operations and science. Table 5.7-1 shows a delta in NSF funding in FY15 which would be required to begin supporting an NSO Directorate location and to begin the ramp up to ATST operations. This delta would be part of the Cooperative Agreement proposal to NSF that is needed for ramping up operations on Maui and at NSO HQ. The delta is only for operations; it does not include moving costs or costs of closing current facilities. The figure for FY18 assumes we are in full operation of ATST and all NSO personnel have shifted either to the new Directorate Site or to Maui for ATST operations.

¹Assumes that the Deputy Director moves from the Tucson budget to the Director's office budget in FY 2015.

²Assumes a delta in FY 2014 and FY 2015 to accommodate new directorate site location.

³Relocation of operations personnel to Maui for integration, testing and commissioning (ITC) training, ramping up to initial operations in FY 2017 and full operations in FY 2018.

⁴In-house development of ATST operations model, data handling, multi-instrument programs; uses DST as test bed.

⁵Assumes that GONG and SOLIS are combined into a single program, SOLIS science and operations support are ramped up, and that GONG continues to obtain outside funding (not included in this table) to support its operations.

⁶Some residual funding is left at Sac Peak to cover staff assistance with closedown of facility. A rough estimate of actual closing costs is \$5.2M-\$7.2M, but this has not been accurately costed. A better scenario is to find an organization willing to assume operations.

5.7.1 Final FY 2011 Budget

The detailed breakdown of the final NSO budget for FY 2011 by work area and functional unit is shown in Table 5.7-2. This is a revision of the budget submitted in the Program Plan for FY 2011 and reflects the latest guidance from NSF. Compared to the target budget at the beginning of FY 2011, it is reduced by \$410K. In order to meet this reduced budget, NSO left unfilled several scientific and technical position vacancies. These reductions impacted the amount of support NSO could offer its users and slowed completion of SPINOR and FIRS at the DST and implementation of the SOLIS data pipeline. The upper portion of the table shows the projected total NSO funding, including 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 NSO operations and maintenance programs. The revenue line labeled Programmed Indirects 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.

Table 5.7-2. NSO FY 2011 Revised Spending Plan (Dollars in Thousands)						
	,			Tucson		
	Director's	Sunspot		SYNOPTICS		TOTAL
Expenses	Office		McMP	GONG	SOLIS	
Director, Staff, Committee Support	425					425
Directorate Site Development	16	6				22
Scientific Staff		713	159	970	473	2,315
Scientific Support/Computing		367	56	673	663	1,759
Instrument Development		837	195	284	504	1,820
Maintenance/Telescope Operations		348	211	663	251	1,473
Facilities		682				682
Administrative Support		226	99	199	66	589
Educational & Public Outreach	108 ¹	163	66			336
NOAO Business Support ²	45	171	152	267	209	844
ATST Fellowship ³		150				150
AURA Management Fee	256					256
Program Total	850	3,663	938	3,056	2,166	10,671
Revenue		0				
Programmed Indirects/Carryover	(24)	0	0			(24)
Housing Revenue		(104)				(104)
Meal Revenue		(17)				(17)
NSF REU/RET Funding		(66)	(66)			(132)
Air Force Support		(400)		(740)		(1,140)
ATST Fellowship Support		(100)				(100)
Visitor Center Revenue		(55)				(55)
NSF/AST Funds	826	2,921	872	2,316	2,166	9,100

¹ These funds are transferred to NOAO to support mutual EPO programs.

² These funds are transferred to NOAO for HR, accounting, contracting and facilities services in Tucson.

³ AURA provides support for cost sharing of an ATST Fellowship.

5.7.2 FY 2012 Preliminary Budget

Table 5.7-3 shows NSO's preliminary FY 2012 spending plan, conforming to the President's proposed budget of \$9,790K.

Table 5.7-3. NSO FY 2012 Preliminary Spending Plan (Dollars in Thousands)						
	5:	Director's Office Sunspot	,			
				SYNOPTICS		TOTAL
Expenses			McMP	GONG	SOLIS	
Director, Staff, Committee Support	568					568
Site Development	16	6				22
Scientific Staff		686	166	1,010	491	2,353
Scientific Support/Computing		376	55	746	682	1,860
Instrument Development		899	221	294	533	1,947
Maintenance/Telescope Operations		362	226	686	286	1,560
Facilities		730	0	0	0	730
Administrative Support		232	102	206	68	608
Educational & Public Outreach ¹	111	163	66	0	0	339
NOAO Business Support ²	46	176	157	274	217	870
ATST Fellowship ³		220	0	0	0	220
AURA Management Fee	296	0	0	0	0	296
Program Total	1,036	3,850	992	3,217	2,277	11,373
Revenue						
Programmed Indirects/Carryover	(24)	0	0	(11)		(35)
Housing Revenue		(104)				(104)
Meal Revenue		(17)				(17)
NSF REU/RET Funding		(66)	(66)			(132)
Air Force Support		(400)		(740)		(1,140)
ATST Fellowship Support		(100)				(100)
Visitor Center Revenue		(55)				(55)
NSF/AST Funds	1,012	3,108	926	2,467	2,277	9,790

¹ The EPO funds under the Director's Office are transferred to NOAO to support mutual EPO programs.

In addition to operations, this funding level will support the continued ramp up of SOLIS science, the MCAO project at the DST, strong support of the solar community, the development of ATST operational concepts and data handling, and provide data for space weather. The \$740K of revenue shown under GONG is the \$800K provided by the Air Force Weather agency for GONG operations less the 5% to NSF, the AURA fee, and the usual G&A charges. This allows us to reduce the NSF cost of operating GONG and use those funds to ramp up SOLIS operations and explore the development of a SOLIS network as suggested in the Senior Review.

Since obtaining the Presidents target figure is unlikely, we have also developed a funding scenario based on continued level funding. It is shown in Table 5.7.-4. The difference of \$680K is substantial and will slow the development of SOLIS science and data pipeline, SPINOR data pipeline, and force

² These funds are transferred to NOAO for HR, accounting, contracting and facilities services in Tucson.

³ AURA provides support for cost sharing of an ATST Fellowship.

us to continue operations short-handed by leaving unfilled three Synoptic Program positions. The increase in the projected budget from \$9.1M in FY 2011 to \$9.790M in FY 2012, in addition to paying for merit raises, was programmed into projects and filling some of our open positions.

Table 5.7-4. NSO FY 2012 Preliminary Spending Plan						
	Dinastanta					
	Director's Office	Sunspot		SYNOPTICS		TOTAL
Expenses	ome:		McMP	GONG	SOLIS	
Director, Staff, Committee Support	433					433
Site Development	16	6				22
Scientific Staff		671	160	951	475	2,258
Scientific Support/Computing		371	56	682	657	1,767
Instrument Development		793	195	279	509	1,776
Maintenance/Telescope Operations		352	213	651	251	1,468
Facilities		686	0	0	0	686
Administrative Support		229	99	201	66	595
Educational & Public Outreach ¹	108	163	66	0	0	337
NOAO Business Support ²	45	172	153	268	210	848
ATST Fellowship ³		220	0	0	0	220
AURA Management Fee	282	0	0	0	0	282
Program Total	884	3,663	942	3,033	2,168	10,692
Revenue						
Programmed Indirects/Carryover	(24)	0	(19)			(43)
Housing Revenue		(104)				(104)
Meal Revenue		(17)				(17)
NSF REU/RET Funding		(66)	(66)			(132)
Air Force Support		(400)		(740)		(1,140)
ATST Fellowship Support		(100)				(100)
Visitor Center Revenue		(55)				(55)
NSF/AST Funds	860	2,921	857	2,293	2,168	9,100

¹ These funds are transferred to NOAO to support mutual EPO programs.

5.7.3 ARRA Infrastructure Support

At the end of FY 2009/beginning of FY 2010, we received \$1.4M in American Recovery and Reinvestment Act funding that has allowed us to accomplish several large maintenance and upgrade projects, including some that have been deferred for many years. Approximately 87% of these funds have been expended through the first three quarters of FY 2011. The remaining funds will be expended over the next few months.

² These funds are transferred to NOAO for HR, accounting, contracting and facilities services in Tucson.

³ AURA provides support for cost sharing of an ATST Fellowship.

Table 5.7-5. ARRA Funded Infrastructure Improvements						
Item	Cost	Description	Status			
DST Deformable Mirror Replacement	\$180,000	Replace old AO mirror.	Completed			
Sac Peak Road Maintenance	\$200,000	Maintenance/Safety.	Completed			
SOLIS Tower Clamshell Hydraulic Rams	\$80,000	Replace failing hydraulic system.	Completed			
MCMP Telescope Control System	\$75,000	Upgrade to modern control system.	Final phase of software integration; to be completed by end of FY11			
McMath-Pierce Glycol Inspection/Maintenance	\$30,000	Safety – Replace corroded pipes.	Completed			
GONG Network Site Workstations	\$81,000	Replace site workstations purchased in 1999.	Completed			
Synoptic Data Processing	\$68,000	Increase capacity of data management and archive to handle SOLIS and real-time GONG data.	Completed			
DST Basic Infrastructure Needs	\$225,000	Upgrade/replace old equipment; improve safety.	To be completed by end of FY11			
McMP CCD Camera	\$35,000	Upgrade to modern CCD.	Completed			
McMP Enclosure Clean and Paint Interior	\$60,000	Maintenance; decrease dust.	Completed			
NSO/SP Workstation Upgrade	\$62,000	Allow rapid reduction of large data sets and modeling.	Completed			
NSO/SP Local Area Network	\$170,000	Upgrade LAN to handle increased data processing	Completed			
NSO/SP Server Upgrades	\$50,000	Replace obsolete equipment to handle increased data flow.	Completed			
GONG Real-Time Data Transfer	\$84,000	Real-time transfer of full resolution GONG data.	Hardware on order; to be completed by end of FY11			
Total ARRA Funds	\$1,400,000					

5.7.4 FY 2011 Unfunded Infrastructure Improvement Requests

While the NSO FY 2011 budget contains sufficient funding to carry out essential routine maintenance, and the ARRA funds are allowing NSO to complete some of the higher priority infrastructure issues, there remains several major infrastructure and maintenance items that are beyond the range of our normal funding. Table 5.7-5 lists these items and is followed by descriptions of each of the items broken down by site. Completion of these items would ensure that NSO continues with a robust operation at its current sites until ATST is online, and that the facilities would be attractive to potential organizations willing to take over when NSO ceases operations.

Table 5.7-6 Unfunded Infrastructure Improvements (Dollars in Thousands)							
Item	Cost	Notes					
NSO/Sac Peak							
DST Turret Repair	75	Replace obsolete controls and hardware					
Zygo Interferometer	75	Optical testing					
Computer Numerical Controlled (CNC) Lathe	50	Instrument development for SP and ATST					
DST Data Acquisition System	50	Continue upgrade to handle larger, faster CCDs					
Loader	85	Snow removal and maintenance					
Main Lab Boiler Lines and Radiators	50	Replace obsolete heating system, reduce cost					
Apartment Building Boiler Lines and Water Lines	50	Replace obsolete heating and water lines, reduce cost					
Vehicle Replacement	25	Replace older vehicle					
Dump Truck/Snow Plow	65	Replace old truck					
Redwood Building Painting	35	Contract to paint redwood buildings					
Total NSO/SP	560						

Table 5.7-6 Unfunded Infrastructure Improvements (cont.)					
		• • • • • • • • • • • • • • • • • • • •			
NSO/Tucson					
GONG Farm Air Conditioner	8	Replace obsolete unit			
McMP Mirror Refigure	60	Improve imaging			
McMP Optical Tunnel Chiller Compressor	40	Improve internal seeing			
FTS Refurbishment	132	Decrease maintenance			
Total NSO/T	240				

5.7.4.1 NSO/SP

DST Basic Infrastructure Improvements

Other basic infrastructure investments needed at the DST to upgrade/replace aging equipment, provide safety improvements, and ensure continued smooth DST operations include:

- DST Turret Repair and Controls Upgrade. Replace 1960's hardware with digital hardware. Estimated Cost: \$75K.
- *Zygo Interferometer*. Enable in house testing of optics and reduce operations cost: Estimated Cost: \$75K.
- CNC Lathe. Needed for on-site ATST machine shop work. Estimated Cost: \$50K.
- *Modernizing the DST Data Acquisition System (DAS),* i.e., data storage, network, acquisition system (to handle the increased data loads from high-speed large-format cameras). Estimated Cost: \$50K.

NSO/SP Facilities

Historically, the budget for NSO/SP has included approximately \$40K in funds above our normal maintenance program for use on larger "projects." Typically, we saved or carried over some of these funds to accomplish these projects that were beyond our normal budget. With the continuing rise in cost of building supplies, propane, and electricity, and our flat budgets, our discretionary funds have been absorbed into the daily maintenance activities. The size of these projects make them very difficult or impossible for us to accomplish without supplemental funding. Each of these items has been evaluated with the development of the ATST and the expected closure or transfer of Sac Peak in mind, and represents improvements needed in the short term.

- Equipment Replacement. Request \$85K: Our current loader is approximately 15 years old. It is heavily used, especially for snow removal, and is experiencing more breakdowns and subsequent downtime. A catastrophic failure would severely impact our ability to complete snow removal and other critical tasks.
- Main Lab Boiler Line and Radiator Replacement. Request \$50K: The Main Lab houses the offices of three-quarters of our staff and computing facilities. The facility is over 40 years old and is heated with a hot water system with radiators in individual offices. The boiler was replaced about 15 years ago but remains serviceable. The hot water lines connecting the boiler to the individual radiators and the radiators themselves have never been replaced. We are experiencing multiple failures of these lines each winter and expect that pattern to worsen. A catastrophic failure during the winter months could make the facility uninhabitable for an extended period of time. This project would replace all of the lines and the radiators. Replacement of the radiators with more modern units should increase the efficiency and improve the quality of heat in the building.

- Apartment Building Boiler Line and Water Line Replacement. Request \$50K: The apartment building is our primary source of housing for official visitor and users of the telescopes. As with the Main Lab, the facility is over 40 years old and has had little maintenance to the hot water heating and drinking water lines during that time. Failures are becoming frequent and maintenance costs are rising. This project would replace all the hot water heater lines, radiators and drinking water lines. This will greatly improve the quality of heat in the building and the drinking water.
- Vehicle Replacement. Request \$25K: One of our current staff vehicles has well over 100K miles and is beginning to experience more maintenance problems. These vehicles are heavily used for transportation of our staff to Tucson, El Paso (airport) and other locations. Frequently, they are driven in very remote parts of the country and at odd hours and conditions where breakdowns could be dangerous. Also, with the funding of the ATST and the participation of many of our current employees, our travel to Tucson and other locations will increase dramatically, requiring that all of our staff vehicles be available for use.
- *Dump Truck/Snow Plow Replacement*. Request \$65K: Current dump truck is about 20 years old. As with the loader, it is heavily used for snow removal and is experiencing more problems. Maintenance costs and dependability have negatively impacted our facilities maintenance staff and will continue to grow as it ages. As our main road plow, a catastrophic breakdown during the winter would have a severe impact on our ability to complete snow removal.
- Redwood Building Painting. Request \$35K: Redwoods including the apartment building and the community center have not been repainted for approximately 20 years. Paint is beginning to peel and subject the wood exterior to the severe elements at Sac Peak. The wood exteriors will deteriorate fairly quickly in this environment causing more costly repairs in the future.

5.7.4.2 NSO/T

McMath-Pierce

- Refigure & Polish the 1.5-m Cervit #2 Mirror for the McMP. Request: \$60K. The McMP 1.6-m quartz imaging (#2) mirror was damaged in an incident that occurred in the 1970's. The 0.9-m #2 mirror from the West Auxiliary Telescope came free of its mounting and crashed to the bottom of the telescope. The mirror impacted the carriage of the main 1.6-m #2 mirror causing the main #2 to momentarily bounce up out of its mirror cell before settling back into it. In the process, one of the mirror's retaining clips caught the edge of the mirror resulting in a ~8" chip in the edge of the mirror's front surface. A replacement 1.5-m Cervit blank was quickly procured, ground, polished, coated and put into service. It was later realized that the mirror was rushed too quickly through the optical shop which left the mirror with a poor optical figure. The mirror had a badly rolled edge plus a central peak that limited its image quality. In the late 1980's, the original quartz mirror was tested and, with the exception of the chipped region, found to still have a good surface. It was then reinstalled in the telescope and so has been used as the telescope's imaging mirror ever since. Cervit has a lower coefficient of expansion compared to quartz. The focus is currently known to drift by several cm through the day as the telescope mirror warms. Replacing the quartz mirror with Cervit would result in improved focus stability.
- *McMP Subterranean Optical Tunnel Chiller Compressor.* Request: \$40K. The subterranean section of the McMP optical tunnel is lined with refrigerant lines that can be used in the winter to improve tunnel seeing when the cavern's surrounding rocks are deemed too warm compared to the frigid outside temperature. The system is used only occasionally as the rock is normally thought to be

close enough to the proper temperature to stabilize the internal seeing. The chiller system utilizes a large compressor that resides in the telescope pump house located just north of the telescope itself. The compressor is of an old design that is less efficient than a modern unit, and is difficult to maintain and find replacement parts for. It has been recommended that the refrigeration compressor unit be replaced. A modern replacement would likely cost somewhere in the \$40K range. More research would be required to better establish the actual cost.

Fourier Transform Spectrometer (FTS)

- Reference Laser. note that the current laser is over 30 years old. Zeeman Stabilized HeNe Laser Agilent Technologies Model 5517A. Estimated Cost: \$12K.
- Lock-in Amplifier. Estimated Cost: \$10K.
- *Beamsplitter Recoating*. Note that recoating the beamsplitters is less expensive than replacing them. Recoating would be done by Barr Associates. There are four beamsplitters (UV beamsplitter Al + MgF2; Visible beamsplitter Ag + MgF2; CaF2 beamsplitter GaP; KCl beamsplitter GaAs) at an estimated cost of \$20K each. Total Estimated Cost: \$80K.
- Steering Optics Recoating Al and Ag. Estimated Cost: \$20K.
- Redesign and Fabrication of 8-inch Steering Mirror Mounts (2 ea.). Estimated Cost: \$10K.
- Total FTS Estimated Cost: \$132K.

GONG

• New Air Conditioning Unit for Tucson GONG Farm Office Trailer. The current unit is old and needs frequent servicing. Estimated Cost: \$8K.

ACRONYM GLOSSARY

ADAPT Air Force Data Assimilative Photospheric flux Transport

AFRL Air Force Research Laboratory
AFWA Air Force Weather Agency

AIA Atmospheric Imaging Assembly (NASA)

AISES American Indian Science and Engineering Society

AMOS Advanced Mechanical and Optical Systems

AO Adaptive Optics

ARRA American Recovery and Reinvestment Act
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

CCMC Community Coordinated Modeling Center

CD-ROM Compact Disk – Read Only Memory
CDUA Conservation District Use Application
CDUP Conservation District Use Permit

CfA Center for Astrophysics (Harvard-Smithsonian)

CfAO Center for Adaptive Optics

CISM Center for Integrated Space Weather Modeling
CLEA Contemporary Laboratory Exercises in Astronomy

CMEs Coronal Mass Ejections
CoDR Conceptual Design Review

CoSEC Collaborative Sun-Earth Connection

D&D Design & DevelopmentDAS Data Acquisition System

DASL Data and Activities for Solar Learning
DEIS Draft Environmental Impact Statement
DLSP Diffraction-Limited Spectro-Polarimeter

DMAC 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)

FAA Federal Aviation Administration

FDP Full-Disk Patrol FDR Final Design Review

FEIS Final Environmental Impace Statement

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

HO Haleakalā High Altitude Observatory Site

HOO Hands-On Optics

IBIS Interferometric BIdimensional Spectrometer (Arcetri Observatory)

ICD Interface Control Document IDL Interactive Data Language

If A Institute for Astronomy (University of Hawai'i)

IHY International Heliophysical Year

IR Infrared

ISOON Improved Solar Observing Optical Network (now O-SPAN)

ISS Integrated Sunlight Spectrometer

IT&C Integration, Testing, & Commissioning

KCE KC Environment (Maui)

KPNO Kitt Peak National Observatory KPVT Kitt Peak Vacuum Telescope

LAPLACE Life and PLAnets Center (University of Arizona)

LPL Lunar and Planetary Laboratory (University of Arizona)

LRP Long Range Plan

LTE Local Thermodynamic Equilibrium

LWS Living With a Star (NASA)McMP McMath-Pierce Solar TelescopeMCAO Multi-Conjugate Adaptive Optics

MCC Maui Community College

MEDB Maui Economic Development Board

MHD Magnetohydrodynamic MKIR Mauna Kea Infrared

MREFC Major Research Equipment Facilities Construction (NSF)

MRI Major Research Instrumentation (NSF)

NAC NSO Array Camera

NAI NASA Astrobiology Institute NAS National Academy of Sciences

NASA National Aeronautics and Space Administration

NASM National Air and Space Museum NHWG Native Hawaiian Working Group

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

NMSU New Mexico State University

NOAA National Oceanic and Atmospheric Administration

NOAO National Optical Astronomy Observatory

NOI Notice of Intent

NPDES National Pollutant Discharge Elimination System (US Environmental Protection Agency)

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 National Solar Observatory

NSO/SP National Solar Observatory Sacramento Peak

NSO/T National Solar Observatory Tucson
OMB Office of Management Budget

O-SPAN Optical Solar Patrol Network (formerly ISOON)

PAARE Partnerships in Astronomy & Astrophysics Research and Education

PAEO Public Affairs and Educational Outreach

PCA Principal Component Analysis PDR Preliminary Design Review

PSPT Precision Solar Photometric Telescope RASL Research in Active Solar Longitudes RET Research Experiences for Teachers

REU Research Experiences for Undergraduates

RISE/PSPT Radiative Inputs from Sun to Earth/Precision Solar Photometric Telescope

RMS Root-Mean-Square

ROB Remote Operations Building

ROD Record of Decision

ROSA Rapid Oscillations in the Solar Atmosphere

SACNAS Society for the Advancement of Chicanos and Native Americans in Science

SAN Storage Area Network

SCB Sequential Chromospheric Brightening

SCOPE Southwest Consortium of Observatories for Public Education

SDEIS Supplemental Draft Environmental Impact Statement

SDO Solar Dynamics Observatory SFC Space Flight Center (NASA) SMD Steaming Media Decoder

SOC Solar Observatory Council (AURA)SOHO Solar and Heliospheric ObservatorySOI 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)
SWG Science Working Group (ATST)

SWPC Space Weather Prediction Center

STEM Science Technology Engineering and Mathematics

STEP Summer Teacher Enrichment Program

STEREO Solar TErrestrial RElations Observatory (NASA)

TAC Telescope Time Allocation Committee

TB Tera Bytes

TCS Telescope Control System

TLRBSE Teacher Leaders in Research Based Science Education

TMA Telescope Mount Assembly

TRACE Transition Region and Coronal Explorer

UA University of Arizona
UBF Universal Birefringent Filter
USAF United States Air Force
USFWS US Fish and Wildlife Service

VCCS Virtual Camera Control System (Dunn Solar Telescope)

ViSP Visible Spectro-Polarimeter
VSM Vector Spectromagnetograph
VSO Virtual Solar Observatory
WBS Work Breakdown Structure

WWW World Wide Web