NATIONAL SOLAR OBSERVATORY Long Range Plan FY 2005-2009

Origins of Solar Magnetic Variabilty







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MISSION

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

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, and mentoring high school students;
- innovative staff research.

RESEARCH OBJECTIVES

The broad research goals of NSO are to:

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

TABLE OF CONTENTS

| ΕX | ECU | JTIVE SUMMARY | 1 |
|----|-----|---|------|
| 1 | IN7 | TRODUCTION | 4 |
| 2 | SCI | IENCE PROGRAM | 5 |
| | 2.1 | Interior Structure and Dynamics | 5 |
| | 2.2 | Origin of the Solar Activity Cycle and the Dynamo | 5 |
| | 2.3 | Transient Eruptions: Flares and Coronal Mass Ejections | 6 |
| | 2.4 | Origin of Variability in Solar Irradiance | 6 |
| | 2.5 | Heating of the Outer Atmosphere and the Origin of Solar Wind | 7 |
| | 2.6 | Surface and Atmosphere Structure and Dynamics | 7 |
| | 2.7 | The Solar-Stellar Connection | 8 |
| 3 | MA | AJOR INITIATIVES | 9 |
| | 3.1 | Advanced Technology Solar Telescope (ATST) | 9 |
| | | 3.1.1 ATST Science Working Group and Science Requirements | 9 |
| | | 3.1.2 ATST Project Engineering and Design Progress | 9 |
| | | 3.1.2.1 Construction Phase Planning | 9 |
| | | 3.1.2.2 Current Design Activities | 10 |
| | | 3.1.3 ATST Management Activities | 11 |
| | | 3.1.4 ATST Site Selection | 12 |
| | | 3.1.5 ATST Plans | 12 |
| | | 3.1.5.1 Project Planning | 13 |
| | | 3.1.5.2 Construction Phase | 13 |
| | | 3.1.5.3 Funding | 13 |
| | 3.2 | High-Order Adaptive Optics (AO) | 14 |
| | 3.4 | Virtual Solar Observatory (VSO) | 16 |
| 4 | CU | JRRENT SUPPORT FOR SOLAR PHYSICS | . 18 |
| | 4.1 | Dunn Solar Telescope (DST) | 18 |
| | 4.2 | McMath-Pierce Solar Telescope (McMP) | 18 |
| | 4.3 | Global Oscillation Network Group (GONG) | 19 |
| | 4.4 | Post-focus Instrument Development | 19 |
| | | 4.4.1 The Diffraction-Limited Spectro-Polarimeter (DLSP) | 20 |
| | | 4.4.2 Infrared Instrumentation | 20 |
| | | 4.4.2.1 Infrared Spectropolarimeter | 20 |
| | | 4.4.2.2 NSO Array Camera (NAC) | 20 |
| | | 4.4.3 Spectro-Polarimeter for Infrared and Optical Regions (SPINOR) | 21 |
| | | 4.4.4 Telescope Upgrades | 21 |

| | 4.5 | The Synop | otic Facilities | |
|------|------|-------------|--|----|
| | | 4.5.1 S | OLIS and SOLIS Global Network | |
| | | 4.5.2 E | vans Solar Facility (ESF) | |
| | | 4.5.3 H | lilltop Facility | |
| | 4.6 | Digital Lib | prary | |
| 5 | PU | BLIC AN | D EDUCATIONAL OUTREACH | |
| | 5.1 | Education | nal Outreach | 24 |
| | 5.2 | Other Ou | ıtreach | |
| | 5.3 | Media an | d Public Information | |
| 6 | IMI | PLEMEN | TATION | |
| | 6.1 | The Evol | ution of NSO | |
| | 6.2 | NSO Scie | ntific Staff | |
| | | 6.2.1 S | unspot-Based Scientific Staff | |
| | | 6.2.2 T | ucson-Based Scientific Staff | |
| | | 6.2.3 F | uture Staffing | |
| | 6.3 | Commu | ity Partnerships and NSO Leadership Role | |
| | 6.4 | Operatio | nal Partnerships | |
| | 6.5 | NSO Org | anization | |
| | 6.6 | Spending | Plan | |
| | | 6.6.1 St | rategic Needs | |
| | | 6.6.2 F | Y 2005 Budget | |
| | | 6.6.3 FY | 2006 Budget | |
| | | 6.6.4 FY | 2 2007 – FY 2009 Budgets | |
| 4.01 | | | | 10 |
| API | PENI | JIX A.I | ATST Science Working Group | |
| API | PENI | DIX A.2 | ATST & Site Survey Staffing | |
| API | PENI | DIX A.3 | ATST Design Review Committee | |
| API | PENI | DIX B | ATST Work Breakdown Structure for Design & Development | |
| | | | and Construction Phases | |
| API | PENI | DIX C | Acronym Glossary | |
| | | | | |

EXECUTIVE SUMMARY

Through the development of revolutionary observational capabilities, such as the Advanced Technology Solar Telescope (ATST), the NSO program will advance our understanding of the physics of solar magnetic variability and the resulting variations in solar outputs. The NSO plan addresses the origins of solar variations that effect Earth and the near-space environments in which we live. The societal impacts range from space weather hazards to climate variability, and from biodiversity to life near other stars. NSO recognizes that the study of the Sun offers many unique and exciting educational opportunities that extend across a broad range of intellectual inquiry. Accordingly, NSO will continue to expand and improve its already effective educational outreach program to reach an even wider audience, from K-12 to the scientific community, with the excitement of the new results and a goal of increasing diversity.

As a national observatory, NSO collaborates with other solar groups on most of its endeavors. Current examples of this include a close working relationship with the High Altitude Observatory (HAO) to obtain advanced Stokes polarimetry measurements of all layers in the solar atmosphere, and collaboration with NASA and US Air Force (USAF) scientists (who are collocated with NSO staff) on many of the projects aimed at obtaining synoptic data as inputs to forecasting solar activity and variability and its impacts on space weather and the climate. Strong relationships have been established with the New Jersey Institute of Technology (NJIT) and the University of Hawaii for development of adaptive optics (AO) and infrared (IR) technologies, respectively. NSO scientists also work with the Kiepenheuer-Institut für Sonnenphysik (KIS), the University of Alabama, NASA Marshall Space Flight Center and the solar group at Arcetri Observatory in Naples on narrow-band imaging. Recently, NSO collaborated with the University of Arizona to create a new faculty position in solar physics.

The current Long Range Plan, spanning fiscal years 2005 through 2009, continues with the implementation of the NSO strategic goals as called out in the NSF/AURA cooperative agreement and refined in the AURA/NSO Strategic Plan. Key components of that strategy are:

- developing a 4-meter *Advanced Technology Solar Telescope* on behalf of, and in collaboration with, the solar community;
- expanding the current NSO solar adaptive optics program to develop the AO technology needed for the ATST, including multi-conjugate adaptive optics (MCAO), which will allow diffraction-limited imaging over larger fields of view;
- operating the Dunn Solar Telescope (DST) and the McMath-Pierce (McMP) Solar Telescope, incorporating AO, new IR techniques, and diffraction-limited instrumentation to explore solar magnetism and provide the science impetus for the ATST;
- operating a suite of instruments comprising the *Synoptic Optical Long-term Investigation of the Sun (SOLIS)* and expanding SOLIS into a network;
- operating the *Global Oscillation Network Group (GONG)* telescopes;

and when the ATST is commissioned,

• decommissioning or divestment of the DST and McMP and an orderly transition to a new NSO structure, which can efficiently operate the new facilities to advance the frontiers of solar physics.

During the past four years, NSO and its co-principal investigators at the High Altitude Observatory, the New Jersey Institute of Technology, the University of Hawaii, and the University of Chicago, along with collaborators at 17 other institutions, representing a broad spectrum of the solar community, have developed and costed a conceptual design for the ATST. The project is now ready to enter the construction phase. Given a one- or two-year delay in construction and a limited funding scenario, the project will concentrate on retiring the remaining high-risk areas. The NSO has successfully built and demonstrated a scalable solar adaptive optics system that has revolutionized the use of current telescopes and paves the way for achieving diffraction-limited images with the ATST, thus retiring one of the primary risks. We will target thermal and telescope controls and other factors that could affect telescope performance.

The SOLIS vector spectromagnetograph (VSM) and the integrated sunlight spectrometer (ISS) where installed on Kitt Peak and are producing synoptic data. VSM magnetograms far surpass any previous synoptic maps and it provides a totally new vector magnetogram capability. A world-wide network of SOLIS instrumentation was one of the low-cost recommendations of the Decadal Survey. Now that SOLIS is coming on line, NSO will explore partnerships for developing a SOLIS network.

GONG is routinely producing high-resolution data products and has obtained resources from NASA to implement real-time capabilities. GONG's rapid cadence magnetograms and farside imaging are proving to be valuable tools for understanding space weather. The GONG data pipeline has been upgraded to handle the much higher volume of data.



Figure 1. Strategic Road Map of NSO Facilities.

NSO, with sites currently operating at Tucson, Arizona and Sunspot, New Mexico, plans to decommission the telescopes at those sites and consolidate its scientific staff at a headquarters location and ATST operating site upon completion of the ATST. NSO has started the process of planning for consolidation and for operations in the ATST era. A series of community wide workshops to define ATST science operations will take place over the

next few years. The roadmap 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. Note that in the figure it is assumed that ATST construction will commence in 2007. Phase out of the DST and McMP is shown as occurring with the beginning of ATST operations. The exact phase out dates for the Evans Solar Facility (ESF) is uncertain because the primary support currently comes from the USAF solar group collocated with NSO at Sunspot. The High Altitude Observatory is also interested in maintaining operation of the 40-cm coronagraph in the Evans facility. NSO will continue operating the Evans facility as long as support is provided by these outside sources.

NSO's five-year spending plan reflects the need to continue the strong community momentum developed for the ATST project, the resurgence of strong 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 and completion of SOLIS. The operational budget of \$8,248K in FY 2005 and the planned budget of \$8,331K in FY 2006 do not fully support current NSO operations. NSO continues to look for ways to reduce operational costs with the least amount of impact on users. The planned increment of \$2,000K for the ATST will allow the project to begin some of the risk retirement efforts with vendors and continue work towards preliminary design reviews (PDRs) with the current ATST project team.

1 INTRODUCTION

Major highlights since the 2004-2008 Long Range Plan (available at <u>http://www.nso.edu/general/docs/</u>) encompass the ATST construction proposal reviews, selection of an ATST site, refinement of the enclosure, coudé, optic feed, and instrument designs, and appointment of a new Project Manager. A second high-order adaptive optics system for the Dunn Solar Telescope was completed, enabling all DST instruments to now be fed by adaptive optics. A first demonstration run was made with an MCAO system. The SOLIS vector spectromagnetograph is making routine synoptic magnetograms (Figure 1-1) and will release calibrated vector magnetograms in a few months. The other SOLIS instruments should be fully developed and operational later this year. The GONG data pipeline is functioning smoothly and producing near-real-time data for space weather, as well as high-resolution data for imaging near surface layers of the Sun and active regions on the farside of the Sun. GONG produced real-time images of the Mercury and Venus transits and was one of the most visited Web sites during their passage.

The ATST is now ready to enter the construction phase. A delay in starting the construction also delays implementation of the NSO long range plan for phasing out assets that are critical to the support NSO provides the solar research community and NSO and community development of cutting edge instrumentation. Phasing out these facilities is planned to coincide with the beginning of ATST operations. Because solar physics is very much an experimental science, progress is driven by the close relationship between theory and new instrumentation needed to test and drive new models.

Section 2 provides a brief description of some of the science areas addressed through NSO facilities. Section 3 discusses NSO's major initiatives, with emphasis on the ATST. Current user support and NSO public and educational outreach are described in Sections 4 and 5, respectively. Section 6 presents programmatic and budgetary needs for implementing NSO's long range plan.



Figure 1-1. The distribution of magnetic flux on the entire surface of the Sun. Inward and outward directed flux is shown as dark or light shades respectively. Maps of this type are constructed every day using new SOLIS data and are widely used as the boundary conditions for mathematical models of the structure and dynamics of the helio-sphere. Such models allow forecasts of space weather near the Earth. The maps are also used to study the basic physical processes that produce the solar activity cycle.

2 SCIENCE PROGRAM

NSO facilities and programs support investigations by the user community and its own staff that are at the forefront of current solar research. The major telescope facilities of the NSO—the Dunn Solar Telescope (DST) and the McMath-Pierce Solar Telescope (McMP)—combined with the upgraded GONG facility and the new SOLIS suite of instruments, essentially constitute a telescope-instrument system designed for the advanced investigation of the complex physical system that is our Sun. Progress toward resolving many of the crucial problems in solar physics is only possible by combining data from several sources. Therefore, NSO also strongly supports collaborative efforts that combine data from multiple ground- and space-based facilities. The science can be subdivided into fundamental but overlapping themes. The following sections briefly summarize NSO's pivotal role in addressing these themes. Highlights of NSO supported science during the past year are summarized in our annual report (available at <u>http://www.nso.edu/general/docs/</u>).

2.1 Interior Structure and Dynamics

Through the Global Oscillation Network Group (GONG) program, NSO provides a fundamental data set and contributes substantial staff research to the study of the structure and evolution of the solar interior over extended periods of time. Combined with data from the SoHO/SOI experiment, these helioseismology experiments are revolutionizing our 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 (as confirmed with the recent awarding of the Nobel prize in physics), 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.

Through operating the GONG instruments, now upgraded to higher spatial resolution, over the 22-year Hale Cycle of magnetic activity, NSO makes a substantial contribution to the data set that the solar community requires in order to advance our understanding of solar (and stellar) structure and dynamics. These 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.

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 those producing the strong fields more often associated with solar activity. However, available data are not of sufficient quality to verify that the mechanisms are distinct, and it is now a goal of the Synoptic Optical Long-term Investigation of the Sun (SOLIS) to address this fundamental issue.

There is preliminary evidence that more magnetic flux may be generated from small-scale turbulent dynamo processes than is seen in the form of active regions; this needs to be verified. Data acquired with the DST and the McMP, using their newly developed adaptive optics systems, and the data anticipated from the SOLIS instruments, will be used to investigate the nature of the dynamo models. For example, the helicity of solar

magnetic fields contains important information about the interaction between magnetic fields and plasma in the convection zone as well as the nature of the underlying dynamo. This property of the solar magnetic field will be systematically studied with SOLIS.

New observations using infrared spectral lines at the McMP will be made with a variety of infrared detectors, including the new NSO Array Camera (NAC). From polarization measurements using the well-known He I 1083 nm and Fe I g=3 1565 nm spectral lines, to sunspot studies with the 2231 nm Ti I line, to the most sensitive magnetic measurements possible with the 12000 nm Mg I emission line, the high flux and all-reflecting optics of the McMP still provide a unique facility to conduct highly sensitive IR magnetic measurements. Unique spectral measurements of the coronal emission line at 3934 nm will also be made at the McMP with the NAC, taking advantage of the darker sky background at longer infrared wavelengths.

Planned instruments, including the ATST, and supported by GONG and SOLIS, will provide the data required to address fundamental questions concerning the dynamo process and the solar cycle such as: How do strong fields and weak fields interact? Does the weak-field component have a large-scale structure? What is the small-scale structure of the global component? How are both generated? How do they disappear?

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

NSO synoptic observing facilities currently provide some information on flares and CMEs, but crucial measurements are unavailable, such as the evolution of the vector magnetic field. SOLIS will provide these as well as a large variety of data suited to address the topic of transient activity. It is this transient activity that is especially relevant to the determination of space weather and its potential hazards to space activity. In addition to the 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.

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 even triggering flare outbursts in distant active regions. A unique combination of full-disk observations (SOLIS, 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 the major drivers of the physical conditions in the near-Earth space environment.

The DST, the 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.

2.4 Origin of Variability in Solar Irradiance

The KPVT, and now SOLIS, provides the basic magnetic field maps that are successfully used in modeling solar irradiance variations. The RISE/PSPT network, developed at NSO and now operated by HAO 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 may shed light on how magnetic fields interact to provide the energy driving these irradiance variations.

2.5 Heating of the Outer Atmosphere and the Origin of 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 the non-radiative heating have been studied, but combining observations and models to identify the mechanism(s) have yet to show promise. Similarly, the detailed mechanism 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.

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, the observation of the vector magnetic fields in the photosphere and chromosphere are essential for understanding and modeling the process of magnetic reconnection. SOLIS (and, to a lesser extent, GONG) will play a unique role in providing such data.

2.6 Surface and Atmosphere Structure and Dynamics

Using the newly developed adaptive optics system and image reconstruction techniques, NSO staff and visiting scientists have obtained the highest resolution time sequences of solar magnetic, intensity, and velocity fields ever made (~0.14"). 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 were used to uncover a dynamic of 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 the studies using a combination of ground-based and space-borne instruments is a necessary step in bringing further understanding of the evolution of magnetic flux in solar atmosphere.

SOLIS is now providing gold-standard magnetic boundary conditions used for models of the solar corona structure and the solar wind so important in space weather forecasting. As vector magnetic field observations regularly become available from SOLIS, more realistic MHD models will become a superior standard for such modeling.

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, the ATST will also provide accurate measurements of coronal magnetic fields off the limb in

the infrared. Visitors at the McMath-Pierce telescope have already conducted preliminary observations of this kind (Judge et al. 2002; *ApJ*, 576, 157). In addition, techniques for measuring coronal fields are being developed by HAO and tested at the NSO Hilltop One-Shot Coronagraph. 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 FASR—the Frequency Agile Solar Radio telescope—a recommendation of the Decadal Survey.

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 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. 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.

In the further application of unique solar data in a stellar context, NSO/KP full-disk magnetograms, in combination with X-ray (Yohkoh) and EUV (EIT) data, were used to demonstrate a relationship between magnetic flux and X-ray luminosity extending from quiet Sun areas to T-Tauri stars. This study yielded important insights on the possible coronal heating mechanisms that can operate in the Sun and other stars.

An active nighttime program of solar system investigations, supported primarily by NASA grants, continues at the McMath-Pierce complex. In addition, preliminary discussions have begun (with Prof. Jian Ge, University of Florida) concerning the establishment of a long-term program of Doppler spectroscopic observations of extrasolar planetary systems. This project would utilize a significant fraction of the available nights at the McMath-Pierce telescope. These kinds of long-term investigations serve as prototypes of the programs that could be initiated at the 4-m ATST on behalf of the community. Finally, NSO scientists are actively participating in a NASA-supported (NAI) program in astrobiology, 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.

3 MAJOR INITIATIVES

With the strong support and participation of the solar community, NSO has implemented a plan to develop the next generation high-resolution, infrared-capable solar telescope, and to continue to provide the highest quality and quantity of solar synoptic data.

The introduction of novel, post-focus instrumentation and adaptive optics have greatly enhanced the capabilities of the solar telescopes of the NSO, thereby enabling whole new areas of scientific inquiry, especially in high-resolution and infrared observations of the Sun. As a result of these developments at the NSO, it has become clear that further progress requires instrumental advances in spatial, temporal and spectral resolution combined, and that the basic limitations inherent in the current suite of NSO facilities can only be overcome by developing and building new facilities.

3.1 Advanced Technology Solar Telescope (ATST)

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

3.1.1 ATST Science Working Group and Science Requirements

The ATST Science Working Group (SWG) (Appendix A.1) has both US and international members who report to and advise the project scientist. The SWG produced a Science Requirements Document (SRD) (#SPEC-0001), contributed to the science write-up for the ATST construction proposal, and recommended the primary and alternate sites for the ATST.

3.1.2 ATST Project Engineering and Design Progress

The ATST project accomplished several major milestones during this past year, including successful design reviews and workshops focused on the M1 assembly, enclosure, telescope control system (TCS) and common services software. The ATST project team continues to draw from a broad range of resources, which, in addition to new hires, include members of the NSO staff, individuals from other organizations, and Co-PI teams that review instrumentation, operations, and design issues. Appendix A summarizes the current staffing for ATST.

3.1.2.1 Construction Phase Planning

Construction phase management and systems engineering efforts were focused on requirements for the construction phase including the integration, testing, and commissioning phase. These efforts were in addition to management and systems engineering efforts that supported the design phase tasks. We have considered a range of possible subcontracting options during the construction phase and developed these options with interface requirements and project organization in mind. The interface control document (ICD) system and the work breakdown structure (WBS) were refined through the construction phase again during the last year. As in the design phase, the WBS is consistent with the subsystems, has an accounting number system that

matches both the WBS and ICD organization, and includes the detailed plans and schedules for the project through the construction phase and into early operations. Current lead engineers and team members assigned to each of the major WBS design elements are shown in Table 3.1-1.

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

The current schedule critical path is presented in Appendix B.

| TABLE 3.1-1. ATST Engineering Responsibilities | | | | | |
|--|-------------------------|--|--|--|--|
| Systems Engineering | Eric Hansen | | | | |
| | Rob Hubbard | | | | |
| Telescope Assembly | Mark Warner | | | | |
| Telescope Mount | Mark Warner | | | | |
| M1 Assembly | Ron Price | | | | |
| M2 Assembly | Ron Price | | | | |
| Feed Optics | Ron Price | | | | |
| Thermal Systems | Nathan Dalrymple (USAF) | | | | |
| Stray and Scattered Light Control | Rob Hubbard | | | | |
| Wavefront Correction | Thomas Rimmele | | | | |
| | Steve Hegwer | | | | |
| | Kit Richards | | | | |
| Instrument Systems | Jeremy Wagner | | | | |
| | Rob Hubbard | | | | |
| High-Level Controls and Software | Bret Goodrich | | | | |
| | Steve Wampler | | | | |
| | Janet Tvedt | | | | |
| Enclosure | Mark Warner | | | | |
| | LeEllen Phelps | | | | |
| Support Facilities (includes infrastructure items) | Jeff Barr | | | | |

3.1.2.2 Current Design Activities

Current design activities include mechanical and optical layouts for the Nasmyth feed, finalizing the instrument feed to the coudé lab, updates to the telescope structure, enclosure thermal design, including vents and liquid cooling, thermal design and analysis for the interface to the coudé lab, and performance updates based upon the Haleakala site testing data. The current design is shown in Figure 3.1-1. The design includes the simplified one-level coudé instrument area and feed arrangement. The feed for instrumentation associated with this is more compact and simpler to direct to multiple instrument stations. It includes a simplified upgrade path to future multi-conjugate adaptive optics (MCAO) use, which will require replacing some mirrors, but will not require additional mirrors.



Figure 3.1-1. Current ATST facility design with enclosure vents, telescope, and large single-coudé lab.

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

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

University of Hawaii (Near IR Polarimeter Design (Lead); Site Survey Operations on Haleakala).

New Jersey Institute of Technology (Site Survey Operations at Big Bear; Tunable IR Filter Design).

Lockheed Martin (Broad-band Filter Contributions).

NASA Marshall SFC (Visible Tunable Filter/Polarimeter Design working with NSO).

3.1.3 ATST Management Activities

Current management activities include planning for potential scenarios to bridge funding gaps between the design and development (D&D) phase and the construction phase. Scenarios have been developed, in consultation with NSF, for covering needs of the project given the delay in the start of construction to FY 2007. If a delay beyond 2007 is necessary, this process will be revisited. The most likely scenario includes:

- Continued funding in 2006 for ATST staff and anticipated industry design studies (\$2M new money in 2006).
- Funding for outside design completion contracts (\$3M new money in 2006 and \$3.15M in FY 2007).

See Section 3.1.5.3 for details on this scenario.



The overall top-level schedule is shown in Figure 3.1-2. It assumes that construction will begin in 2007.

Figure 3.1-2. ATST High-Level Schedule

3.1.4 ATST Site Selection

The choice of the site for the ATST remains a critical aspect in its design. The dominant site requirements are: minimal cloud cover, many continuous hours of sunshine, excellent average seeing and many continuous hours of excellent seeing, good infrared transparency, and frequent coronal skies. In order to perform a quality site evaluation and selection for the ATST, an ATST Site Survey Working Group (SSWG) with broad community participation was established. This committee has representatives from other nations that have expressed interest in participating in the ATST.

In November 2003, the SSWG released an interim report (ATST RPT-0016) with results of the site survey. On the basis of that report, the Science Working Group recommended that the number of sites undergoing testing be reduced from six to three. Testing continued at Big Bear Solar Observatory (California), Mees Solar Observatory (Haleakala, Hawaii) and Observatorio Roque de Los Muchachos (La Palma, Canary Islands, Spain) in order to increase measurement statistics, while testing was discontinued at Panguitch Lake (Utah), San Pedro Martir (Baja California, Mexico), and Sacramento Peak (New Mexico). Additional sky brightness measurements were also made, and further verification was obtained for the data analysis that estimates seeing as a function of height.

In October 2004 the SSWG submitted its final report (ATST RPT-0021) to the SWG for review. The SWG met shortly thereafter and after discussion and review recommended Haleakala as the primary site and La Palma and Big Bear Lake as the alternate sites for the ATST. The project scientist submitted this recommendation to the NSO director, who endorsed it and forwarded it to AURA. The AURA Solar Observatory Council reviewed and endorsed the SWG recommendation for Haleakala and La Palma in December 2004 and submitted the recommendation to the AURA Board for consideration at their January 2005 meeting. The

AURA Board reviewed the recommendation in January 2005 and ratified the selection of Haleakala as the primary site and La Palma as the alternate site.

3.1.5 Plans

During 2005–2009, the ATST project will transition from design to construction phase. In the near-term, preliminary design efforts, site infrastructure and environmental impact studies (EIS) process, and review of the construction proposal will be the principal project planning activities. Near-term design efforts are concentrating on refinement of the thermal control design for the enclosure, detailed optical feeds to instruments, more complete instrument concepts, Nasmyth instrument and feed concepts, system error budgeting, and performance modeling using the latest Haleakala site data.

3.1.5.1 Project Planning

The engineer responsible for each WBS has developed detailed plans, including schedules and budgets, for the construction phase. The systems engineer and project manager have integrated these details into the overall project schedule. Emphasis will be on near-term planning, but longer-term plans through the construction phase are essential for keeping the end-project goals in mind. An overview of the D&D and construction schedule critical-path (i.e., primary mirror procurement) is shown in Appendix B.

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

3.1.5.2 Construction Phase

Current planning, based on an FY2007 construction start, has the second half of calendar year 2013 targeted for obtaining the first scientific data with an ATST instrument. Assuming the early procurement of the primary mirror by a partner organization moves this milestone forward to the second half of calendar year 2012. To maintain the overall schedule, the construction funding must begin in FY 2007. During the first two years of construction, immediate site work, as well as manufacture of the primary mirror blank and completion of the final fabrication designs will be crucial. Construction of main components such as the enclosure and telescope structure should also be well underway. The schedule is shown in Appendix B. There will be a year-for-year slip in this schedule if the start of construction funding is delayed further.

3.1.5.3 Funding

In FY 2007, adequate construction funding is needed in order to commit many of the major subcontracts. The funding requirements are based on the budget described in the original construction proposal and as revised following the March 2005 NSF Cost Review Panel's recommendations.

The cost review resulted in the identification of six main areas that affect the construction proposal budget:

- Delayed start to FY 2007;
- Consequences of site selection;
- Preliminary design effort;
- Specific NSF Cost Review Panel recommendations (e.g., in-process spares);
- Major Research Equipment Facilities Construction (MREFC) requirements; and
- 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 to maintain the overall contingency above 19% as recommended by the review panel.

The result of the panel's recommendations and the re-costing exercise is an overall adjustment to the proposal estimate of 8.42%, or \$13.6M. This estimate incorporates the costs associated with a delayed construction start to FY 2007 (i.e., inflation), selection of the Haleakala site (e.g., regional cost factors, telescope height, shipping), preliminary design progress (e.g., M1 and enclosure thermal control), review panel recommendations (e.g., in-process spare M2), MREFC requirements (no subsidy/support to ATST from NSO or NOAO), and the recent significant increases in the cost of commodities (e.g., concrete and steel). Therefore, based on the panel's recommendations, the total cost for ATST was adjusted to \$175M. This estimate includes inflation based on an FY 2007 construction start and a 19% overall contingency.

The estimate of required funds is given in Table 3.1-2, assuming no advanced purchase of the primary mirror. Inflation and an overall 19% contingency on base costs are included.

| TABLE 3.1-2. ATST Cost Summary Based upon Commit-Profile Needs (Dollars in Thousands) | | | | | | | | | |
|---|--------|---------|---------|---------|---------|---------|---------|---------|--|
| WBS Element | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | |
| Project Management (includes contingency) | 11,400 | 6,808 | 4,007 | 5,100 | 1,720 | 2,180 | 1,301 | 0 | |
| Systems | 414 | 429 | 444 | 459 | 475 | 492 | 394 | 0 | |
| Fabrication | 56,805 | 20,532 | 21,788 | 11,040 | 6,981 | 1,810 | 1,041 | 0 | |
| Integration, Testing, and Commissioning | 0 | 0 | 0 | 1,141 | 2,319 | 2,901 | 2,465 | 0 | |
| Science Support | 228 | 236 | 340 | 352 | 390 | 404 | 349 | 0 | |
| Operations Phase Preparation | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Education & Public Outreach | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Support Services (includes AURA fee) | 2,338 | 1,384 | 1,436 | 1,279 | 751 | 630 | 457 | 0 | |
| Yearly Total | 71,186 | 29,389 | 28,015 | 19,372 | 12,636 | 8,417 | 6,007 | 0 | |
| Cumulative Total | 71,186 | 100,574 | 128,589 | 147,961 | 160,597 | 169,015 | 175,022 | 175,022 | |

3.2 High-Order Adaptive Optics (AO)

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 one-meter 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.

The high-order AO development has been brought to a successful conclusion. The project, carried out in primary partnership with the New Jersey Institute of Technology, has resulted in two fully operational AO systems at the 76-cm Dunn Solar Telescope (DST) at Sacramento Peak. A similar system was deployed at the 65-cm telescope at Big Bear Solar Observatory (BBSO). The NSF has sponsored this project within the Major Research Instrumentation (MRI) program with substantial matching funds from the participating partner organizations, which include the NSO, the NJIT, the Kiepenheuer Institute in Germany, and the Air Force Research Laboratory.

The high-order AO systems has upgraded the DST to a diffraction-limited solar telescope, greatly increasing user demand and improving the DST's scientific output. The two identical AO systems are well matched to seeing conditions at the DST and feed two different instrument ports that can accommodate a variety of facility-class instrumentation, such as the Diffraction-Limited Spectro-Polarimeter (DLSP) and the new Spectro-Polarimeter for Infrared and Optical Regions (SPINOR). Experimental setups and visitor instruments, such as the Italian BI-dimensional Spectrometer (IBIS), can also be accommodated. This has made the DST the most powerful facility in terms of post-focus instrumentation.

The resulting systems also serve as proofs-of-concept for a scalable AO design for the much larger 4-meter ATST. Compared to the low-order AO system that has been operating at the DST since 1998, the high-order AO system provides a threefold increase in the number of deformable mirror actuators that are actively controlled. The DST systems will serve as test beds for the development of the ATST AO system. For example, we plan to test reconstruction algorithms needed for the ATST AO, where the pupil on the deformable mirror will rotate with respect to the wavefront sensor.

The Diffraction-Limited Spectro-Polarimeter is now fully integrated with one of the high-order AO systems (port 2). A 1 Å K-line imaging device and a high-speed $2K \times 2K$ 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/pixel, 60"FOV) and a medium-resolution mode (0."25/pixel, 180" 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. As was the case for the DLSP development, this will be done in close collaboration with the High Altitude Observatory. The raw data from the DLSP will be calibrated and a Stokes inversion will be performed on the fly. There are plans to make the reduced data available via the Virtual Solar Observatory.

The DLSP will be used to implement a "solar queue observing mode" at the DST. Pre-defined observations, or observations of targets of opportunity, will be carried out by the observing support staff. Implementation of this mode will allow 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.

Another important aspect of this project is the development of AO data-reduction techniques and tools. The interpretation of AO data for an extended object like the Sun is challenging. The AO point spread function, and temporal and spatial variations thereof, must be understood in order to be able to interpret high-resolution imaging and spectroscopic data of solar fine structure. The performance limitations of solar AO systems also have to be understood. AO technology and AO data-reduction tools have been developed by a graduate student and in collaboration with the Center for Adaptive Optics (CfAO) and researchers at the Herzberg Institute in Canada. The work is expected to be completed at the end of 2005. Results obtained so far are very encouraging (see Figure 3.2-1).

With the completion and deployment of the high-order AO systems at the DST and at BBSO, the technical efforts of the AO project are now focused on the development of multi-conjugate adaptive optics. The Sun is an ideal object for the development of MCAO since solar structure provides the "multiple guide stars" needed to determine the wavefront information in different parts of the field of view. During FY 2004, the loop was



Figure 3.2-1. Plotted is the root-mean-square (rms) contrast as a function of r_0 of a time sequence of sunspot images during variable seeing conditions. Left: rms contrast without PSF correction showing the loss in image contrast as the seeing gets worse. Right: PSF corrected image contrast. The contrast curve is flat demonstrating that the PSF reconstruction recovers the intensities correctly and consistently.

successfully closed on the MCAO system for the first time and the extension of the corrected field by the MCAO system in comparison to MCAO was demonstrated. The NSO system is one of the first successful onsky MCAO experiments (the Kiepenheuer MCAO system being the other). During FY 2005-FY 2006, additional MCAO work will focus on evaluating and improving the system performance and making comparisons with model predictions. The major challenge is to develop and implement efficient control algorithms and find optimum and practical positions for the deformable mirrors. More wavefront sensor subfields may also 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.

3.3 Virtual Solar Observatory (VSO)

In order to leverage further the substantial national investment in solar physics, NSO is participating in the development of a Virtual Solar Observatory, the European Grid of Solar Observations (EGSO), and the Collaborative Sun-Earth Connection (CoSEC). The VSO comprises a collaborative distributed solar data archive and analysis system with access through the WWW. Version 1.0 of the system was released for general public use in December 2004 at <u>http://vso.nso.edu/, http://vso.stanford.edu/, and http://virtualsolar.org/</u>. The release was mentioned in the February 2005 issue of *Physics Today* (p. 28). The overarching goal of the VSO is to facilitate correlative solar physics studies using disparate and distributed data sets. Necessary related objectives are to improve the state of data archiving in the solar physics community; to develop systems, both technical and managerial, to adaptively include existing data sets, thereby providing a simple and easy path for the addition of new sets; and eventually to provide analysis tools to facilitate data mining and content-based data searches. None of this will be possible without community support and participation. Thus, the solar physics community is actively involved in the planning and management of the VSO. For further information, see <u>http://vso.nso.edu/</u>.

In the time frame covered by this Long Range Plan, NSO should make major strides toward becoming a central component of both the VSO and EGSO. Both of these community-wide systems should be on-line by the end of this LRP period. In addition, the NSO archives should be observatory-wide with components at both sites.

These components should link together enhanced pipeline processing systems similar to those now available as the Improved Solar Observing Optical Network (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 <u>http://www.nso.edu/general/docs/</u>).

4 CURRENT SUPPORT FOR SOLAR PHYSICS

Improved instrumentation, especially adaptive optics, has kept NSO telescopes at the leading edge of solar physics. They remain extremely productive and among the most useful solar telescopes in the world. Although the major NSO telescopes are three 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 a new ATST. Consequently, telescope and instrument upgrades and operations are reviewed and supported on the basis that they serve as necessary preludes to the ATST initiative while concurrently serving the needs of the scientific community.

4.1 Dunn Solar Telescope (DST)

The 76-cm *Dunn Solar Telescope*, located on Sacramento Peak at an altitude of 2804 m, remains one of the premier and best-instrumented facilities for high-resolution solar physics. It is an evacuated tower telescope with a 1.6-m mirror stopped down to 76 cm by the entrance window. The evacuated light path eliminates internal telescope seeing. The new high-order adaptive optics systems provide diffraction-limited seeing under moderate to poor conditions, making possible stunning time sequences of not only images, but of spectral sequences leading to vector magnetic field and Doppler measurements.

Recent diffraction-limited observations with the DST are providing new insights into the fundamental nature of convective overshoot and solar magnetic fields and activity. 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 given ground-based solar astronomy the excitement shared by space missions.

A major effort to be completed within the next two-to-three years is the DST control system upgrade. The task is to replace obsolete and unreliable telescope control hardware that can no longer be maintained. The control system upgrade is also required to enable the implementation of new instrumentation, such as SPINOR, into the DST. ATST controls concepts will be developed and tested in close collaboration with the ATST controls group.

4.2 McMath-Pierce Solar Telescope (McMP)

The *McMath-Pierce Solar Telescope* on Kitt Peak, at an altitude of 2096 m, is currently the largest unobstructed-aperture optical telescope in the world, with a diameter of 1.5 m. Thus, it is uniquely capable of panchromatic, flux-limiting studies of the Sun. In particular, it is the only solar telescope in the world on which investigations in the relatively unexplored infrared domain beyond 2.5 microns are routinely accomplished. A new low-order AO system will provide diffraction limited imaging and spectroscopy at these infrared wavelengths. Coupled with the InSb-based detector of the NSO Array Camera (NAC), the McMP will likely produce the best mid-infrared solar observations ever achieved.

Infrared polarimetry and infrared imaging developed at NSO have been combined with the McMath-Pierce Telescope to reveal a ubiquitous presence of weak fields associated with turbulent convection at the solar surface

that could play an important role in solar magnetic flux loss and heating of the outer solar atmosphere. Other observations with these systems have measured chromospheric magnetic fields and may provide the opportunity to directly observe coronal magnetic fields.

Much of the infrared spectrum is still barely explored, especially in flares, sunspots, and the corona. The McMath-Pierce telescope will be used to pursue IR studies to develop techniques and science questions that will continue to refine the ATST IR capabilities.

The *Fourier Transform Spectrometer* (FTS), located at the McMath-Pierce Solar Telescope 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 solar physics, laboratory spectroscopy and atmospheric sciences. 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.

4.3 Global Oscillation Network Group (GONG)

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

Results to date have substantially advanced our knowledge of solar internal structure from the core to the surface, and we are now beginning to measure significant structural variations and flows through the solar magnetic activity cycle, in addition to variations on shorter time scales. 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 farside of the Sun to support a space weather predictive capability; and to provide continuous high-time-cadence and coverage, low-noise and precise magnetograms to support non-helioseismic studies such as the formation of coronal holes and coronal mass ejections, using extrapolations from changes at the solar surface.

4.4 Post-focus Instrument Development

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 first light at the ATST. The NSO instrumentation program is focused on the development of enabling technologies that will be central to the Advanced Technology Solar Telescope and a strong program of understanding solar magnetic variability. The primary areas of instrumental initiatives at NSO are the adaptive optics program and the infrared program. Instrument development and scientific applications in these areas rely on the unique capabilities of the Dunn Solar Telescope and the McMath-Pierce Solar Telescope, respectively.

4.4.1 The Diffraction-Limited Spectro-Polarimeter (DLSP)

Development of the Diffraction-Limited Specto-Polarimeter is a collaboration between the High Altitude Observatory and NSO. The DLSP permits different image scales, from high-resolution (at the diffraction limit of the Dunn Solar Telescope) to lower resolution with a larger field-of-view. The DLSP instrument is completed and now is now fully integrated with the high-order adaptive optics system at the DST. The DLSP will be fully commissioned for operations in July 2005. After commissioning, we plan to make the DLSP available for a "solar queue observing mode." This mode will make more efficient use of the optimal seeing conditions at the DST. The solar queue observing mode will be defined within the observatory in close consultation with users and the ATST project and community. We plan to start implementation of this mode during FY 2005. In addition to more efficient DST operations and higher scientific productivity, we expect the experience gained at the DST to be very valuable in developing efficient operational modes for the ATST.

4.4.2 Infrared Instrumentation

4.4.2.1 Infrared Spectropolarimeter

This is a collaborative project between the National Solar Observatory and the University of Hawaii Institute for Astronomy (IfA) to provide a facility-class instrument for infrared spectropolarimetry at the Dunn Solar Telescope (DST). 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. NSO has made tremendous progress in adaptive optics instrumentation to provide the highest quality images possible on its existing telescopes in the past few years, and as of now, both Ports 2 and 4 at the DST are equipped with high-order AO systems. The IR polarimeter will reside on Port 2. A dichroic beamsplitter will be used to direct infrared light to the instrument. The detector is a $1K \times 1K$ IR camera synced to a liquid crystal modulator. The project is currently in its conceptual design phase. Most of the effort is located at the IfA. The NSO will contribute mechanical design work and manufacturing, and will assist with electronic and software design.

4.4.2.2 NSO Array Camera (NAC)

The McMath-Pierce facility is the world's only large solar telescope without an entrance window, thus giving it unique 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 (NAC), which will observe wavelengths from 1 to 5 microns. NAC is being built using an ALADDIN-III InSb array with electronics and a cryostat from Mauna Kea Infrared (MKIR). With 16 times as many pixels, higher quantum efficiency, and lower read-out noise, the NAC represents a significant improvement over previous NSO IR cameras. New types of scientific observations will be enabled by the NAC at the McMath-Pierce, such as sensitive magnetic field measurements in sunspot umbra, studies of molecular line formation, and opportunities for polarimetric observations from 3 to 5 microns. The NAC will also open new windows on flares and other solar processes (like Evershed flows) at infrared wavelengths. In addition to these PI-driven studies, NSO is exploring using the NAC for regular highly sensitive vector magnetograms of solar active regions in synoptic or campaign-mode observing runs.

Implementing and demonstrating the scientific value of a fast, large-format infrared camera is an important component of NSO's preparation for the IR-capable ATST. The 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.

4.4.3. Spectro-Polarimeter for Infrared and Optical Regions (SPINOR)

SPINOR is a joint HAO/NSO program to upgrade the existing advanced Stokes polarimeter (ASP) at the Dunn Solar Telescope. The ASP has been the premier solar research spectro-polarimeter for the last decade. Its ability to explore new spectral lines and to observe in multiple lines simultaneously is still unique. The ASP wavelength range, however, is restricted to the visible, limiting its ability to sample new solar diagnostics, and its hardware is becoming outdated and difficult to maintain. HAO has received National Center for Atmospheric Research (NCAR) funding to start building SPINOR. SPINOR extends the wavelength of the ASP from 750 nm to 1600 nm with new cameras and polarization optics, provides improved signal-to-noise and field-of-view, and replaces obsolete computer equipment. Software control of SPINOR will be brought into the DST control system as opposed to the stand-alone ASP. SPINOR will augment capabilities for research spectropolarimetry at the DST and extend the lifetime of state-of-the-art research spectropolarimetry at the DST for another decade.

4.4.4 Telescope Upgrades

To operate the DST and McMP until a smooth transition to the ATST can be affected, NSO will upgrade their operating systems over the next year or two. The upgrades will be performed with ATST requirements in mind and performed in such a way as to test ATST concepts such as instrument and data interfaces and software architecture.

4.5 The Synoptic Facilities

4.5.1 SOLIS and SOLIS Global Network

SOLIS (Synoptic Optical Long-term Investigations of the Sun) is a project to make optical measurements of processes on the Sun, the study of which requires well-calibrated, sustained observations over a long time period (25 years). SOLIS replaces several antiquated synoptic facilities. The major and unique SOLIS instrument is a vector spectromagnetograph (VSM), which was installed on Kitt Peak in April 2004 after seven months of preliminary observing at a temporary site in Tucson. Regular observations from Kitt Peak have been underway since May 2004, with several data products being rapidly made available on the Internet. Researchers have reported excellent results from using high-quality VSM data. The other two SOLIS instruments are a full-disk patrol (FDP) imager and an integrated sunlight spectrometer (ISS). The ISS is also installed on Kitt Peak and is currently being tuned and calibrated. The FDP was purposely given low priority in a resource-constrained environment and is now being completed in Tucson prior to its move to Kitt Peak later in 2005. All of the SOLIS instruments have produced good data.

In the near future, our emphasis is on completion and stable operation of SOLIS. A large number of unique full-disk vector magnetic field observations have been accumulated since September 2003 and these are being carefully calibrated and reduced before an eagerly awaited general release. SOLIS VSM observations have shown a wealth of interesting new phenomena and this should lead to many research publications, once the scientific staff has completed initial deployment and data reduction jobs. Initial operation of the VSM has revealed unexpected degradation of some of the optical components. The spectrograph entrance slit and some

of the polarization calibration optics were replaced with more robust components in April 2005. The VSM uses interim cameras of lower capability than originally planned. Cameras that closely match the original design have recently become available. However, the software and hardware costs of modifying the data acquisition system to use the data produced by the new cameras are beyond currently available resources. An important goal in the near term is to develop an affordable way to replace the interim cameras so that the VSM will reach its original design goals.

Once all of the SOLIS instruments are completed and consistently produce high-quality data, NSO will seek international (or other national) partners and, if successful, propose to build two additional SOLIS 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. This proposal will also be an opportunity to seek funding to replace the temporary cameras installed in the VSM and to make additional upgrades including vector magnetic field observations in the chromosphere. Scientists of the Air Force Research Laboratory initiated preliminary discussions about a joint SOLIS-ISOON network and we are pursuing this attractive opportunity.

Due to basically level NSO funding accompanied by inflationary pressures, funding for the operation of SOLIS and to exploit its new science potential is considerably less than what was originally proposed or is needed. Therefore, a proposal to NASA for additional support was submitted and recently funded for three years starting in February 2005. This will help the VSM to achieve some of its full capabilities, particularly in the area of space weather forecasting. This funding will also help offset recent loss of support from long-time partners NOAA Space Environment Center, NASA Goddard Space Flight Center, and the US Office of Naval Research. If NSO receives funding in FY 2007 at the level originally proposed for the cooperative agreement, the plan is to substantially increment the support for SOLIS. NSO is also exploring combining SOLIS data handling with GONG data processing to take advantage of synergisms in storage and dissemination.

4.5.2 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 are the primary users of the ESF 40-cm coronagraph. The coelostat is used in the NSO Ca II K-line monitoring program and will be closed after six months of simultaneous operations with SOLIS. SOLIS and ISOON have replaced the spectroheliogram capability of the ESF with full disk imaging. The Air Force group provides funding for a part time observer and provides NSO with some funds for minimal maintenance. The High Altitude Observatory has expressed recent interest in using the coronagraph for a visible and IR coronal polarimeter, building on the recent tantalizing observations of coronal magnetic fields. This new instrumentation would provide core capabilities for the next generation of ground- and space-based coronal telescopes.

4.5.3 Hilltop Facility

The *Hilltop Facility* houses the white-light and H α flare patrols, the coronal one-shot coronagraph, and a multi-band solar photometer. In addition, it has a 10-arcsec coelostat that feeds a laboratory for testing filters. ISOON and the SOLIS full-disk-patrol have replaced the white-light and H α flare patrols which are no longer operated. The High Altitude Observatory has recently developed a new focal plane instrument for the one-shot coronagraph to measure coronal magnetic fields. This instrument is now being tested and will begin synoptic observations this summer. HAO will provide funding for the necessary manpower to operate the one-shot.

4.6 Digital Library

In addition to its dedicated telescopes, the NSO operates a Digital Library that provides synoptic data sets (daily solar images from the KPVT, FTS data, and a portion of the Sacramento Peak spectroheliograms) over the Internet to the research community. Since the inception of the Digital Library in May 1998 up until March 31, 2005, more than 3.7 million science data files have been distributed and more than 15,000 unique computers have accessed the system. These figures exclude any NSO or NOAO staff members. The holdings of the NSO Digital Library are currently stored on a set of RAID5 disk arrays and are searchable via a Web-based interface to a relational database. A higher capacity storage system was installed in August of 2003. This system, named *solarch* (for SOLIS or solar archive), also holds the Digital Library contents. The *solarch* system currently has 18 TB of on-line RAID5 storage. The Digital Library is an important component of the Virtual Solar Observatory.

5 PUBLIC AND EDUCATIONAL OUTREACH

NSO has a comprehensive public affairs and educational outreach plan that includes graduate research and training, undergraduate research, teacher research and research-to-classroom experiences, public programs, media information, elements of distance (Internet) learning, and K-12 education. A scientist at each site has responsibility for the local educational and public outreach (EPO) program, with additional support provided by other members of the scientific and administrative staff. The EPO officer for ATST now coordinates outreach activities to schools, colleges and the media for both the ATST and NSO programs.

NSO EPO goals are:

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

NSO will work with its university based user community and the ATST consortium to support EPO on several fronts that leverage and expand existing programs within the partnering groups and create unique opportunities offered by the ATST. Many of the activities described here will be developed with an eye towards supporting both NSO and ATST educational goals.

Table V-1 summarizes the level of EPO personnel support embedded in the NSO and ATST program. In addition, NSO participates in and receives support from the NOAO Public and Educational Outreach (PAEO) office. NSO makes resources available to support its EPO effort in the form of supplies and materials, computer workstations, WWW site, housing, Visitor Center and telescope time. Including the manpower shown in Table V-1, NSO devotes about 5% of its resources to outreach when scientific staff effort is included.

| | | | | | | · (· · | /- | | |
|-------------------------------------|------|---------|----------|-----------|---------|--------|-------|--------|-------|
| | SRA | | WWW | | | | | | |
| | REU | | Public | WWW | HS/K-12 | Public | K-12 | EPO | |
| Function | RET | TL-RBSE | Outreach | Sci. Data | Tasks | Tours | Tours | Admin. | TOTAL |
| ATST EPO Officer | 0.10 | | 0.50 | | 0.20 | | | 0.20 | 1.00 |
| Web Master (part-time at each site) | | | 0.60 | 0.20 | 0.00 | 0.20 | 0.10 | 0.10 | 1.20 |
| Scientific Staff | 0.50 | 0.10 | 0.10 | 0.20 | 0.10 | 0.10 | 0.10 | 0.10 | 1.30 |
| Scientific Support Staff | 0.10 | 0.05 | 0.10 | 0.30 | 0.10 | 0.10 | 0.10 | 0.10 | 0.95 |
| Summer Students | | | 0.20 | 0.00 | 0.10 | 0.20 | 0.20 | 0.00 | 0.70 |
| TOTAL | 0.70 | 0.15 | 1.50 | 0.70 | 0.50 | 0.60 | 0.50 | 0.50 | 5.15 |

TABLE V-1. Annual Educational and Public Outreach (FTEs).

5.1 Educational Outreach

NSO conducts several programs designed to train the next generation of solar physicists as well as introduce future taxpayers to the importance of solar physics.

Research Fellows. Although funding has limited the number of NSO postdoctoral positions, NSO continues to host several each year through grants. Several postdoctoral fellows have participated in the adaptive optics program both at NSO and NJIT. GONG has sponsored up to two fellowship positions through NASA grants. During FY 2005, NSO filled an ATST fellowship position and has plans to fill another such position in FY 2006 to exploit the new high-resolution capabilities and to participate in the ATST program.

Thesis Students. NSO annually hosts students working on advanced degrees. Typically, NSO staff members serve as adjunct faculty and act as local thesis advisors. Thesis students during the past year include Jose Marino (PhD candidate, NJIT), Brian Lundberg (PhD candidate, Utah State University), Hyun Kyoung An (PhD candidate, University of Alabama-Huntsville). Their work has included development of image reconstruction for AO systems, studies of chromospheric Alfven Waves, and modeling active region magnetic fields.

REU/SRA. Since the inception of NSO in 1983, the observatory has conducted programs that offer undergraduate and graduate student research opportunities. Large fractions of active solar astronomers worldwide (as well as science/engineering leaders in other disciplines) have been alumni of the NSO summer programs. In recent years, many of our students have been drawn from universities participating in the ATST program. Primary programs are the Research Experiences for Undergraduates (REU), and the Summer Research Assistant (SRA) program for graduate and non-REU undergraduate students. Annual enrollment for the REU program is 6-8 undergraduates and for the SRA program 4-6 students. These programs actively recruit minority students and women. Women have comprised 50% of the REUs and 26% of the SRAs, and minorities 5% of the two programs. During the past four years, some of these students have participated in the ATST site survey instrumentation and data analysis, adaptive optics, and high-resolution observational and theoretical projects that directly bear on ATST science to understand solar magnetism.

Teacher and Student Programs for K-12. Participation in research and training for high school teachers is provided at NSO through the Research Experience for Teachers (RET) program. Currently, approximately four

teachers participate each summer. They are given solid exposure to the NSO and ATST program, and have worked with staff members and REU students on a variety of projects that have provided both research experience and material for classroom programs. NSO also participates in the Teacher Leaders in Research Based Science Education (TLRBSE) program developed by NOAO. NSO provides teachers with hands-on observational opportunities to collect and analyze data on solar magnetism and variability. Scientists from NSO then interact with the teachers at the institute and provide research guidance throughout the year. These teachers in turn form a cadre for developing classroom programs that can be disseminated to broader audiences.

Examples of modules that have been developed for younger students include Data and Activities for Solar Learning (DASL) and Research in Active Solar Longitudes (RASL), and the K-3 solar music educational module from GONG data. NSO will build on this experience to construct modules on solar magnetism, initially based on SOLIS data and then working in ATST goals.

Astrobiology. Astrobiology is a key focus for science at the start of the 21st century. In the 20th century, the individual physical and biological sciences attained a high level of development and understanding. It is the role of astrobiology to bring the techniques of these individual disciplines bear on the questions of how the solar system began, how life on earth originated, and how common life is in the universe. In a joint program with the University of Arizona's newly established Life and PLAnets Center (LAPLACE) and the NOAO, the NSO is participating in a program of research and educational outreach funded by a five-year award from the NASA Astrobiology Institute (NAI). NSO (Mark Giampapa and postdoctoral research associate William Sherry) is leading a program that focuses on delineating the joint evolution of magnetic activity and luminosity variations in Sun-like stars that may be the hosts of developing planetary systems.

In the area of educational outreach in astrobiology, the joint program organizes exchanges of students and staff with other NAI member institutions. For example, members of the NSO staff participated in the LAPLACE-University of Washington (UW) exchange in the spring of 2005, which involved a visit to Kitt Peak by 14 graduate students from the UW astrobiology program along with members of UA LAPLACE. The graduate students represented a broad range of disciplines in the life and physical sciences, and engineering. The students participated in demonstration observing exercises in order to gain an understanding of how astronomical data relevant to goals in astrobiology are obtained, reduced and analyzed. At the McMath-Pierce solar telescope, the grad students obtained infrared spectra of sunspots and measured umbral field strengths based on the observed Zeeman splitting of a magnetically sensitive Fe I line at 1.56 microns. In addition, they saw Ca II H and K spectra acquired for active regions in the vicinity of the spot, similar to the kind of spectra obtained at the nighttime telescopes for active solar-type stars. Exchanges of this kind will be held annually during either the winter or spring breaks, and feature hands-on demonstration observing programs at the NSO McMath-Pierce Solar Telescope on Kitt Peak.

Project ASTRO. Project ASTRO is an educational outreach program initiated by the Astronomical Society of the Pacific to build relationships between astronomers and educators by encouraging interaction in the development and execution of astronomy activities in the classroom. NSO provides guest astronomers for the program and hosts an annual workshop for astronomers and educators.

Further Undergraduate and Graduate Outreach. NSO is investigating hosting an engineering challenge wherein college teams would be invited to design and build basic instrumentation that would be evaluated on existing NSO telescopes. The intent is to provide practical engineering experience to stimulate future candidates for REU and other advanced programs. NSO also is placing a lecture and resources list online for use by students in the Space Studies program at the University of North Dakota. This accompanies a colloquium lecture

delivered by the EPO officer in 2003 and taped for distance students. The EPO officer and two NSO scientists will write a chapter for an advanced undergraduate book on observational astronomy.

New Programs. NSO is undertaking three new EPO initiatives and included them as part of the EPO section of the ATST proposal. These initiatives include *Magnetic Carpet Ride* (formerly called *Max 2008*), *The Goldilocks Star* (formerly called *Other Suns for Other Worlds*), and *The Sun on Wheels*. These will be designed to complement TLRBSE and Project ASTRO as well as outreach to schools and public programs. *Magnetic Carpet Ride* will take advantage of the anticipated Cycle 24, which starts around 2008, the centennial of Hale's discovery of solar magnetism, and the International Heliophysical Year. It will develop classroom activities and traveling exhibit materials to teach the basics of solar magnetism and why it is the key to understanding solar activity. It will include a combination of computer stations with interactive graphics, hands-on units, and models of the Sun and of a sunspot. *Other Suns for Other Worlds* will take the natural interest in nighttime astronomy and the hunt for other planets supporting life as a means of teaching about our Sun. The goal will be to make visitors understand that in order to define a life-supporting star properly, we must also understand our own star better. *The Sun on Wheels* will be a van equipped with telescopes, lesson plans, and other materials that can take *Magnetic Carpet Ride, The Goldilocks Star*, and existing programs to schools and public events. The telescopes initially will be ATST survey telescopes adapted for public programs. Advanced imaging systems will be added as the program evolves. Funding will be sought through NSF and other organizations.

5.2 Other Outreach

At the Sunspot Astronomy and Visitor Center, a live solar viewer that will project a white-light image of the Sun from a heliostat outside the Visitor Center to a screen inside the center is near completion. NSO is developing *Ride a Magnetic Carpet* to educate visitors about the magnetic nature of the Sun. This now is a major component of Magnetic Carpet Ride, which will be developed for delivery in both classrooms and public displays. Additional exhibit materials include new display panels for the Dunn Solar Telescope lobby and the Visitor Center to highlight current observing programs at Sunspot. NSO also has developed initial plans for a scale model of the solar system that will have an 18-foot-diameter walk-through model of the Sun at the Visitor Center, plus aluminum models of the planets. At this scale, Neptune passes through the space museum in Alamogordo and Pluto through the village of Cloudcroft. We anticipate that placing markers for the planets at scale distances along the Sunspot Highway will help draw more traffic to Sunspot and thus offer a chance for more people to learn about solar physics, including the need for ATST. We also are defining a computer kiosk that would provide access to real-time imagery from ISOON and allow visitors to perform simple image manipulations through a subset of IDL routines use by the ISOON team. Both the exhibit and kiosk will be designed to be transportable for use at either the Sunspot or Kitt Peak visitor centers or by other members of the Southwestern Consortium of Observatories for Public Education (SCOPE). NSO will continue with exhibits at the National Science Teachers Association annual convention. NSO is applying to join the outreach component of NASA's Living With a Star (LWS) program, a broad, powerful outlet for NSO materials and messages. NSO continues to participate in SCOPE, a consortium of research institutions in the southwest that promote a public awareness of astronomy through access and education.

5.3 Media and Public Information

Print Products. NSO prepared a fact sheet, *Einstein and the Sun*, for the World Year of Physics to highlight how Albert Einstein's seminal papers were validated by using the Sun, and how they advanced solar physics. Planned new print products include a press kit on ATST (fact sheet, technical news reference, image collection), and fact sheets and trifolds on SOLIS and GONG, and a revised tourism brochure for Sunspot.

Web-Based Outreach. The Ask Mr. Sunspot feature will be revamped to streamline past answers into a comprehensive set and to write new tutorials about the Sun and ATST. Web stories anticipated in FY 2005 and FY 2006 include SOLIS becoming operational, the AO/DLSP combination at the Dunn Solar Telescope, and expansion of ISOON capabilities. Other stories will be based on observing programs at Kitt Peak and Sunspot and of science papers published by the NSO staff. With the Scientific Visualization Studio at NASA's Goddard Space Flight Center, the NSO will explore new computer visualization concepts. NSO also is developing a streamlined online catalog of solar and instrumentation images for use by the public and the media.

6 IMPLEMENTATION

Continuing the effective support NSO provides to the solar and space physics research community will require an evolutionary change in NSO structure and its mode of operation over the next several years. Implementation of NSO's strategic long-range plan by its staff in collaboration with the community provides this evolution and will play a fundamental role in maintaining US preeminence in solar physics. As NSO facilities and programs evolve, the fundamental structure of the NSO will also evolve to ensure continued efficient and effective operations. NSO will continue to form strong collaborations to enhance both the long-term program and NSO's impact in strengthening the solar physics community as it undertakes the tasks outlined in its strategic plan.

6.1 The Evolution of NSO

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

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

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

- 1. Funding of the ATST construction phase proposal (2007);
- 2. Decision on NSO headquarters location (2008-2009);
- 3. Commissioning of the ATST (2013-2014);
- 4. Relocation of SOLIS to the ATST site (2012-2014);
- 5. Divestment of older facilities (2013)
- 6. Consolidation of the NSO (2012-2014).

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. 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. NSO will strive to raise ATST funds without premature telescope closures that could eliminate entire areas of research in solar physics.

Much of NSO support for synoptic studies of the Sun has changed over the past few years. SOLIS data has supplanted the magnetograms, Dopplergrams, and spectral images that were obtained with the KPVT, and the spectroheliograms obtained at the Evans Solar Facility. Once the SOLIS integrated sunlight spectrometer is cross-calibrated with the Sun-as-a-Star spectral measurements made at the ESF and McMP, these older programs also will be terminated.

NSO's current operations, encompassing two major operational sites, Sacramento Peak in New Mexico and Tucson/Kitt Peak in Arizona, as well as several remote sites for the GONG network, address the needs of a diverse set of users in the solar community. The NSO maintains scientific staff at both of the major sites, which greatly enhances the scientific return from these national facilities. The close proximity of the staff to the telescopes has yielded a wealth of evolving capabilities, thereby maintaining the NSO at the forefront of solar research. Through its adaptive optics, infrared, and advanced instrumentation projects, the current NSO program is highly invested in the future and the implementation of ATST. The Dunn Solar Telescope and the McMath-Pierce Solar Telescope have experienced renewed interest as manifested by strong proposal pressure as a direct result of these new capabilities. Maintaining scientific staff at both sites in the near-term will continue to provide the best support for the solar user community, the maximum scientific return from the facilities in both quality and quantity, and the most effective structure for developing the technologies needed to exploit the ATST. When the ATST becomes operational, the plan calls for consolidation of the NSO program to provide the most effective scientific utilization of its cornerstone facilities and the most efficient operations.

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

NSO and its Director will be responsible for the operation of ATST and its integration into existing programs. Support for the operations of ATST will be allocated by the NSO Director according to the annual program plan, which is submitted to the NSF for review and approval. To involve the community in the operation of ATST, we propose to establish an ATST Users' Committee that would be concerned with the telescope, its instrumentation, and support infrastructure.

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

of national laboratories aligned with universities to see if they might serve as a suitable model for a joint university-NSO relationship that includes one or more joint faculty/staff appointments.

In establishing a joint program and assigning teaching responsibilities, 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, must be a primary criterion.

NSO will coordinate the development of a restructuring plan with NSF.

6.2 NSO Scientific Staff

The key to implementing the NSO strategic plan is a robust scientific staff. The responsibilities of a scientific staff member are divided between 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 provide 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 and affiliated staff are listed below, along with their primary area of expertise and key observatory responsibilities.

6.2.1 Sunspot-Based Scientific Staff

NSO Staff

- K. S. Balasubramaniam Solar activity; magnetism; polarimetry; ATST narrowband imager; International Heliophysical Year liaison and editor of the *IHY Newsletter*.
- Stephen L. Keil NSO Director; ATST PI; solar variability; convection.
- Alexei A. Pevtsov Solar activity; coronal mass ejections, Site Director, NSO REU/RET Program; ATST broadband imager.
- Thomas R. Rimmele Solar fine structure and fields; adaptive optics; instrumentation; ATST Project Scientist; Dunn Solar Telescope Program Scientist; ATST/AO program lead.
- Han Uitenbroek Atmospheric structure and dynamics; radiative transfer modeling of the solar atmosphere; Ch., NSO/SP Telescope Allocation Committee; ATST thermal IR.

Grant-Supported Staff

- K. Sankarasubramanian Solar fine structure; magnetism; Stokes polarimetry; ATST polarimetry.
- Brian Robinson ATST instrumentation.

Air Force Research Laboratory Staff at Sunspot

- Richard C. Altrock Coronal structure and dynamics.
- Nathan Dalrymple Polarimetry; ATST thermal analysis.
- Joel Mozer Coronal structure; remote sensing; space weather.
- Richard R. Radick Solar/stellar activity; adaptive optics.

Thesis Students

- Hyun Kyoung An ATST instrumentation.
- Brain Lundburg Solar activity; magnetism; polarimetry.
- Jose Marino Adaptive optics; solar imaging.

6.2.2 Tucson-Based Scientific Staff

NSO Staff

- Mark S. Giampapa NSO Deputy Director; stellar dynamos; stellar cycles; magnetic activity; Ch., Tucson Project Review Committee; Ch., Scientific Personnel Committee; SOLIS PI.
- Irene E. González-Hernández Helioseismology.
- John W. Harvey Solar magnetic and velocity fields; helioseismology; instrumentation; SOLIS Project Scientist; Ch., NSO/KP Telescope Allocation Committee.
- Carl J. Henney Solar MHD; polarimetry; space weather, SOLIS Program Scientist.
- Frank Hill Solar oscillations; data management.
- Rachel Howe Helioseismology; the solar activity cycle.
- Shukur Kholikov Helioseismology; data support.
- John W. Leibacher Helioseismology; GONG PI.
- Matthew J. Penn Solar atmosphere; solar oscillations; polarimetry; near-IR instrumentation; Co-Site Director, NSO REU/RET Program; ATST near-IR.
- Candido D. Pinto GONG instrumentation.
- Clifford G. Toner Global and local helioseismology. Image restoration; data analysis techniques.

Grant-Supported Scientific Staff

- Michael Dulick Molecular spectroscopy; high-resolution Fourier transform spectrometry.
- Rudolph W. Komm Helioseismology; dynamics of the convection zone.
- Olena Malanushenko Structure of the solar chromosphere and transition region; coronal holes.
- Nour-Eddine Raouafi Solar magnetic fields.
- William H. Sherry Evolution of stellar activity; protoplanetary disks.
- Aleksander V. Serbryanskiy Helioseismology; dynamics of the convection zone.
- Sushanta C. Tripathy Helioseismology; solar activity.
- Roberta M. Toussaint Helioseismology; image calibration and processing; data analysis techniques.

Emeritus Staff in Tucson

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

6.2.3 Future Staffing

NSO currently has 17 scientists on its permanent staff including the director. Six of these are tenured astronomers, four are tenure-track astronomers, and the remaining seven are non-tenured scientific staff. In addition, there are ten NSO scientists supported on externally funded projects, grants, contracts and other soft money.

The implementation of new capabilities such as adaptive optics, diffraction-limited polarimetry, large format IR cameras, and the high-resolution GONG, as well as the completion of new facilities such as SOLIS and ATST, substantially enhances the quality and quantity of NSO data and observational capabilities. Taking advantage of the new facilities and capabilities will require increased scientific efforts, continued development of new instrumentation, enhancement of the NSO Digital Library, and the development of and linkage to the Virtual Solar Observatory.

Most of the senior scientific staff are deeply involved in projects (as seen from the staff list above). The nearterm addition of four NSO postdoctoral positions, two at each site, would substantially enhance the scientific output of the NSO and increase its support of users. More importantly, it would begin training the next generation of solar observational scientists and provide a science cadre that can fully exploit the new capabilities provided by the ATST. We anticipate that many of the scientists filling these postdoctoral positions would eventually assume positions at universities, thus fulfilling one of the high priorities of the National Research Council's decadal report, "Astronomy and Astrophysics in the New Millennium" (Decadal Survey), i.e., to build up the presence of solar physicists at universities. The cost of adding four postdoctoral positions to the NSO staff would be approximately \$380K per year.

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

Once ATST construction funding is secured, NSO will develop a staffing plan that will accommodate the transition from operating its current facilities to those needed in the ATST era. As we begin operating SOLIS, gain more experience with operating the high-resolution GONG, determine the level of support needed to sustain participation and leadership in the VSO, and refine the operational plan for ATST that was part of the ATST construction proposal, we can accurately determine the required staffing levels.

6.3 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. Some past examples of NSO meeting this responsibility include development of GONG and enhancement of the GONG network, development of solar adaptive optics and multi-conjugate adaptive optics, development of infrared observing capabilities in collaboration with the University of Hawaii, California State University-Northridge, and NASA, and participation in the development of the advanced Stokes polarimeter in collaboration with HAO. Table 6.3-1 lists several ongoing joint projects and development efforts.

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

| Table 6.3-1. Joint Development Efforts | | | | | | |
|--|---|--|--|--|--|--|
| Telescope/Instrument/Project | Collaborators | | | | | |
| Advanced Technology Solar Telescope | HAO, U. Hawaii, U. Chicago, NJIT, Montana State U., Princeton U., Harvard/Smithsonian, UC-San Diego, UCLA, U. Colorado, NASA/GSFC, NASA/MSFC, Caltech, Michigan State U., U. Rochester, Stanford U., Lockheed-Martin, Southwest Research Institute, Colorado Research Associates, Cal State Northridge | | | | | |
| Adaptive Optics | NJIT, Kiepenheuer Institute, AFRL | | | | | |
| Diffraction-Limited Spectro-Polarimeter ((DLSP) | НАО | | | | | |
| Spectro-Polarimeter for Infrared and Optical Regions (SPINOR) | НАО | | | | | |
| Narrowband Filters and Polarimeters | Arcetri Observatory, U. Alabama, Kiepenheuer Institute | | | | | |
| Synoptic Solar Measurements | USAF, NASA | | | | | |
| Fourier Transform Spectrometer | NASA | | | | | |
| IR Spectrograph and Cameras | U. Hawaii, Cal State Northridge | | | | | |

6.4 Operational Partnerships

NSO's strategic planning embraces the interdisciplinary nature and dual objectives of solar physics in that it is both basic science and applied research. Likewise, NSO's relationships to its users reflect the diversity and richness of the communities they represent—solar and stellar astronomy, space plasma physics, solar-terrestrial relationships, space weather prediction, terrestrial atmospheric chemistry, and more. Table 6.4-1 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. The Air Force Office of Scientific Research (AFOSR) has indicated a desire to keep their basic solar research program co-located with NSO and have indicated that they will help purchase and polish the mirror for the ATST.

| Table 6.4-1. Current NSO Partnerships | | | | | | | |
|---------------------------------------|---|--|--|--|--|--|--|
| Partner | Program | | | | | | |
| Air Force Research Laboratory | Solar Activity Research at NSO/SP; Telescope Operations; Adaptive Optics; | | | | | | |
| | Instrument Development; 6 Scientists Stationed at NSO/SP; Daily Coronal Emission | | | | | | |
| | Line Measurements; Provides Operational Funding: \$400K-Base and Various | | | | | | |
| | Amounts for Instrument Development. | | | | | | |
| NASA | Operational Funding for SOLIS: 2 Asst. Scientists; 1 Postdoctoral Research Asst.; | | | | | | |
| | 0.5 Instrument/Observing Specialist. | | | | | | |
| | McMath-Pierce: Support for Operation of the FTS; Upper Atmospheric Research. | | | | | | |
| NSF Chemistry | FTS Support | | | | | | |

6.5 NSO Organization

NSO is managed in four major functional units, NSO/Sacramento Peak (NSO/SP), NSO/Tucson (NSO/T), NSO/GONG, and NSO/ATST. NSO conducts operations and projects with a combination of positions funded from its base NSF support, "soft money" positions funded from projects and grants, and positions funded by its collocated partner organizations. In addition, NSO shares support personnel (e.g., shops, facilities maintenance, computing, administration) with NOAO in Tucson and on Kitt Peak. Funds for these shared services are in the NSO budget and are shown on the NSO spending plan, but the funds are currently committed to NOAO for shared services, which result in considerable cost savings. The NSO Director's office consists of two employees, the Director and an executive assistant, and receives financial and budget support from the NSO/SP site manager. The Director currently resides at NSO/SP. A site director for NSO/T also serves as deputy director and oversees operations at Tucson. NSO/SP has a site manager for operations and facilities. In addition, the NSO Director shares support personnel with NOAO for accounting, human resources, graphics, and educational outreach.

NSO/SP primarily operates the Dunn Solar Telescope on Sacramento Peak as well as offices, computing, instrument development, and housing facilities for visitors and the resident scientific and technical staff. Some support is also provided to AF and HAO funded programs at the Evans Solar Facility and Hilltop, respectively. Major projects at NSO/SP include development of multi-conjugate adaptive optics, collaboration with HAO on the DLSP and SPINOR, upgrading the data and control systems at the DST, and work on the ATST design. In addition, NSO/SP conducts experiments and smaller projects to improve near-IR cameras and spectroscopy, narrowband imaging in the visible and IR, and vector polarimetry techniques that can take advantage of high-resolution facilities.



Figure 6.5-1. NSO High-Level Organization Chart

NSO/T operates the McMath-Pierce Solar Telescope and SOLIS on Kitt Peak, offices in Tucson, and conducts projects at the Tucson facilities. NSO shares support personnel with KPNO on Kitt Peak and with the other NOAO divisions in Tucson. Major projects at NSO/T include completing SOLIS instrumentation, large-format IR camera development, and work on the ATST design. NSO/T also conducts experiments and minor projects to improve Stokes polarimetry techniques, imaging at the McMath-Pierce Solar Telescope, solar-stellar observation techniques, and speckle imaging techniques.

NSO/GONG, located in Tucson, operates and maintains the GONG network of six telescopes, collects, processes and provides data to users.

NSO/ATST is funded primarily by the ATST D&D proposal and planned funding to bridge the period leading up to the start of construction. The ATST staff resides in both Tucson and Sacramento Peak, allowing the team to interact with NSO staff and take advantage of lessons learned from current telescope operations and projects at both sites.

6.6 Spending Plan

The NSO spending plan is summarized in Table 6.6-1 and detailed in Table 6.6.2. The plan covers a fiveyear period beginning in FY 2005 and represents the allocations needed to implement the long-range strategic plan. The budget is summarized by functional units in Table 6.6-1 and shown in detail with each functional unit broken into work areas in Table 6.6-2.

| Table 6.6-1. F | ive Year Sp | pending Sun | nmary | | |
|----------------------------|-------------|-------------|---------|---------|---------|
| | (Dollars in | Thousands) | | | |
| _ | FY 2005 | FY 2006 | FY 2007 | FY 2008 | FY 2009 |
| Director's Office | 320 | 328 | 338 | 348 | 358 |
| Tucson Operations | 1,592 | 1,608 | 1,647 | 1,647 | 1,646 |
| Sacramento Peak Operations | 1,727 | 1,737 | 1,822 | 1,826 | 1,881 |
| ATST In-House Contribution | 656 | 701 | 977 | 1,130 | 1,214 |
| GONG | 2,416 | 2,415 | 2,437 | 2,511 | 2,586 |
| SOLIS | 313 | 322 | 532 | 598 | 616 |
| Base Budget Program Totals | 7,025 | 7,111 | 7,753 | 8,060 | 8,301 |
| General NOAO Support | 991 | 1,000 | 1,030 | 1,061 | 1,093 |
| AURA Management Fee | 218 | 220 | 227 | 234 | 241 |
| Base NSO Program | 8,234 | 8,331 | 9,010 | 9,354 | 9,635 |
| ATST | | | | | |
| AST ATST D&D Proposal | 2,400 | | | | |
| ATST ATM Funding | 13 | | | | |
| ATST Increment | | 2,000 | | | |
| ATST Construction Proposal | | - | 40,000 | 41,000 | 33,000 |
| Total ATST | 2,413 | 2,000 | 40,000 | 41,000 | 33,000 |
| Base NSO + ATST | 10,647 | 10,331 | 49,010 | 50,354 | 42,635 |

The FY 2005 spending plan is a revision of the FY 2005 program plan budget, based on the current allocation from NSF and the actual funds received from partners. Development of the FY 2006 plan was based on current guidance from NSF and the President's budget submission. The FY 2007 budget is based on the amount submitted as part of the cooperative agreement between AURA and NSF covering the period from 2003-2007. It assumes that ATST construction funding will begin in FY 2007. The FY 2008-FY 2009 budgets contains inflationary increases from FY 2006 and reflect the evolution of ongoing programs towards eventual ATST operations. These budgets will be negotiated as part of the next cooperative agreement for operation of the NSO. They were developed assuming continued transfer of in-house effort to the ATST project, placing scientific emphasis on the high-resolution program at the DST, the IR program at the McMP, a ramp-up in SOLIS operations, taking advantage of synergisms between SOLIS and GONG data handling, and participation in the development of the VSO. The budgets also assume that NSO will continue to receive support from its partner organizations (shown as revenues in Table 6.6-2).

Although we allocate the base budget through functional areas, the actual budget is developed from the tasks in our work breakdown. Table 6.6-2 shows each of the functional areas broken down by work areas. Funding for the support received from NOAO is listed separately because it is embedded in the NOAO budget. Approximately 17% of the NOAO support goes to computer support, 33% to facilities in Tucson, 11% to educational outreach, and 39% to business services and human resources support. While the NSO base budget shown in Tables 6.6-1 and 6.6-2 allows NSO to conduct a robust program in solar physics, funding increments in certain areas discussed in the following section would greatly enhance our support for the user community and accelerate development of the ATST.

THE NATIONAL SOLAR OBSERVATORY

| | | (Dollars in Tl | housands) | y Fiall | |
|---------------------------------------|----------|----------------|-----------|---------|---------|
| | FY 2005 | FY 2006 | FY 2007 | FY 2008 | FY 2009 |
| Director's Office | | | | | |
| Director's Office | 338 | 346 | 356 | 367 | 378 |
| Programmed Indirects | (18) | (18) | (19) | (19) | (20) |
| Total Director's Office | | 320 | 328 | 338 | 348 |
| Tucson Operations | | | | | |
| Scientific Staff | 776 | 803 | 777 | 750 | 723 |
| Software Support | 193 | 198 | 204 | 210 | 216 |
| Instrument Development | 340 | 318 | 368 | 379 | 391 |
| NOAO/ETS Support | 105 | 105 | 108 | 111 | 115 |
| Telescope Operations ⁽¹⁾ | 159 | 167 | 172 | 177 | 182 |
| Utilities on Kitt Peak ⁽¹⁾ | 50 | 50 | 52 | 53 | 55 |
| Educational Outreach ⁽²⁾ | 56 | 58 | 59 | 60 | 62 |
| Revenue | (88) | (90) | (92) | (94) | (97) |
| Total NSF Tucson | <u>`</u> | 1,592 | 1,608 | 1,647 | 1,647 |
| Sacramento Peak Operations | | | | | |
| Scientific Staff | 422 | 399 | 361 | 322 | 331 |
| Scientific Support/Computing | 274 | 275 | 284 | 293 | 303 |
| Instrument Development/Maintenance | 475 | 479 | 576 | 593 | 611 |
| Telescope Operations | 199 | 207 | 213 | 220 | 226 |
| Facilities | 630 | 641 | 660 | 680 | 701 |
| Administrative Support | 243 | 252 | 260 | 268 | 276 |
| Educational Outreach ⁽²⁾ | 149 | 150 | 153 | 155 | 159 |
| Revenue ⁽³⁾ | (665) | (666) | (686) | (705) | (726) |
| Total NSF SP | | 1,727 | 1,737 | 1,822 | 1,826 |
| ATST In-House Contributions | | | | | |
| ATST Fellow ⁽⁴⁾ | - | - | 175 | 254 | 262 |
| ATST Science Support | 100 | 145 | 249 | 307 | 366 |
| Technology Development ⁽⁵⁾ | 556 | 556 | 553 | 569 | 586 |
| In-house Site Testing | - | - | - | - | - |
| Total ATST | | 656 | 701 | 977 | 1,130 |
| GONG | | | | | |
| Scientific Staff ⁽⁶⁾ | 421 | 426 | 439 | 452 | 466 |
| DMAC Operations | 691 | 695 | 666 | 686 | 707 |
| Telescope Operations | 1,133 | 1,115 | 1,149 | 1,183 | 1,219 |
| Administrative Support | 171 | 178 | 184 | 189 | 195 |
| Total NSF GONG | | 2,416 | 2,415 | 2,437 | 2,511 |
| SOLIS | | | | | |
| Scientific Staff | 82 | 85 | 217 | 274 | 282 |
| Operations | 232 | 237 | 315 | 324 | 334 |
| Total SOLIS | | 313 | 322 | 532 | 598 |

991

218

8,234

2,400

2,413

10,647

13

1,000

8,331

2,000

-

2,000

10,331

220

1,030

227

9,010

40,000

40,000

49,010

1,061

9,354

41,000

41,000

50,354

234

Table 6.6.2 Detailed Eive-Vear Sponding Plan

358

1,646

1,881

1,214

2,586

616

1,093

9,635

33,000

33,000

42,635

241

ATST

NOAO Business/Educ Outreach Support

Total Base Program

Total ATST

Total NSO+ATST

AURA Management Fee

AST ATST D&D Proposal

ATM ATST D&D Proposal

ATST Construction Proposal

ATST Bridge Funding

Notes for Table 6.6-2:

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

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

(3) – Revenues in Tucson include \$32K from NASA and \$56K from the REU/RET program. Sac Peak revenues include meal revenues (\$17K), housing revenues from rent (\$91K), funds received from the Air Force for operations (\$450K), earnings at the Visitor Center gift shop (\$50K), and from the REU/RET program (\$57K). Funds received from the Air Force (AF) are variable due to DoD budget variations and are negotiated annually. While NSF charges ~5% overhead, this is always returned to NSO from the AST Division under the MOU with the AF; thus there is no reduction in the amount available to NSO.

(4) – In FY 2004 and FY 2005 this position is supported by an AURA fellowship that is cost shared with NSO/ATST. In FY 2007 and beyond NSO will add additional fellowships

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

(6) - Three of the scientists accounted for in Tucson operations also devote considerable time to GONG.

6.6.1 Strategic Needs

There are several areas in which funding delta's would make a large impact on implementing the NSO strategic plan, ensuring that ATST continues its vigorous schedule, and providing improved service to the user community. Specific areas include (listed in prioritized order):

- *FY 2006* (see Section 3.1). As discussed in Section 3.1, the \$2M ATST bridge funds allow the ATST project to continue its in-house development program and to begin some of the vendor contracts needed to complete the design-to-build effort. Some of the major design completion vendor contracts cannot be started at the proposed bridge funding level. An additional \$3M in FY 2006— bringing the bridge funding to \$5M—would allow the ATST to begin all of the major design completion efforts. This would allow the project to concentrate on retiring risk areas such as the thermal control of the enclosure, feed optics, and AO deformable mirror, as well as both the thermal and figure control of the primary mirror. Beginning the major design completion vendor contracts would minimize the risk of having to rework the design later on. If ATST construction is delayed beyond FY 2007, additional bridge funding will be needed to ensure a smooth transition to construction.
- *Postdoctoral Fellows* (see Section 6.2.3). The addition of postdoctoral fellows to the NSO staff would greatly increase the scientific productivity of senior and tenure-track staff. Currently the division between service, projects and science is out of balance, with science taking the biggest hit. Postdoctoral fellows are needed to work with staff scientists on high-resolution observing and modeling in support of the ATST program and to work on the new data stream that SOLIS is producing. Typical postdoctoral costs, including benefits and support, are approximately \$90K. An increment of \$380K/year in FY 2006-2009 would fund four positions.

6.6.2 FY 2005 Budget

The detailed breakdown of the NSO budget for FY 2005 by work area and functional unit is shown in Table 6.6-3. This is a revision of the budget submitted in the Program Plan for FY 2005 and reflects the latest guidance from NSF. The upper portion of the table shows the projected total NSO funding including the ATST D&D effort, REU/RET support, revenues from meal service and housing, and partner funding, while the bottom portion removes revenues outside NSF/AST, showing the total NSF/AST funding for the combined NSO-ATST program. The portion of NOAO support going into outreach is shown in the Educational and Public Outreach line under the Director's Office.

Figure 6.6-1 shows the percentage breakdown for the total NSO program in FY 2005. ATST is now the dominant NSO program.

| | Director's Office | Sunspot | Tucson | GONG | ATST | SOLIS | Total Budget |
|---|----------------------|--|-----------------------|-------|---------------|-------|--|
| Director's Office | 338 | | | | | | 338 |
| Scientific Staff | | 422 | 776 | 421 | 100 | 82 | 1,800 |
| Scientific Support/Computing | | 274 | 193 | 691 | | | 1,158 |
| Instrument Development/Maintenance | | 475 | 445 | - | 556 | | 1,476 |
| Telescope Operations | | 199 | 209 | 1,133 | | 232 | 1,773 |
| Facilities | | 630 | | | | | 630 |
| Administration | | 243 | | 171 | | | 415 |
| Educational & Public Outreach | 112 | 149 | 56 | | | | 317 |
| NOAO Business Support | 17 | 149 | 396 | 317 | | | 879 |
| ATST D&D | | | | | 2,368 | | 2,368 |
| ALIPA Management Eee | 219 | | | | 46 | | 264 |
| AUNA management i ee | 210 | | | | | | 204 |
| Program Total | 685 | 2,540 | 2,076 | 2,733 | 3,069 | 313 | 11,418 |
| Program Total Revenues | 685 | 2,540 | 2,076 | 2,733 | 3,069 | 313 | 11,418 |
| Program Total Revenues NSF ATST D&D Proposal (ATM Div) | 685 | 2,540 | 2,076 | 2,733 | 3,069 (13) | 313 | 11,418 (13) |
| Program Total Revenues NSF ATST D&D Proposal (ATM Div) Programmed Indirects | <u>685</u> (18) | 2,540 | 2,076 | 2,733 | 3,069 (13) | 313 | (13) (18) |
| Program Total Revenues NSF ATST D&D Proposal (ATM Div) Programmed Indirects Housing Revenue | <u>685</u> (18) | 2,540 (91) | 2,076 | 2,733 | 3,069 (13) | 313 | (13) (18) (91) |
| Program Total Revenues NSF ATST D&D Proposal (ATM Div) Programmed Indirects Housing Revenue Meal Revenue | <u>685</u> (18) | 2,540 (91) (17) | 2,076 | 2,733 | 3,069 (13) | 313 | (13) (18) (91) (17) |
| Program Total Revenues NSF ATST D&D Proposal (ATM Div) Programmed Indirects Housing Revenue Meal Revenue NSF REU/RET Funding | (18) | 2,540 (91) (17) (57) | 2,076 | 2,733 | 3,069 (13) | 313 | (13) (13) (18) (91) (17) (113) |
| Program Total Revenues NSF ATST D&D Proposal (ATM Div) Programmed Indirects Housing Revenue Meal Revenue NSF REU/RET Funding AF Support | (18) | 2,540 (91) (17) (57) (450) | 2,076 | 2,733 | 3,069 (13) | 313 | (13) (13) (18) (91) (17) (113) (450) |
| Program Total Program Total Revenues NSF ATST D&D Proposal (ATM Div) Programmed Indirects Housing Revenue Meal Revenue NSF REU/RET Funding AF Support NASA Support | (18) | 2,540 (91) (17) (57) (450) | 2,076 (56) (32) | 2,733 | 3,069 (13) | 313 | (13) (18) (91) (17) (113) (450) (32) |
| Program Total Program Total Revenues NSF ATST D&D Proposal (ATM Div) Programmed Indirects Housing Revenue Meal Revenue NSF REU/RET Funding AF Support NASA Support Visitor Center Revenue | (18) | 2,540 (91) (17) (57) (450) (50) | 2,076 (56) (32) | 2,733 | 3,069 (13) | 313 | (13) (18) (91) (17) (113) (450) (32) (50) |

Table 6.6-3. FY 2005 Budget Allocations (Dollars in Thousands)



Figure 6.6-1. Budget breakdown by work areas in FY 2005. NSO will transfer an increasing percentage of its resources from its current program to ATST development over the period covered by this plan.

6.6.3 FY 2006 Budget

Table 6.6-4 shows NSO's planned FY 2006 allocations, conforming to the President's proposed budget of \$10,331K. The table assumes \$2M in ATST bridge funding, thus \$8331K is allocated to the base NSO program. This is only slightly higher than was allocated to the base in FY 2005 (\$8234K). This severely limits NSO's ability to provide salary adjustments to its staff in FY 2006 without making programmatic cuts. The allocations assume that additional NSO manpower is devoted to ATST development and no ramp-up in SOLIS operations from FY 2005.

| | (Dolla | rs in Thous | ands) | | | | |
|------------------------------------|------------|-------------|--------|-------|-------|-------|--------|
| | Director's | | | | | | Total |
| | Office | Sunspot | Tucson | GONG | ATST | SOLIS | Budget |
| Director's Office | 346 | | | | | | 346 |
| Scientific Staff | | 399 | 803 | 426 | 145 | 85 | 1,858 |
| Scientific Support/Computing | | 275 | 198 | 695 | | | 1,168 |
| Instrument Development/Maintenance | | 479 | 423 | - | 556 | | 1,458 |
| Telescope Operations | | 207 | 167 | 1,115 | | 237 | 1,726 |
| Facilities | | 641 | | | | | 641 |
| Administration | | 252 | | 178 | | | 431 |
| Educational & Public Outreach | 113 | 150 | 58 | | | | 321 |
| NOAO Business Support | 17 | 150 | 450 | 320 | | | 937 |
| ATST Bridge Funding | | | | | 1,962 | | 1,962 |
| AURA Management Fee | 220 | | | | 38 | | 258 |
| Program Total | 696 | 2,553 | 2,098 | 2,735 | 2,701 | 322 | 11,105 |
| Revenues | | | | | | | |
| Programmed Indirects | (18) | | | | | | (18) |
| Housing Revenue | | (91) | | | | | (91) |
| Meal Revenue | | (17) | | | | | (17) |
| NSF REU/RET Funding | | (58) | (58) | | | | (116) |
| AF Support | | (450) | | | | | (450) |
| NASA Support | | | (32) | | | | (32) |
| Visitor Center Revenue | | (50) | | | | | (50) |
| NSF Funds - ATST | 678 | 1,887 | 2,008 | 2,735 | 2,701 | 322 | 10,331 |

| Table 6.6-4. | FY 2006 | Budget | Allocations |
|--------------|---------|--------|-------------|
|--------------|---------|--------|-------------|

6.6.4 FY 2007- FY 2009 Budgets

Tables 6.6-5 through 6.6-7 show preliminary detailed budgets for the out years. They reflect cost for operation of current facilities and a steady shifting of scientific and project efforts to the ATST. The FY 2007 budget is based on the amount proposed for FY 2007 in the revised recompetition proposal budget plus \$40M for ATST construction. Assuming ATST construction is funded, it represents a much needed increase in the NSO base budget from \$8331K in FY 2006 to \$9010K in FY 2007. These funds would be used to ramp up ATST in-house support and SOLIS operational and scientific support. If ATST construction does not start in FY 2007 additional bridge funds would be needed to continue ATST design completion and risk reductions.

The FY 2008 and FY 2009 allocations assume inflationary increases in the base of 3% and continued funding of the ATST construction. Additional resources are transferred into ATST and SOLIS support.

| | Director's | | | | | | Total |
|------------------------------------|------------|---------|--------|-------|--------|-------|--------|
| | Office | Sunspot | Tucson | GONG | ATST | SOLIS | Budget |
| Director's Office | 356 | | | | | | 356 |
| Scientific Staff | | 361 | 777 | 439 | 424 | 217 | 2,219 |
| Scientific Support/Computing | | 284 | 204 | 666 | | | 1,154 |
| Instrument Development/Maintenance | | 576 | 476 | - | 553 | | 1,605 |
| Telescope Operations | | 213 | 172 | 1,149 | | 315 | 1,848 |
| Facilities | | 660 | | | | | 660 |
| Administration | | 260 | | 184 | | | 444 |
| Educational & Public Outreach | 116 | 153 | 59 | | | | 329 |
| NOAO Business Support | 18 | 155 | 464 | 330 | | | 965 |
| ATST Construction | | | | | 39,240 | | 39,240 |
| AURA Management Fee | 227 | | | | 760 | | 987 |
| Program Total | 717 | 2,662 | 2,151 | 2,767 | 40,977 | 532 | 49,806 |
| | | | | | | | |
| Revenues | | | | | | | |
| Programmed Indirects | (19) | | | | | | (19) |
| Housing Revenue | | (94) | | | | | (94) |
| Meal Revenue | | (17) | | | | | (17) |
| NSF REU/RET Funding | | (60) | (59) | | | | (119) |
| AF Support | | (464) | | | | | (464) |
| NASA Support | | | (33) | | | | (33) |
| Visitor Center Revenue | | (52) | | | | | (52) |
| NSF Funds - ATST | 698 | 1.976 | 2,059 | 2,767 | 40,977 | 532 | 49.010 |

Table 6.6-5. FY 2007 Preliminary Budget (Dollars in Thousands)

Table 6.6-6. FY 2008 Preliminary Budget

(Dollars in Thousands)

| | Director's | | | | | | Total |
|------------------------------------|------------|---------|--------|-------|--------|-------|--------|
| | Office | Sunspot | Tucson | GONG | ATST | SOLIS | Budget |
| Director's Office | 367 | | | | | | 367 |
| Scientific Staff | | 322 | 750 | 452 | 561 | 274 | 2,359 |
| Scientific Support/Computing | | 293 | 210 | 686 | | | 1,189 |
| Instrument Development/Maintenance | | 593 | 491 | - | 569 | | 1,653 |
| Telescope Operations | | 220 | 177 | 1,183 | | 324 | 1,904 |
| Facilities | | 680 | | | | | 680 |
| Administration | | 268 | | 189 | | | 457 |
| Educational & Public Outreach | 120 | 155 | 60 | | | | 335 |
| NOAO Business Support | 18 | 159 | 477 | 339 | | | 994 |
| ATST Construction | | | | | 40,221 | | 40,221 |
| AURA Management Fee | 234 | | | | 779 | | 1,013 |
| Program Total | 738 | 2,690 | 2,165 | 2,850 | 42,130 | 598 | 51,172 |
| _ | | | | | | | |
| Revenues | | | | | | | |
| Programmed Indirects | (19) | | | | | | (19) |
| Housing Revenue | | (97) | | | | | (97) |
| Meal Revenue | | (18) | | | | | (18) |
| NSF REU/RET Funding | | (60) | (60) | | | | (120) |
| AF Support | | (477) | | | | | (477) |
| NASA Support | | | (34) | | | | (34) |
| Visitor Center Revenue | | (53) | | | | | (53) |
| NSF Funds - ATST | 719 | 1,985 | 2,071 | 2,850 | 42,130 | 598 | 50,354 |

Table 6.6-7. FY 2009 Preliminary Budget (Dollars in Thousands)

| | (2000 | | 1103) | | | | |
|--|------------|---------|--------|-------|--------|-------|--------------|
| | Director's | | | | | | Total |
| | Office | Sunspot | Tucson | GONG | ATST | SOLIS | Budget |
| Director's Office | 378 | | | | | | 378 |
| Scientific Staff | | 331 | 723 | 466 | 628 | 282 | 2,430 |
| Scientific Support/Computing | | 303 | 216 | 707 | | | 1,226 |
| Instrument Development/Maintenance | | 611 | 505 | - | 586 | | 1,703 |
| Telescope Operations | | 226 | 182 | 1,219 | | 334 | 1,961 |
| Facilities | | 701 | | | | | 701 |
| Administration | | 276 | | 195 | | | 471 |
| Educational & Public Outreach | 123 | 159 | 62 | | | | 344 |
| NOAO Business Support | 19 | 164 | 492 | 350 | | | 1,024 |
| ATST Construction | | | | | 32,373 | | 32,373 |
| AURA Management Fee | 241 | | | | 627 | | 868 |
| Program Total | 761 | 2,771 | 2,180 | 2,936 | 34,214 | 616 | 43,477 |
| | | | | | | | |
| Revenues | | | | | | | |
| Programmed Indirects | (20) | | | | | | (20) |
| Housing Revenue | | (99) | | | | | (99) |
| Meal Revenue | | (18) | | | | | (18) |
| NSF REU/RET Funding | | (62) | (62) | | | | (124) |
| AF Support | | (492) | | | | | (492) |
| | | | | | | | (· |
| NASA Support | | | (35) | | | | (35) |
| NASA Support Visitor Center Revenue | | (55) | (35) | | | | (35) (55) |

APPENDIX A.

| A.1 | ATST SCIENCE WORKING GROUP |
|--------------------------|---|
| Thomas R. Ayres | University of Colorado, CASA |
| Thomas E. Berger | Lockheed Martin, Solar & Astrophysics Laboratory |
| Tim Brown | High Altitude Observatory |
| Fausto Cattaneo | University of Chicago |
| Manolo Collados Vera | Instituto de Astrofisica de Canarias, Spain |
| G. Allen Gary, | NASA Marshall Space Flight Center |
| Donald E. Jennings | NASA Goddard Space Flight Center |
| Philip G. Judge | High Altitude Observatory |
| Christoph U. Keller | NSO/Tucson |
| Jeffrey R. Kuhn | University of Hawaii, Institute for Astronomy |
| K.D. Leka | Colorado Research Associates |
| Haosheng Lin | University of Hawaii, Institute for Astronomy |
| Bruce W. Lites | High Altitude Observatory |
| Pere L. Pallé | Instituto de Astrofisica de Canarias, Spain |
| Thomas R. Rimmele, (Ch.) | NSO/Sacramento Peak |
| Sigwarth, Michael | Kiepenheuer Institut fuer Sonnenphysik, Germany |
| Luigi Smaldone | University of Naples, Italy |
| Hector Soccas-Navarro | High Altitude Observatory |
| Robert F. Stein | Michigan State University |
| Jan Stenflo | ETH Zürich, Institute of Astronomy |
| Adriaan Van Ballegooijen | Harvard-Smithsonian Center for Astrophysics |
| Haimin Wang | New Jersey Institute of Technology/Big Bear Solar Observatory |

| A. 2 ATST & SITE SURVE | Y STAFFING |
|------------------------|------------|
|------------------------|------------|

| Position | Name | ATST Loading | Funding Source |
|-------------------------------------|-------------------------|--------------|----------------|
| Project Director | Keil, Steve | 0.5 | NSO |
| Education & Public Outreach Officer | Dooling, Dave | 1.0 | ATST |
| Project Scientist | Rimmele, Thomas | 0.5 | NSO |
| Visible Polarimetry Scientist | OPEN | 0.4 | NSO |
| Near IR Polarimetry Scientist | Penn, Matt | 0.3 | NSO |
| Narrow-Band Filter Scientist | Balasubramaniam, K.S. | 0.1 | NSO |
| Thermal IR Scientist | Uitenbroek, Han | 0.1 | NSO |
| ATST Fellow | Kasiviwanathan, Sankara | 1.0 | ATST |
| Site Survey Scientist | Hill, Frank | 0.5 | NSO |
| Site Survey Science Support | Radick, Richard | 0.3 | USAF |
| Site Survey Software Engineer | Fletcher, Steve | 0.3 | NSO |
| Site Survey & AO Manager | Hegwer, Steve | 0.3 | NSO |
| AO Research Associate | OPEN | 0.5 | ATST |
| Adaptive Optics Engineer | Richards, Kit | 0.7 | NSO |
| Project Manager | Wagner, Jeremy | 1.0 | ATST |
| Deputy Project Manager | OPEN | 1.0 | NSO |
| Administrative Coordinator | Ditsler, Jennifer | 1.0 | ATST |
| Lead Optical Systems Engineer | Hansen, Eric | 1.0 | ATST |
| Systems Engineer | Hubbard, Rob | 1.0 | ATST |
| Optical Engineer | Liang, Ming | 0.5 | NOAO |
| Systems Librarian | Kneale, Ruth | 1.0 | ATST |
| Mechanical Systems | Warner, Mark | 1.0 | ATST |
| Enclosure Mechanical Systems | Phelps, LeEllen | 1.0 | ATST |
| Thermal Systems | Dalrymple, Nathan | 0.5 | USAF |
| Mechanical Designer | Schoening, Bill | 1.0 | ATST |
| Opto-Mechanical Designer | Duffek, Gerry | 1.0 | NSO |
| Opto-Mechanical Engineer | Price, Ron | 1.0 | ATST |
| Software & Control Systems | Goodrich, Bret | 1.0 | ATST |
| Controls Engineer | OPEN | 1.0 | ATST |
| Software Engineer | Tvedt, Janet | 1.0 | ATST |
| Software Engineer | Wampler, Steve | 1.0 | ATST |
| Facilities Engineer | Barr, Jeff | 0.5 | NOAO |
| - | | 20 | FTĒ's |

A.3 ATST DESIGN REVIEW COMMITTEE

| Torben Andersen (Lund University) | Brent Ellerbroek (Gemini Observatory) |
|---|--|
| Eli Atad (Royal Observatory Edinburgh) | Matt Johns, Ch. (Carnegie Observatories) |
| Jacques Beckers (University of Chicago/NSO) | Chris Mayer (Observatory Sciences, CO) |
| Chas Cavedoni (Gemini Observatory) | Mike Sheehan (Gemini Observatory) |
| Ciro Del Vecchio (Arcetri Observatory) | Larry Stepp (AURA/TMT) |

APPENDIX B. ATST WORK BREAKDOWN STRUCTURE

Task Name 2004 2005 2007 2008 2009 2010 2011 2002 2003 2006 2012 2013 2014 ATST Project ATST Design & Development Design Telescope Assembly (sans M1) Trade Studies **Conceptual Design Phase** Preliminary Design Phase **Critical Design Phase** 7 Long Lead Item - Primary Mirror Blank, contract prep Fabrication Study Contracts General Discussions/Visits to Fabricators Prepare/Send Out RFP for Blank Fab RFP Repsonse Period Source Selection Process Contract Negotiations/Award Major D&D Milestones ATST Construction & Commissioning Fabrication Telescope Assembly M1 Assembly M1 Mirror Mirror Blank Blank Fabrication Generation Acid Etch Transportatoin to Polisher Mirror Grind, Polish, Ship Polishing Preparation M Polishing/Testing Transport to Site Cell Integration Coating Integration, Test & Commissioning Telescope Integration 9 Telescope Commissioning Visible Light Broadband Imager Visible Spectropolarimeter Near-IR Spectropolarimeter Visible Tunable Filter ATST Operations & Maintenance Science Operations Ramp-up 9/23/13 Full Operations Start

ATST Design & Development and Construction Phase Critical-Path Schedule (Assumes Partner Early Procurement of Primary Mirror)

APPENDIX C. ACRONYM GLOSSARY

| AFRL | Air Force Research Laboratory |
|---------|---|
| AO | Adaptive Optics |
| ATST | Advanced Technology Solar Telescope |
| ATM | Atmospheric Sciences (Division of NSF) |
| AURA | Association of Universities for Research in Astronomy, Inc. |
| BBSO | Big Bear Solar Observatory |
| CD-ROM | Compact Disk – Read Only Memory |
| CfAO | Center for Adaptive Optics |
| CMEs | Coronal Mass Ejections |
| CoDR | Conceptual Design Review |
| CoSEC | Collaborative Sun-Earth Connection |
| D&D | Design & Development |
| 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 Studies |
| EPO | Educational and Public Outreach |
| ESF | Evans Solar Facility |
| ETS | Engineering and Technical Services (NOAO) |
| FDP | Full-Disk Patrol |
| 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 |
| IBIS | Italian BI-dimensional Spectrometer |
| ICD | Interface Control Document |
| IDL | Interactive Data Language |
| IfA | Institute for Astronomy (University of Hawaii) |
| IHY | International Heliophysical Year |
| IR | Infrared |
| ISOON | Improved Solar Observing Optical Network |
| ISS | Integrated Sunlight Spectrometer |
| KPNO | Kitt Peak National Observatory |
| KPVT | Kitt Peak Vacuum Telescope |
| LAPLACE | Life and PLAnets Center (University of Arizona) |
| LRP | Long Range Plan |
| LWS | Living With a Star |
| МсМР | McMath-Pierce |
| MHD | Magnetohydrodynamic |
| MKIR | Mauna Kea Infrared |
| MREFC | Major Research Equipment Facilities Construction (NSF) |

| MRI | Major Research Instrumentation (NSF) |
|---------|--|
| NAC | NSO Array Camera |
| NAS | National Academy of Sciences |
| NASA | National Aeronautics and Space Administration |
| NCAR | National Center for Atmospheric Research |
| NDSC | Network for the Detection of Stratospheric Change |
| NJIT | New Jersey Institute of Technology |
| NOAA | National Oceanic and Atmospheric Administration |
| NOAO | National Optical Astronomy Observatory |
| NRC | National Research Council |
| 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 |
| PAEO | Public Affairs and Educational Outreach |
| PDR | Preliminary Design Review |
| PSPT | Precision Solar Photometric Telescope |
| RET | Research Experiences for Teachers |
| REU | Research Experiences for Undergraduates |
| RMS | Root-Mean-Square |
| SCOPE | Southwest Consortium of Observatories for Public Education |
| SFC | Space Flight Center (NASA) |
| SoHO | Solar and Heliospheric Observatory |
| SOI | Solar Oscillations Investigations (SoHO) |
| SOLIS | Synoptic Optical Long-term Investigations of the Sun |
| SPD | Solar Physics Division (AAS) |
| SRA | Summer Research Assistant |
| SRD | Science Requirements Document |
| SWG | Science Working Group (ATST) |
| SSWG | Site Survey Working Group (ATST) |
| STEP | Summer Teacher Enrichment Program |
| TAC | Telescope Time Allocation Committee |
| ТВ | Tera Bytes |
| TLRBSE | Teacher Leaders in Research Based Science Education |
| UA | University of Arizona |
| UBF | Universal Birefringent Filter |
| USAF | United States Air Force |
| UW | University of Washington |
| VSM | Vector Spectromagnetograph |
| VSO | Virtual Solar Observatory |
| WBS | Work Breakdown Structure |
| WWW | World Wide Web |