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MISSION

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

NSO accomplishes this mission by:

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

RESEARCH OBJECTIVES

The broad research goals of NSO are to:

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

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NSO EXECUTIVE SUMMARY

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

While the *New Worlds, New Horizons* (NWNH) decadal survey did not directly consider solar science and assets, it did point out the importance of solar investigations that touch on its major science objectives and themes. NSO supported facilities and instruments address several of these including: Cosmic Order, where the Sun is the stepping stone to understanding stars, which in turn are the foundation for understanding galaxies and the rest of the universe (NWNH, pp. 57, 59, 203); habitability of planets through understanding stellar activity, winds and mass loss which are related to magnetic fields, and that the Sun is our primary laboratory for studying their fundamental physics (Frontiers of Knowledge) in an astrophysical setting (NWNH, pp. 60, 61, 67, 68, 115, 202). NWNH (p. 55) points out that ATST will enable critical tests of models of these solar plasma processes.

A key strength of the NSO, necessary to achieve its mission, is its scientific staff, who provide support for the user of NSO facilities, actively and visibly participate in the community, develop advanced instrumentation, participate in educational outreach, establish new initiatives, and engage in frontier research. A further strength is that, as a federally-funded research and educational institution, the NSO is able to provide leadership, continuity and stability for the conduct of long-term programs and projects that are a scientifically necessary component of solar and solar-terrestrial research. Finally, the interdisciplinary nature of, and multi-agency participation in, solar astrophysics enables the formation of productive partnerships with the NSO that result in a stronger and broader-based program (NWNH Recommendation, p. 34).

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

NSO's long-range vision includes making fundamental measurements of the solar magnetic field on spatial and temporal scales on which the field interacts with the dynamic solar atmosphere and on which it evolves over the poorly understood solar cycle. The former requires bringing on line the large-aperture Advanced Technology Solar Telescope (ATST), while the latter requires long-term synoptic measurements of the ever changing solar magnetic field.

The ATST is the major focus of the NSO Long Range Plan (LRP). Its 4-meter aperture will permit us for the first time to unravel magnetic structures at all atmospheric heights and finally understand how the highly turbulent Sun imparts energy to the field which then manifests itself as the violent

activity than impacts Earth and the interplanetary environment. While gravity has structured planetary systems like our solar system, magnetic fields, which both create activity and protect us from many of its consequences, govern the destiny of life within these systems (NWNH, pp. 37, 38, 60, 61).

ATST is currently scheduled to come on line in 2018. The other major component of NSO in the FY 2018 time frame will be an enhanced synoptic program that combines monitoring both solar atmospheric and internal magnetic fields

The NSO primary role of supporting the science of the solar community continues throughout the five years covered by this LRP. Particular emphasis is on the development of a community that can fully exploit ATST and synoptic data. The heavily subscribed Dunn Solar Telescope will not only continue supporting high-resolution observations, it will also play a major role in developing ATST instrumentation systems, adaptive optics needed for the success of ATST, and because of its similarity to the ATST coudé room layout, the development of the ATST operation model. The large volume of data currently being produced at the DST will also serve as a catalyst in developing the ATST data pipeline.

Major actions that NSO will undertake to advance solar physics during the period covered by this LRP include the following:

- Construction of the Advanced Technology Solar Telescope. The ATST will be the premier ground-based facility for high-resolution studies of solar magnetism and dynamics in the solar atmosphere. It will support the next generation of solar researchers as a primary tool for probing the Sun.
- Engaging the national and international community in developing a multi-station synoptic network based on experience gained with the Synoptic Optical Long-term Investigations of the Sun (SOLIS) and Global Oscillation Network Group (GONG) programs. Long-term synoptic observations are critical to fully understanding the Sun's variable output and its effects on space weather and Earth's climate.
- Developing an NSO organizational structure that effectively operates new capabilities, consolidates the scientific staff currently separated in Tucson and Sunspot, and provides effective support for the observational and data needs of the solar research community. Planning for divestiture and/or closure of existing NSO high-resolution and IR facilities is part of this process.
- Maintaining existing facilities as needed to ensure community access for continued scientific productivity until future assets (i.e., ATST) are in place, and continued use of existing facilities to develop ATST instruments and operations model, including data handling, and to train the next generation of solar astronomers that can fully exploit the ATST.
- Use of the opportunities provided by ATST development, SOLIS, the enhanced GONG network, and the new adaptive optics (AO) and infrared (IR) capabilities to promote a strong university/student basis for solar physics. This includes participation in university partnerships that have been formed through programs such as the NSF Partnerships in Astronomy & Astrophysics Research and Education (PAARE) program and Fisk-Vanderbilt

Masters-to-PhD program to increase the diversity of NSO and the solar community by recruiting candidates from underrepresented communities.

- Taking a leadership role in developing a community-wide roadmap for ground-based solar facilities and working closely with NASA to link space-based and ground-based facilities to maximize their synergy for advancing understanding of the Sun.
- Providing the space weather community with the data needed to monitor, model, and understand solar activity and variability through the development and operation of enhanced and new observing capabilities (e.g., continual near-real-time GONG magnetograms and H-alpha imaging, SOLIS vector magnetic field maps, calibrated GONG farside images).
- Continuing to enhance the NSO Digital Library so that all NSO data collected on behalf of the community are available online; continuing to partner with NASA and universities in the development of the Virtual Solar Observatory (VSO), which provides community access to all aspects of solar data.
- Continuing NSO's scientific and instrumentation leadership by balancing staff responsibilities, increasing staff opportunities for research and postdoctoral support, developing strong university collaborations, and strengthening partnerships with other solar organizations; and developing and strengthening connections with the university community of researchers and educators in solar physics, including assisting in strengthening their programs through participation in the NSO program of research, education, and the implementation of new scientific capabilities.

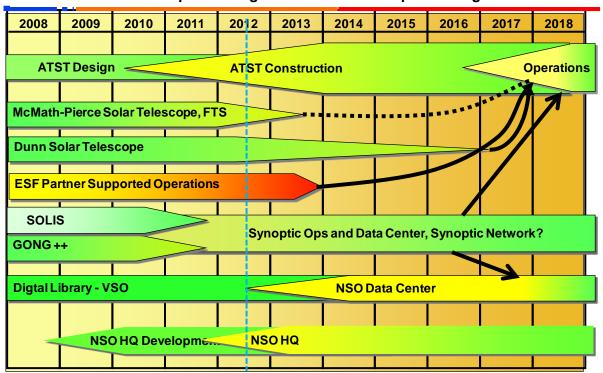
The NSO long-range road map is shown in Figure 1. It has been coordinated with the solar community, the NSO Users' Committee, and the AURA Solar Observatory Council (SOC). It has strong community buy in for the long-term future of ground-based solar physics. Ongoing and future NSO efforts are summarized in Figure 2 and explained in detail in the body of this plan. The ongoing program is strongly focused toward NSO operations in the ATST era, while still maintaining NSO's high-quality user support as the ATST is developed. Approval of observing proposals for programs at the large NSO telescopes is based on contributions to ATST technology and operations, such as diffraction-limited imaging and spectropolarimetry, infrared technologies, and telescope and instrument controls.

NSO and its co-principal investigators at the High Altitude Observatory (HAO), New Jersey Institute of Technology (NJIT), University of Hawai'i, and University of Chicago, along with collaborators at 17 other institutions representing a broad spectrum of the solar community, have developed a design for the ATST. The ATST project has entered the construction phase.

GONG and SOLIS are now formally combined into a single Synoptic Program. The SOLIS vector spectromagnetograph (VSM) and the integrated spectrometer (ISS) are producing highly accessed synoptic data. The VSM provides unique vector magnetograms that enable new types of synoptic maps. VSM full-disk and selected active region vector magnetograms are available from the NSO Digital Library and are used to support both space and ground-based observations. NSO will explore partnerships for developing a network of SOLIS vector magnetograms. GONG data have

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

NSO, with sites currently operating at Tucson, Arizona and Sunspot, New Mexico, plans to decommission the telescopes at those sites and consolidate its scientific staff at a headquarters location and ATST operating site as preparation for operating the ATST. Ideally the NSO would continue to operate its current suite of telescopes in support of the user community until ATST is operational. Unfortunately, the current funding environment may not allow this. Section 8 outlines the NSO plans for consolidation and for operations in the ATST era. Community workshops will help define modes of ATST science operations. The road map in Figure 1 summarizes the Observatory's strategic plan, showing when new NSO capabilities will become operational and when older, replaced facilities can be phased out. We have planned phase-out of the Dunn Solar Telescope (DST) and McMath-Pierce Solar Telescope (McMP) as occurring with the beginning of ATST operations. However, recent budget cuts will force earlier closures. The map shows a ramp down of the McMP in FY13. We are seeking ways to extend this as was done with the Evans Solar Facility (ESF) by finding outside funding and/or a consortium interested in taking over McMP operations. NSO will continue operating the Evans facility as long as support is provided by external sources.



Current Cooperative Agreement Next Cooperative Agreement

Figure 1. Strategic road map for NSO facilities.

NSO 2012-2018 Facility Planning

ATST

- o Complete major ATST contracts
- Complete building permitting process for Haleakalā (FY12)
- o Begin site construction (FY12)
- o Telescope completion (FY18)

Dunn Solar Telescope

- o Continue development of multi-conjugate adaptive optics
- o Maintain and operate current instrument packages for user community
- o Test bed for ATST instrument development
- Divest or close Sunspot facility (FY16/FY17)

McMath-Pierce Solar Telescope

- Continue development of IR instruments and techniques
- Divest or close facility (end of 2013)

• Synoptic Program

- o Conduct joint GONG/SDO helioseismic measurements
- o Conduct Air Force supported GONG space weather operations
- Operate full suite of SOLIS instruments
- o Incorporate SOLIS data into Digital Library and Virtual Solar Observatory
- Develop proposal for VSM network with international partners

Digital Library and Virtual Solar Observatory

- o Develop Data Center that incorporates ATST & Synoptic Data
- o Continue work on next release version of VSO; operate NSO VSO node
- Continue strong collaboration with US and European institutions on VSO

NSO Directorate Site Development and Staff Consolidation

- o Negotiate with host site
- Develop site proposal as part of next cooperative agreement
- o Appoint a transition team
- o Develop a transition plan for the selected site
- Education and Outreach and Broadening Participation
 - o Continue strong graduate and undergraduate programs
 - o Coordinate with Akamai Internship Program and UH Maui College
 - Increase outreach to underrepresented minorities

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

1 INTRODUCTION

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

The study of the Sun as a star guides astronomers in their investigations of other stars, and was the main aspect of solar physics touched on by the *New Worlds, New Horizons* (NWNH) decadal survey. As stated in NWNH (pp. 61, 64), "to understand the lives of stars and the role they play in cosmic evolution we must understand the roles of mass loss, rotation, and magnetic fields in stellar evolution." Magnetic fields play a role in both mass loss and rotation, and they also play a role in the evolution and destiny of life around stars through control of the radiation environment to which planets are subjected. The latter touches on the habitability of planets (NWNH p. 37). A goal of the NSO long-range program is to understand the role of solar magnetic fields on all of its various scales.

Solar physics is entering a new period in which the coupling of advanced instrumentation and detailed modeling are challenging what solar physicists think they know about the Sun and the solar processes that affect life on Earth and govern interplanetary space. MHD simulations of magneto-convection and models of chromospheric and coronal magnetic fields have enjoyed considerable progress as computation capabilities increase. These models are providing detailed predictions of the evolution of surface structure and magnetic fields that are pushing and often surpassing the ability to test the models with observations having sufficient resolution in both time and space. Solar science is a mature discipline that has developed questions of fundamental importance not only to solar physics, but also to astrophysics and plasma physics. Among these questions are: Why does the Sun have a magnetic field? How does the Sun produce cycles of varying activity? What causes sunspots? How does the Sun produce violent explosions? Answers to these questions will help with understanding and someday predicting the influence of the Sun on Earth and space weather (NWNH serving the nation, pp. 28, 29), and understanding the role of the Sun and its variability in the evolution of life in planetary systems (NWNH, pp. 37, 39, 202).

The period covered by this Long Range Plan comes at a very dynamic time for solar physics. The continued observations of the Solar and Heliospheric Observatory (SOHO), *Hinode*, Solar TErrestrial RElations Observatory (STEREO) and Solar Dynamics Observatory (SDO) provide solar physicists with a wealth of space-based data. Striking new data and images from space missions continue to give solar physics high public visibility and have revealed a wealth of new phenomena and information about the complexity and dynamics of the corona and chromosphere. Ground-based facilities play a key role by providing simultaneous observations in many spectral lines and at higher spatial and temporal resolution than available from space. More often than not, detailed and

flexible ground-based observations are needed to clarify processes and challenge theories. In particular, the Dunn Solar Telescope is providing detailed polarimetric, imaging, and spectral data in the visible and near-IR, and the McMath-Pierce is providing infrared imaging and spectroscopy beyond 2000 nm. Precision spectral polarimetric observations provide the information on velocities and fields needed for comparisons with theoretical predictions. These include theories for the structure of sunspots and models of magnetoconvection and its relationship to chromospheric structure. Measurements with the Interferometric BIdimensional Spectrometer (IBIS), the Spectro-Polarimeter for Infrared and Optical Regions (SPINOR), the Rapid Oscillation of the Solar Atmosphere (ROSA) high-speed cameras (ROSA) and the Diffraction-Limited Spectro-Polarimeter (DLSP) at the Dunn Solar Telescope reveal problems with MHD models for these phenomena. Observations with IBIS, SPINOR, ROSA and the DLSP show that chromospheric fields and heating mechanisms do not behave in the force-free manner that MHD models predict. McMath-Pierce Solar Telescope IR measurements of cool molecular clouds in the chromosphere are at odds with existing chromospheric heating models.

When the much more powerful Advanced Technology Solar Telescope is online, it will help answer many of the unresolved questions and undoubtedly reveal even more difficulties with existing models and theories of solar processes and will challenge theorists and modelers to revise what is currently understood about the Sun. The close collaboration between space- and ground-based assets continues with the advent of SDO in 2010. In addition, ground-based observations provide contextual data and data that provide continuity between space missions for understanding solar variability. In this context, NSO provides continuous observations of the solar interior with GONG as well as daily observations of the surface magnetic field, chromospheric structure, and solar activity with SOLIS and GONG.

Section 2 provides a brief description of some of the science areas addressed through NSO facilities. Section 3 discusses current NSO assets, their support of the solar community and their contribution to ATST development. Section 4 discusses ATST's development and its role in advancing solar physics. Section 5 describes early NSO planning for establishing an advanced synoptic network. Section 6 presents plans for the NSO Data Center, and NSO contributions to the development of the next generation of solar researchers and public awareness of solar physics are outlined in Section 7. NSO's implementation of the long-range plan is outlined in Section 8 based on the budget scenario provided by NSF.

2 SCIENCE PROGRAM

The primary science that the NSO supports can be subdivided into fundamental but overlapping themes. The following sections briefly summarize NSO's pivotal role in addressing these themes and how ongoing science programs will lead into the ATST era. Highlights of NSO supported science during the past year are summarized in the NSO FY 2011 Annual Progress Report and FY 2012 Annual Program Plan (available at *www.nso.edu/reports*).

2.1 Solar Cycle and Dynamo

Dynamo creation and maintenance of magnetic fields throughout the universe is likely to be very common. For example, the fate of a star depends on the nature of the magnetic field that it has built (NWNH, pp. 60, 61). The Sun is the touchstone example with dynamos apparently operating on at least two spatial and temporal scales. The well-known 11-year cycle of solar activity is believed to be generated by a self-excited dynamo operating at the base of the solar convection zone. The discovery in the 1970s (using the McMath-Pierce telescope) of a ubiquitous, tangled, small-scale magnetic field everywhere on the solar disk hints that a second dynamo creates the majority of magnetic flux near the surface in a form that is largely independent of the solar cycle. This is confirmed with recent observations with the Dunn Solar Telescope which have attained both higher sensitivity and higher angular resolution, revealing a wealth of small-scale structure, and demonstrating that the net "unsigned" flux of the Sun rivals, or even exceeds, that of the 11-year-period solar active region fields, as well as that from the intense flux concentrations at the boundaries of the quiet solar supergranular network pattern. The time and spatial scales for the cycle dynamo are years and global respectively while the suspected near-surface dynamo operates in minutes on a sub-arcsec scale. Thus this research requires a wide and sustained range of instrumental capabilities.

There are many open questions about the solar dynamos. For nearly four decades, NSO's synoptic program has provided magnetic flux and other measurements for nearly four decades that are widely used in studies of the solar cycle dynamo processes. One example is magnetic boundary conditions for models of the structure and dynamics of the corona and heliosphere. Another example from helioseismology focuses on cycle variations of mass flows within the convection zone. Recently, solar cycle dynamo models that incorporate transport of magnetic flux by mass motions have been developed. The utility of these models depends on knowledge of both poleward and radial mass flows that transport magnetic flux. These quantities can be constrained by observations but not yet with enough precision to drive improvements to the models. NSO is striving to improve this synoptic observational knowledge in moving forward to the ATST era. The continuity of continuous ground-based data sets over times spanning several solar cycles provided by NSO play a crucial role in developing models of the solar cycle.

The "surface" dynamo has not been studied as intensely as the cycle dynamo. Although it is presumed to be operating at the surface where direct observations are possible, a hindrance is limited spatial resolution of critical measurements. The new instrumentation at the Dunn Solar Telescope (DST), including the DLSP, IBIS, and SPINOR, are ideally suited to explore this topic. In combination with adaptive optics systems now in place at the DST, much higher angular resolution of the internetwork fields may be achieved, while maintaining reasonable polarimetric sensitivity. Recent collaborative research by NSO and non-NSO scientists using observations of kinetic vorticity

and current helicity shows evidence that weak magnetic fields are generated by a small-scale nonhelical dynamo process, while helicity properties of strong magnetic fields suggest their origin from deep-seated helical dynamo. The reality of the surface dynamo process, and the influence that the small-scale, mixed-polarity internetwork fields have on heating and dynamics of the solar atmosphere, are issues of considerable prominence in solar physics today. Vector magnetic field measurements, both on sub-arcsecond and global scales will be essential in learning more about the surface dynamo. NSO plans to increase observational efforts with both SOLIS and the instruments at the DST. Decisive observations of the fields on the smallest scales require the ATST.

The surprisingly low level of solar activity following the end of solar cycle 23 and the subsequent slow start and low activity level of cycle 24 provide an opportunity to study the Sun in a state not seen in nearly a century. Infrared observations of the spectra of sunspots using the McMath-Pierce telescope during the last decade suggest that the temperatures of sunspots are systematically increasing and their magnetic field strengths decreasing. If this trend proves to be real and sustained, the number and strength of sunspots (and associated eruptive activity) during the present cycle 24, and especially the following cycle 25, will reach low levels not seen in centuries. It is not clear what physics controls the strength of the solar activity cycle and NSO hopes to provide clues as the ATST era approaches. One clue that has already emerged comes from GONG helioseismic studies of the variation of internal solar rotation. Zones of faster and slower than average rotation rates have been observed at the surface and in the solar interior. These zones migrate in latitude during the course of a solar cycle and appear well before the emergence of other activity at a given latitude. It is now recognized that the slow start of cycle 24 was first signaled in these zones. Three years later than expected, the first weak signs of cycle 25 have just now been detected. The delay hints that cycle 25 may be even weaker than the present cycle. NSO will continue to measure these extraordinary developments and other precursor activity with synoptic observational assets during the lead-up to ATST.

2.2. Sun's Effects on Planetary Habitability

2.2.1 Transient Events

Blasts of hard radiation and energetic particles from violent solar activity can significantly affect planetary environments including societal impacts on Earth (NWNH, pp. 28, 29). NSO currently provides several synoptic solar measurements of violent eruptive activity at a cadence as fast as once per 20 seconds with the aim of helping to understand the basic physics well enough to aid development of a predictive capability. Some of these data have demonstrated that magnetic field changes in the photosphere are almost always seen associated with flares. This observation led to the concept of a magnetic implosion in an active region as a common feature associated with flares, i.e., conversion of stored magnetic energy into an eruption reduces the magnetic pressure, leading to a partial collapse of the lower atmosphere magnetic structure of an active region. Beneath the surface, GONG has revealed that strongly flaring active regions are always accompanied by a distinctive flow pattern below the surface. This velocity field is in the form of two horizontal "tornadoes" with oppositely directed senses of rotation. This discovery suggests that subsurface flows from GONG can be developed into a tool to help predict space weather.

The largest explosions in the solar system, coronal mass ejections (CMEs) associated with flares and filament eruptions, are seemingly triggered by small-scale processes. Though small in origin, the results are sometimes profound. Shocks, waves and particle blasts impact not only the solar surface but also bombard planetary environments as disturbances race through the entire heliosphere. Nearly simultaneous, far-separated eruptions on the Sun have long been noted. The nature of this global coupling of transient activity can be studied with a wide range of instrumentation operating at high cadence including NSO's synoptic assets. With this equipment it may soon be possible to detect the magnetic signature of CME-driven restructuring to help identify conditions that lead up to these events and the possibility of Earth-directed space weather disturbances.

What causes some filaments and active region magnetic fields to quickly become unstable and erupt? High-speed spectral images using IBIS, and Stokes polarimetry with the DLSP, Facility Infrared Spectropolarimeter (FIRS) and SPINOR will measure the interaction between flows and the vector magnetic field to understand the stability of magnetic regions and what triggers their eruptions. At the Dunn Solar Telescope, ROSA, a set of multi-wavelength high-speed cameras, is particularly suited for studying the rapid evolution leading up to and during flares. The full vector field is needed to accurately model overlying loops in the corona. To understand the consequences of flow-magnetic field interaction seen in the photosphere and chromosphere at higher atmospheric layers, these data are combined with data from *Hinode* and SDO. Data from SOLIS, GONG and ISOON (the Air Forces Improved Solar Observing Optical Network) will provide a global picture of how the eruptive fields are interacting with other magnetic regions and will detect eruptions spanning greater spatial distances on the solar surface. The DST and its instruments will provide the high-resolution imaging and polarimetry needed to follow the complex interactions in the lower atmospheric layers. Some of the critical processes most likely occur below current resolution capabilities and will require the 4 meter ATST to unravel.

The DST, McMP, and later the ATST will provide crucial information on the basic physical processes involved in transient eruptions, with particular emphasis on high-resolution, visible and infrared investigations of the origins of these events at the footpoints of magnetic fields in the solar photosphere. The evolution of the footpoints as seen in the infrared He 1083 nm line were captured during an X1.8 flare at the McMP using the NSO array camera (NAC) system. The very bright line-center emission and extremely rapid downflows that were observed will provide new windows for studying the energetics of such a powerful flare. More recently, polarization studies at the DST and the McMP using the full Stokes profiles of He 1083nm are being used to probe the details of the magnetic fields in the dark fibrils surrounding sunspots. Few such measurements exist, and these measurements are expected to provide valuable constraints on the static and dynamic models of the environment around sunspots, and will shed light on how the magnetic fields there are involved in flares and eruptions. The ATST will be required to obtain accurate polarimetry of regions that are rapidly evolving.

2.2.2 Irradiance Variations

A fundamental discovery of 20th-century observational solar physics has been the variation of the total brightness of the Sun by about 0.1% in step with the sunspot cycle. Observations of other stars have now demonstrated this variation to be a widespread property of normal, late-type stars. Understanding this variability is a special topic amongst scientific research problems. Seldom in

astrophysics can our scientific work have such an important bearing on social, cultural, or economic well-being (NWNH, pp. 28, 29). The case for the Sun is dramatic. Evidence for Sun-induced climate change as one of the driving forces in the development and evolution of civilization is considerable. For example, European climate in the late 17th century was brutally cold for several decades when the solar cycle mysteriously vanished for nearly half a century during the Maunder minimum. Conversely the unusual warm period during the Viking colonization of coastal Greenland occurred when the solar cycle was probably only somewhat more vigorous than it is now. The apparent correlative relationship between climate fluctuations and solar activity is intriguing even though the causal mechanism that connects the relatively very small luminosity changes to terrestrial effects is still unknown. Understanding solar irradiance variability is one key to refining our knowledge of climate change on Earth. Solar variability is the major natural mechanism forcing input to global circulation model (GCM) calculations used to understand the relative importance of anthropogenic and natural sources of climate change. Recent studies have shown that solar variations must be taken into account in order to fully model the surface temperature increase seen over the past century.

We live near a star that we don't yet understand. NASA has accepted part of the challenge to deduce what we can about our critical solar-terrestrial relations through the Living With a Star (LWS) program. Unfortunately, some problems, like the irradiance variability, are long-term activities that will outlive any directed series of space experiments. For example, NASA's currently operational Solar Radiation and Climate Experiment (SORCE) to measure solar variability from EUV to visible wavelengths, and the LWS SDO experiment will only provide ``snapshots'' compared to the 50 year lifespan of ATST and the NSO Integrated Synoptic Program (NISP) solar irradiance studies.

The physical mechanisms responsible for solar irradiance changes are still uncertain. These changes could be due primarily to surface magnetic faculae and sunspots or may originate deep in the convection zone. On the surface, the relevant observational limits have been set by seeing and the small apertures of our telescopes, while deeper down the limits are set by the length of synoptic observations. Most importantly we have yet to understand why the Sun organizes its surface magnetic features into sometimes bright and sometimes dark surface elements, but we need these answers before we can understand or predict how the total solar irradiance can vary. ATST will play a crucial role by resolving fields previously unseen that could be a dominate contribution to irradiance.

Solar-stellar studies are also essential for planetary habitability research. 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. One component of the NISP, the integrated sunlight spectrometer (ISS) on SOLIS, 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 which track the solar cycle and are used for stellar activity cycle work as well. The ISS provides both chromospheric and photospheric diagnostics of activity and convection that can be compared with the spatially resolved magnetic on the solar surface. These spectra can 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.

Asteroseismology is another area of convergence between solar and stellar astrophysics. Helioseismology has revealed many new aspects of the solar interior that are important for understanding the mechanism of activity and magnetism that affects the habitability of nearby planets. Kepler and the COnvection ROtation et Transits (CoRoT) spacecraft have demonstrated the power of asteroseismology to characterize central stars of planetary systems with unprecedented detail. NSO is planning to participate in the SONG (Stellar Observations Network Group) program led by the University of Aarhus in Denmark.

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

2.2.3 Heating of the Outer Atmosphere and Origin of the Solar Wind

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

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

Inference of chromospheric magnetic fields using a limited set of spectral lines such as H α , Ca II 8542 Å, and Mg I 5172 Å, are intricately tied to an assumption of a model atmosphere coupled with non-local thermodynamic equilibrium (NLTE) radiative transfer. NLTE radiative transfer methods have been developed at NSO and elsewhere to simulate chromospheric lines under varied magnetic field

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

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

3 CURRENT TOOLS FOR SOLAR PHYSICS

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

3.1 Current NSO Support for Users

Improved instrumentation, especially adaptive optics, has kept NSO's current major telescopes at the leading edge of solar physics. They remain extremely productive and are among the most useful solar telescopes in the world. Although the major NSO telescopes are four or more decades old, they still play a key role in support of US and international solar research. The NSO telescope upgrade and instrument development program is guided by the scientific and technical imperatives for the new ATST. Consequently, telescope and instrument upgrades and operations are reviewed and supported on the basis that they serve as necessary preludes to the ATST initiative, while concurrently serving the needs of the scientific community. Both as a necessary prelude to the ATST and as indispensable facilities for current research in solar physics, NSO operation of the Dunn Solar Telescope and the McMath-Pierce Solar Telescope should ideally continue until the ATST is commissioned. The DST is playing a major role in developing the ATST instrumentation, polarization measurement and calibration, and in defining ATST operations. Early closure of the McMP will end NSO support of observation at wavelengths greater than 2 microns with subsequent loss of experience in this important wavelength region that will play an important role in ATST operations.

Until the ATST is online, the solar community relies on the DST for high-resolution spectropolarimetry and relied on the McMP for infrared spectropolarimetry and imaging observations beyond two microns. The NSO has upgraded many of its existing operating and data-handling systems in order to continue operations at the DST and McMP until a smooth transition to the ATST can be affected. Closure of the McMP in 2013 prevents exploitation of its upgrades. Upgrades are performed with ATST requirements in mind and in such a way as to test ATST concepts such as instrument and data interfaces and software architecture. The successful completion of the German GREGOR telescope and the New Jersey Institute of Technology New Solar Telescope (NST), both of which are 1.6-m aperture, all reflecting, open telescopes, could offer additional observing capability that would ease the transition into the ATST era. Both will have limited public access for US astronomers. The possible development of a large European Solar Telescope (EST), following ATST by several years, could provide extended high-resolution coverage of magnetic fields, and offers the possibility of future cost sharing of instrument development.

3.2 Dunn Solar Telescope (DST)

The 76-cm Richard B. Dunn Solar Telescope, located on Sacramento Peak, is a diffraction-limited solar telescope with strong user demand as indicated by over-subscription and excellent scientific output. It has two identical AO systems, well matched to the local seeing conditions, feeding two exit ports that accommodate a variety of instruments. While new solar telescopes superseded the DST in

aperture, its rich instrument suite and accomplished AO systems continue to allow the DST to play a major role in providing high spatial resolution observing capabilities, in particular those requiring spectro-polarimetry. In addition, its matching instrument makeup allows the DST to serve as a viable platform for testing multi-instrument configuration and operations as well as new observing modes in preparation for ATST. Many of the DST instruments have clear analogues in the ATST instrument suite and, therefore serve to educate the next generation of solar scientists in appropriate observing techniques, and data reduction strategies needed to fully exploit ATST.

3.2.1 Adaptive Optics and Wavefront Sensing

Without AO, the resolution of large-aperture telescopes is limited to about 1 arcsecond because the Fried parameter (the largest aperture telescope that would have diffraction-limited imaging under the prevailing seeing) of a good daytime site is about 10 cm, making AO necessary to reap the benefits of a large aperture. Nearly all observing runs at the DST extensively employ either of the two AO systems. In addition to the path finding experience that the DST AO systems provide for ATST, the NSO is using systems at the DST to continue the development of a 357 actuator system with NJIT for the New Solar Telescope at Big Bear. NSO also conducts experiments in multi-conjugate adaptive optics (MCAO), to correct the seeing-distorted wavefront over a larger field-of-view, in cooperation with the Kiepen-heuer Institute in Freiburg, Germany, with the ultimate goal of designing an MCAO system for the ATST.

3.2.2 DST Instrument Suite

Nearly all instruments at the DST will have an analogue in the ATST era. Table 3.2-1 lists the instruments, their type, their spectral characteristics, and their ATST analogue. The current suite of DST instruments is heavily targeted towards spectro-polarimetry at high temporal and spectral resolution at the angular diffraction limit of the telescope, with a strong focus on characterizing the solar magnetic vector field in the visible and near IR. Even though the setup of DST instruments is typically more flexible, and therefore more cumbersome to achieve, the current capability to combine different instruments in one setup provides the necessary experience for combining the more rigid instruments of the ATST more efficiently.

Table 3.2-1 Dunn Solar Telescope Instrumentation							
Instrument	Туре	Wavelength (nm)	ATST Analogue				
SPINOR	Multi-wavelength, slit spectro-polarimeter	450 - 1600	Visible Spectro-Polarimeter (ViSP)				
IBIS	2D imaging spectro-polarimeter	550 - 860	Visible Tunable Filter (VTF)				
FIRS	Multi-slit spectro-polarimeter	630, 1083, 1564	Diffraction-Limited Near-IR				
			Spectro-Polarimeter (DL-NIRSP)				
ROSA	6 camera, multi-wavelength fast imager	350 - 660	Visible Broadband Imager				

A significant fraction of DST observing time is requested and scheduled for graduate student research. Thus the DST and its instruments serve as a training ground for a new generation of ground-based solar observers. It is therefore of paramount importance that the facility be available for observations until the ATST is operational.

3.2.3 Preparing for ATST Operations

The mode of operation at the DST, with fixed times scheduled every quarter for designated PI programs, is very different from the main operational mode envisioned for the ATST, which is a more flexible service mode scheduled on a much shorter time line. In preparation for this paradigm shift, the NSO will conduct tests of the ATST style of operations at the DST with pre-defined instrument setups and combinations. This will provide valuable insight on how solar observations, which are often driven by targets of opportunity, can be conducted efficiently, at a heavily subscribed facility, without the presence of the PI at the telescope.

3.2.4 Current and Future Use of the DST

In the leapfrog cycle of improvements in observations and modeling the latter has taken a decisive lead in spatial resolution. Radiative MHD simulations of solar magneto-convection have attained such high resolution that current observational capabilities are no longer sufficient to verify the fine details the simulations predict. With its high-order adaptive optics system and suite of spectro-polarimetric instruments, the DST still plays a major role in verifying such models of solar magnetism whenever possible, and often in co-observation with current space missions.

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

3.3 McMath-Pierce Solar Telescope (McMP)

The McMath-Pierce solar facility is a set of three all-reflecting telescopes, with the main telescope having a primary diameter of 1.6 m, and the two auxiliary telescopes (East and West) with diameters of about 0.8 m. The McMP provides large- aperture all-reflecting systems that can observe across nearly two orders of magnitude, from 350 to 23000 nm; the telescopes are very configurable with light beams that can feed a number of large, laboratory-style optics stations for easy and flexible instrument setup. The McMP is unique since it is the only 1.6 m aperture solar telescope fully available to any scientist, the only solar telescope with instrumentation that routinely observes in the infrared beyond 2500 nm, and the only solar facility in the world with instrumentation to observe the Sun at 12000 nm and beyond. Recent joint observations in 2011 with the BBSO/NST illustrate the unique ability of the McMP to collect longer time series observations (factor of 2 or longer) with a much wider field-of-view (covering five times the area or more) than can be obtained by the NST.

3.3.1 Diverse Observing Capabilities

As recognized by the decadal report (NWNH, p. 34) solar physics research draws support from diverse sources and the research recently conducted at the McMP uniquely encapsulates this scientific diversity. Among this work are several infrared studies of the Sun, which range from the long-term (13 years of data) sunspot magnetic field strength observations to the studies of the solar atmospheric dynamics of the cold chromosphere which span just several hours of observations. Unique spectral observations of sodium emission from Mercury and the Lunar CRater Observation and Sensing Satellite (LCROSS) impact event as well as the ultra-high spectral resolution infrared measurements of the atmospheric temperature on Venus illustrate the planetary astronomy

applications of the McMP and its instruments. Measurements of terrestrial HCl molecules have verified the effectiveness of the Montreal protocol. Finally the laboratory determination of new spectroscopic parameters of the ¹³C¹⁴N molecule will enable better analysis of cometary and cool star spectra, and point to the important contribution to fundamental physics by the instrumentation at the McMP facility.

3.3.2 Impacts of Early Closure of the McMP

Funding levels require NSO to ramp down support for the McMP and close it to users at the end of FY 2013. In order to get from the current level of 2 FTEs to the envisioned shutdown with minimal interruption of observations, operations at the McMP have been streamlined by block scheduling to minimize set-up time and by modifying the pointing and guiding system in order to provide more automation for observing programs.

The McMP has been a model of Scientific Diversity. In addition to solar observations, it is used for atmospheric and laboratory spectroscopy, planetary studies and observations of exoplanets and stellar activity cycles. During 2011, the McMP had 32 users from 14 different institutions and accounted for 14 refereed publications. The NSO is involved with both estimating the cost of a complete removal of the McMP from Kitt Peak and is communicating with university partners who have expressed an interest in operating the facility after NSO removes support. Unfortunately, early closure at the end of 2013 may preclude some of these groups from obtaining funds or make it more difficult and costly to operate if the McMP is forced to sit idle for an extended period.

As part of the ramp down, the FTS instrument was moved out of the McMP facility to the campus of a university. This resulted in loss of the NSO's ability to support ultra-high resolution spectroscopy for the laboratory, atmospheric and solar communities.

The research activities at the McMP have several unique applications to the future ATST facility. Infrared spectropolarimetry tests of optics at 4667 nm have been done at the McMP and have direct application to the ATST CryoNIRSP and DL-NIRSP (cryogenic and diffraction limited near-IR spectropolarmeters) instruments. Recent images at the McMP at 4667 nm have provided important design constraints for second generation ATST IR imaging instruments. The low-order adaptive optics system at the McMP recently had its first solar application at 4667 nm wavelength, verifying that daytime wavefront corrections made in the visible improved image quality on measurements across a wavelength range of nearly a factor of ten. These capabilities are lost with its closure.

3.4 NSO Integrated Synoptic Program (NISP)

In mid-2011, NSO merged the Global Oscillation Network Group (GONG) and Synoptic Optical Long-Term Investigations of the Sun (SOLIS) programs into the NSO Integrated Synoptic Program (NISP) under a single lead. Several of the scientific goals of NISP are summarized in Section 3. When ATST is completed, the combination of the ATST and the NISP will provide a complete view of solar phenomena on a range of spatial scales from tens of kilometers to the full disk, and on time scales from milliseconds to decades. The initial programmatic goals of this integration are to increase efficiency and lower total overall costs. The integration will strengthen the use of the NSO synoptic data in the framework of space weather and space

climate for both scientific research and operational forecasting applications (NWNH, Societal Benefits, pp. 28, 29).

3.4.1 GONG Component

The GONG 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 to provide nearly continuous observations of the Sun's five-minute oscillations. The instruments obtain 1K × 1K 2.5-arcsecond pixel velocity, intensity, and magnetic flux images in the photospheric Ni I 676.7 nm line 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. Near-real-time continuous data, such as 10-minute cadence, high-sensitivity magnetograms, seismic images of the far side of the Sun, and 20-second cadence 2K × 2K H α intensity images are also available. These real-time data are used by the US Air Force Weather Agency (AFWA), and NOAA's Space Weather Prediction Center for space weather forecasts. AFWA provides approximately \$800K towards GONG operations.

3.4.2 SOLIS Component

SOLIS has three main components: a vector spectromagnetograph (VSM) capable of observing full-disk vector and line-of-sight magnetograms in the photosphere and chromosphere, a fulldisk patrol (FDP) imager, and an integrated sunlight spectrometer (ISS) for observing the highresolution spectra of the Sun as a star. The VSM produces 2K × 2K longitudinal and vector magnetograms constructed from full Stokes polarization spectra at a resolution of 200,000 in the Fe I 630.15/630.25 nm line pair, and longitudinal magnetograms in the Ca II 854.2 nm line core and wings. This allows the VSM to provide simultaneous photospheric and chromospheric magnetic field measurements, a powerful combination for understanding the structure of magnetic fields in stellar atmospheres. The VSM also produces chromospheric intensity (equivalent width) images in He I 1083.0 nm, which are used for identification of coronal holes. The FDP can take observations with a temporal cadence as short as 10 seconds in several spectral lines including H α , Ca II K, He I 1083.0 nm, continuum (white light), and photospheric lines. The ISS observations are taken in nine spectral bands centered at the CN band 388.4 nm, Ca II H (396.8 nm), Ca II K (393.4 nm), C I 538.0 nm, Mn I 539.4 nm, Hα 656.3 nm, Ca II 854.2 nm, He II 1083.0 nm, and Na I 589.6 nm (D line) with a resolution of 300,000. The ISS can observe any other spectral lines within its operating range.

3.4.3 Data Products

The NISP provides a large number of data products to the community. In addition to the products mentioned above, data processing pipelines produce global helioseismic frequencies, localized subsurface velocity fields derived from helioseismic inversions, synoptic maps of the solar magnetic field, potential field source surface extrapolations of the magnetic field in the corona, vector magnetic field maps of active regions produced from inversions of the Stokes profiles, and the total global magnetic flux. These data products are important for understanding the Sun and its activity cycle and related space weather. They also can be used for understanding the impact of stellar activity on

habitable planets – in the framework of solar-stellar research (NWNH, pp. 60, 61, 64, 67, 68, 115, 202). In addition, the experience of NISP in pipelining a large number of data products, and in performing inversions, can be applied to the development of the ATST data processing and analysis system.

Within the next few years, NISP is expected to provide vector magnetic field observations in the chromosphere using the Ca II 854.2 nm line. This will provide a much fuller picture of the structure of the magnetic field in the lower solar atmosphere, where the field direction changes from primarily vertical to horizontal as it forms the magnetic canopy. This transition takes place in the solar atmosphere near the location where the solar wind is accelerated. These future chromospheric vector magnetic field observations would be extremely important not only for understanding the origins of space weather for planets in our solar system, but also for testing the theories of the generation of stellar winds and their consequences for the habitability of planets around other stars. A combination of the ISS and VSM data would allow us to deconvolve the solar-disk average characteristics of the Sun in terms of activity across the disk. The latter would bring a new understanding of stellar disk-integrated parameters. It is also expected that progress will be made on a new synoptic network with instrumentation capable of providing both vector magnetic field and Doppler data in multiple wavelengths by 2020. This new capability is discussed in Section 6.

3.5 Access to NSO Data

3.5.1 Digital Library

In addition to its dedicated telescopes, the NSO operates a Digital Library that provides synoptic datasets (daily solar images from SOLIS, FTS data, GONG data and a portion of the Sacramento Peak spectroheliograms) over the Internet to the research community. Current NSO Digital Library archives include the Kitt Peak Vacuum Telescope (KPVT) magnetograms and spectroheliograms; the Fourier Transform Spectrometer transformed spectra, the Sacramento Peak Evans Solar Facility spectroheliograms and coronal scans, and solar activity indices. In addition, NISP archives comprise GONG and SOLIS instrument datasets. GONG data includes full-disk magnetograms, Doppler velocity and intensity observations, local and global helioseismology products, and near-real-time Halpha, far-side, and magnetic-field products. The near-real-time products are automatically disseminated to various agencies, including the Air Force Weather Agency (AFWA) and NOAA Space Weather Prediction Center (SWPC) for space weather prediction applications. The SOLIS data archive includes the Vector Spectromagnetograph (VSM), Integrated Sunlight Spectrometer (ISS) and Full Disk Patrol (FDP). In 2011, about 9 TB of combined NISP and Digital Library data were exported to over 1200 users. Additional data sets from ISOON, the DLSP, and the remainder of the NSO/SP spectroheliograms (being digitized at NJIT) will be added in the future. We will also be hosting some non-NSO data sets such as the Mt. Wilson Ca K synoptic maps and the AFRL ADAPT (Air Force Data Assimilative Photospheric flux Transport) magnetic field forecasts.

Since the inception of the Digital Library in May 1998, more than 25 million science data files have been distributed to about 9,000 unique computers. These figures exclude any NSO or NOAO staff members. The holdings of the NSO Digital Library are currently stored on a set of disk arrays and are searchable via a Web-based interface to a relational database. The current storage system currently

has 100 TB of on-line storage. The Digital Library is an important component of the Virtual Solar Observatory.

3.5.2 Virtual Solar Observatory (VSO)

In order to further leverage the substantial national investment in solar physics, NSO is participating in the development of the Virtual Solar Observatory. The VSO comprises a collaborative distributed solar-data archive and analysis system with access through the WWW. The system has been accessed approximately 500,000 times since Version 1.0 was released in December 2004. The current version, 1.4, provides access to more than 80 major solar data sets along with a shopping cart mechanism for users to store and retrieve their search results.

The overarching scientific goal of the VSO is to facilitate correlative solar physics studies using disparate and distributed data sets. Necessary related objectives are to improve the state of data archiving in the solar physics community; to develop systems, both technical and managerial; to adaptively include existing data sets, thereby providing a simple and easy path for the addition of new sets; and eventually to provide analysis tools to facilitate data mining and content-based data searches. None of this is possible without community support and participation. Thus, the solar physics community is actively involved in the planning and management of the Virtual Solar Observatory. None of the VSO funding comes from NSO; it is fully supported by NASA. For further information, see *http://vso.nso.edu/*. Recently, the major effort in the VSO has been the construction of remote mirror nodes for the data set produced by NASA's SDO mission. This effort is now complete, with one of these nodes is now located at NSO.

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

In the time frame covered by this Long Range Plan, NSO will continue to be a central component of the VSO.

4 ATST

4.1 Introduction

The 4m Advanced Technology Solar Telescope (ATST) will be the most powerful solar telescope and the world's leading ground-based resource for studying solar magnetism that controls the solar wind, flares, coronal mass ejections and variability in the Sun's output. The strong scientific case for the ATST was made in two previous decadal surveys (Astronomy and Astrophysics in the New Millennium, The Sun to the Earth—and Beyond) and is discussed in Section 2 in the global context of the NSO mission. The recent NSF sponsored "Community Workshop on the Future of Ground-based Solar Physics" reemphasized the "game changing" science ATST will enable. The detailed science drivers for ATST are discussed in numerous publications (a bibliography is given in Appendix F), including the science requirements document (*http://atst.nso.edu/library/srd*). The science drivers lead to a versatile ATST design that supports diffraction-limited imaging, spectroscopy and, in particular, magnetometry at visible and near- and far-infrared wavelengths, and infrared coronal observations near the limb of the Sun.

A primary scientific objective of the ATST is to precisely measure the three-dimensional structure of the magnetic field that drives the variability and activity of the solar atmosphere. The energy released in solar flares and coronal mass ejections was previously stored in the magnetic field. The magnetic field is structured on very small spatial scales and understanding the underlying physics requires resolving the magnetic features at their fundamental scales of a few tens of km in the solar atmosphere. The large 4-m aperture of the ATST, which represents a transformational improvement over existing solar telescope opens up a new parameter space and is an absolutely essential feature to resolve features at 0."025 (20 km on the Sun) at visible wavelengths.

New technologies developed at existing NSO facilities such as high-order adaptive optics (HOAO) system are incorporated into the ATST design to deliver a corrected beam to the initial set of state-ofthe-art, facility class instrumentation located in the coudé lab facility. At near infrared wavelengths the HOAO will enable space quality observations of high Strehl for a vast majority of the available clear time. Magnetically sensitive spectral lines in the infrared will be used to reveal and study in detail the elusive internetwork magnetic fields that cover the entire solar disk. The impact and significance of these fields, which may contain more than 80-90% of the solar magnetic energy, for the solar dynamo, heating of the upper solar atmosphere and irradiance variations is not yet understood. The ATST will provide high precision polarimetric measurements of these fields, sometimes referred to as hidden or dark magnetic energy, by using combined visible and infrared diagnostics enabled by the powerful and sophisticated ATST first generation instrumentation. The 4m aperture will for the first time provide sufficient spatial resolution at near infrared wavelengths (60 km at 1.6 micron), where spectral lines are found that can provide the critical sensitive diagnostics needed to precisely measure the properties of the weak internetwork fields. The science requirement for polarimetric sensitivity (10⁻⁵ relative to intensity) and accuracy (5 x 10^{-4} relative to intensity) place strong constraints on the polarization analysis and calibration units making ATST a high-precision magnetometer.

A large photon collecting area is an equally strong driver toward large aperture as is angular resolution. Observations of the chromosphere and, even more so, the faint corona are inherently

photon starved. The solar atmosphere is structured on small spatial scales and is highly dynamic. Small structures evolve quickly, limiting the time during which the large number of photons required to achieve measurements of high sensitivity can be collected to just a few seconds. Measurements of the weak coronal magnetic fields are essential to understand the physics of, e.g., coronal mass ejections and aid space weather prediction efforts. Measurements of the coronal intensity is only 10⁻⁵ to 10⁻⁶ of the disk intensity. The polarimetric signal ATST aims to detect is only 10⁻³ to 10⁻⁵ that of the coronal intensity. This means that contrast ratios are of the order of 10⁻⁸ to 10⁻¹¹ and, thus, are not too different from what planet detection efforts are facing. The large collecting area and low scattered light properties of the ATST are essential to achieve the chromospheric and coronal science requirements. The magnetic sensitivity of the infrared lines used to measure coronal fields and the dark sky conditions in the infrared are important motivation to utilize the ATST for exploring the infrared coronal science requirements.

A main driver for a large-aperture solar telescope is the need to detect and spatially resolve the fundamental astrophysical processes at their intrinsic scales throughout the solar atmosphere. Modern numerical simulations have suggested that crucial physical processes occur on spatial scales of tens of kilometers. Observed spectral and, in particular, Stokes profiles of small magnetic structures are severely distorted by telescope diffraction making the interpretation of low-resolution vector magnetograms of small-scale magnetic structures difficult to impossible. Resolving these scales is of utmost importance to be able to develop and test physical models and thus understand how the physics of the small scale magnetic fields drives the fundamental global phenomena. An example is the question of what causes the variations of the solar radiative output, which impacts the terrestrial climate. The Sun's luminosity increases with solar activity. Since the smallest magnetic elements contribute most to this flux excess, it is of particular importance to study and understand the physical properties of these dynamic structures. Unfortunately, even the most advanced and newest current solar telescopes, such as the 1.6m NST or the 1.5m Gregor, cannot resolve such scales because of their limited aperture size (Figure 4.1-1).

The European Association for Solar Telescopes (EAST) has recently and independently developed science requirements for the European Solar Telescope (EST) to be located on the Canary Islands. It is interesting to note that the EST requirement for aperture size is also 4m indicating that this is an aperture size that optimally enables addressing the science drivers.

Science operations, including data handling and dissemination will be much more efficient compared to the operations of current NSO or similar facilities. ATST operational concepts have been developed and will be refined during the construction phase. These concepts build on the lessons learnt from recent spacecraft operations such as TRACE, *Hinode* and SDO. Efficient operational modes such as Service Observations will make more efficient use of the available observing time. The NSO Data Center at NSO headquarters will provide science ready ATST data products to the solar physics community. An open data policy allows for maximum science productivity.

4.2 Broad Community Involvement

The ATST Science Working Group (SWG) provides scientific oversight and advice concerning all aspects of the project, including operations planning. The SWG works closely with the Project Scientist in establishing and tracking science requirements for the telescope and its instruments. The SWG actively participated in developing the ATST Science Requirements Document (SRD), the formal specification document from which all designs flow. The SWG has guided and reviews the Operations Concept Document, which lays out efficient operational modes for the facility. The SWG has broad participation from the US and international solar astronomy community. The SWG meets at least once a year and issues formal findings and recommendations.

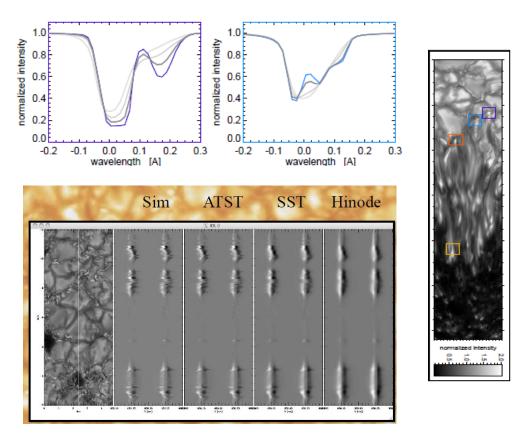


Figure 4.1-1 Complex line profiles (top) seen near a sunspot penumbra (left) where the squares show the location of the profile. The bottom panel shows a simulation of convection (far left) and the resulting profiles along the line shown on the simulation (column labeled Sim). The other columns show the effect of observing the profiles with various apertures (the 4m ATST, the 1m Swedish Solar Tower, and the 0.5m Hinode Solar Optical Telescope.

The SWG has broad participation from the US and the international community and includes members from the fields of stellar and planetary physics, heliospheric physics, geophysics, the space weather community, space sciences and other interdisciplinary fields. The group includes members from the university community, National Labs, NASA, Air Force, and international partners and demonstrates the strong collaborative spirit of the international solar community as well as being an indicator for the broad societal impacts of solar astronomy. A list of members is given in Appendix A.

The SWG has recently formed working groups that will focus on specific areas, including operations planning and data center operations and dissemination. The SWG, in consultation with the Project Scientist. will formulate a Critical Science Plan which will define the science experiments/observations that the ATST must accomplish shortly following the commissioning phase. These observations will lead directly to high-impact refereed papers that will demonstrate the discovery space of the ATST facility. The broad representation of space and ground-based communities on the SWG fosters synergies with space missions taking full advantage of the complementary nature of space and ground based observations.

Involvement and engagement of the entire community is achieved by organizing community workshops, special sessions at e.g. AAS/SPD meetings and by regular international workshops that are generally organized in close collaboration with international partners. For example, the second ATST/EAST workshop took place in Washington, DC on 09 – 11 November 2011. Approximately 90 participants from the international solar physics community engaged in lively scientific discussions during which the strong scientific case for large aperture solar telescopes was made, demonstrating the continuing excitement of the community about the unique capabilities the ATST. A special session on science with large solar telescopes with significant focus on the ATST will be held at the IAU meeting in Beijing in August 2012.

4.3 ATST Design and Capabilities

The Advanced Technology Solar Telescope is an all-reflecting, four-meter, off-axis Gregorian telescope housed in a co-rotating dome. The ATST delivers a maximum 300x300-arcsec circular field of view. Energy outside of this field is rejected from the system by a heat stop located at prime focus, allowing manageable thermal loading on the optical elements that follow. The telescope also includes a sophisticated wavefront control system, including active optics for figure control of the primary, active alignment of the critical optical elements, such as primary and secondary mirrors, and an integrated high order adaptive optics system designed to provide diffraction-limited images to the focal-plane instruments at the coudé observing stations.

The basic telescope parameters and design for the ATST and its subsystems have been described in detail in a number of recent publications to which we refer the reader for design details and performance analysis (see the bibliography in Appendix F). Additional information can be found on the ATST web site *http://atst.nso.edu* and a list of important capabilities can be found in Appendix B.

The solar atmosphere is highly structured by magnetic fields which permeate the solar atmosphere from photosphere to the corona. Understanding the three-dimensional structure of the solar magnetic field and how magnetic fields connect throughout the solar atmosphere is therefore of particular interest and pre-requisite for solving major scientific problems such as flares, coronal mass ejections, and coronal heating. The ATST's instrumentation is designed to provide simultaneous multi-line polarimetry at visible and infrared wavelengths and in combination with ATST's large photon collecting area provides a unique tool for polarimetry, in particular, of the dynamic upper solar atmosphere.

The near-infrared spectrum around 1.56μ has many advantages, particularly, for precise measurements of the weak, hidden magnetic fields that cover the entire solar surface. An aperture of 4m is needed to achieve the required resolution of < 0.1 arcsec at these important near-infrared spectral regions. Simultaneous photospheric and chromospheric magnetic field measurements performed with the ATST instruments will provide crucial information about the 3D structure of the magnetic field. For example, He I 10830 or He I D3 polarimetry can be used to measure chromospheric magnetic fields, for example, in filaments, prominences and spicules.

Ground-based observations of chromospheric dynamics performed at high temporal and spatial resolution in the H α line or the Ca II 8542 line have revealed the highly structured, intermittent, and dynamic nature of the chromosphere. The ATST constitutes a major leap in terms of resolution and also photon flux that will open a new parameter space and finally enable quantitative spectroscopic and polarimetric observations of chromospheric fine structure on their intrinsically short timescales. The far infrared provides particularly powerful diagnostics of magnetic field, temperature, and velocity at the upper layers of the solar atmosphere. For example, observations using the CO lines at 4.7 μ have resulted in a significantly improved understanding of stellar chromospheres. Direct measurements of the magnetic field strength can be performed at 12 μ with sub-arcsecond resolution by the ATST at an important layer in the solar atmosphere where the plasma β changes from >1 to <1 and magnetic energy begin to dominate.

Space missions like TRACE, *Hinode* and now SDO have advanced our knowledge of the Sun's corona enormously and have renewed interest in diverse coronal plasma problems ranging from how coronal mass ejections are formed and accelerated, to how photospheric magnetic fields drive the inverted coronal temperature structure. Numerical simulations of coronal field configurations that might lead to CMEs exist but detailed measurements of the coronal magnetic field are desperately needed to make progress. The magnetic sensitivity of the IR lines and the dark sky conditions in the IR are important motivation to utilize the ATST for exploring the IR coronal spectrum.

Solar-C, a 46-cm off-axis mirror coronagraph on Haleakalā, has demonstrated its capability to perform measurements of coronal magnetic fields. It was shown that the most challenging measurement of the Stokes-V component can be performed with sufficient sensitivity. The sensitivity of the Solar-C magnetic field measurements was 1 G. However, these pioneering measurements were performed with significantly compromised spatial and temporal resolution that is inadequate to probe the coronal loop structure and their dynamics. The ATST will provide a collecting area 75 times that of Solar-C. Controlling the background is paramount for coronal observations and ATST has been designed as a low scattered light facility and is located at an excellent seeing and coronal site.

Important science that will be addressed by the ATST coronagraphic capabilities include:

- What magnetic field configurations lead to CME ejection?
- What is the change in magnetic configurations accompanying CMEs?
- Direct tests of CME, or plasmoid, etc. acceleration models
- Pre- and post-flare loop systems:
 - what configurations lead to flares?
 - what is the change in magnetic configurations accompanying flares?

- Dynamics of coronal magnetic field during:
 - o filament/prominence eruptions
 - flaring active regions
- CME events
- Coronal loops:
 - o are loops all "flux tubes" or are some separators or current sheets?
 - how much twist (free energy) is in the field?
- Prominence cavity structure:
 - o direct test of magnetic models of prominence cavities.
- Extrapolations:
 - how good are extrapolation techniques (force-free, minimum current).
- Wave phenomena:
 - direct detection of low-frequency (< 1Hz) waves in the corona .

4.4 Instrumentation

The initial set of facility instrumentation includes the Visible Broad-band Imager (VBI), the Visible Spectropolarimeter (ViSP), the Diffraction Limited Near-Infrared Spectropolarimeter (DL-NIRSP), the Cryogenic Near-Infrared Spectropolarimeter (Cryo-NIRSP) and the Visible Tunable Filter (VTF). All instrumentation is located on a rotating coudé platform. Instruments that will be added after first-light but are not part of the construction project include a Near-IR Tunable Filter. Visitor instruments can also be accommodated on the coudé platform. One of the attractive aspects of ATST is the requirement for simultaneous observations with several of these instruments and when combined with diffraction limited imaging, offers a tremendous advance in capability to the solar community. This kind of diversity of post-focus instrumentation is crucial for achieving the science requirements. Probing the solar magnetic field throughout the entire solar atmosphere, from photosphere to corona, requires spectral diagnostics that span from the visible to the far infrared. This cannot be achieved with a single instrument but requires coordinated multi-instrument operations.

To accommodate the science requirement for an adaptable facility that can be quickly configured for a variety of diverse experiments, provide long-term support and maintenance of facility instruments, and to accomplish this in a cost-effective manner, the ATST project has adopted a strategy that calls for a high level of standardization. The light feed for all instruments, except for the Cryo-NIRSP, includes the high order adaptive optics system.

A common data acquisition system will be used to collect, pre-process, and display data from all instruments. The polarization calibration and analysis system is common to instruments, spectrographs and narrow-band filter systems. Detector requirements for all instruments are met using two facility-provided camera designs, one large format sensor for visible wavelengths and one for infrared instruments. By adopting these standards, duplication of effort will be avoided in the areas of polarization modulation and calibration, camera control, data storage and display, and mechanism control. "Facility class" implies a high level of instrument stability, operations of the instruments by an expert staff and implementation of efficient and stable calibration procedures.

The individual instruments are described in Appendix C.

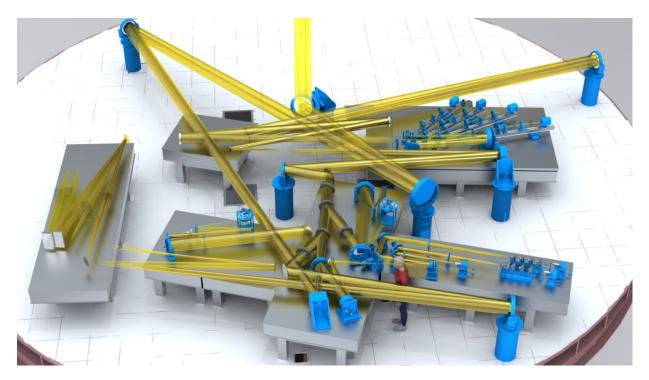


Figure 4.4-1. Example coudé lab instrument layout: Most instruments are currently in the design phase and the layout may change once the instrument designs are completed and instruments have been inter-phased to the telescope beam. Shown are the wavefront correction, including the DM, the DL-NIRSP, VBI and an early VISP conceptual design.

4.5 ATST Construction

The ATST was first proposed to NSF as a design and development project in 2001. Review of the proposal showed that the community had developed an excellent science case for ATST and the design and development (D&D) phase was funded. In late 2003, the ATST project submitted a construction proposal to NSF. After another highly successful review, it was determined that ATST should be the first project to follow the newly developing MREFC guidelines, which were being established to meet congressional concerns. NSF conducted an ATST cost review, which resulted in ATST entering the MREFC "readiness" phase. In the fall of 2006, a successful preliminary design review (PDR) was held, and it was determined that ATST was ready to move into the next phase. At the August 2007 meeting of the National Science Board (NSB), it was recommended that the NSF should consider submitting ATST for funding, moving it from readiness into the approval phase. In May of 2009, NSF conducted a Final Design Review (FDR) of the ATST. The review panel recommended that ATST was ready for construction. The NSB met in August 2009 and resolved: "that the National Science Board authorized the Director, at his discretion, to issue an 8 year award to the Association of Universities for Research in Astronomy for a not-to-exceed amount of \$297,928,000 for the construction of the Advanced Technology Solar Telescope (ATST). This award will be contingent upon the publication of a record of decision authorizing the commencement of construction." The NSF finalized the Environmental Impact Statement (EIS) for the proposed

construction site on Maui in December 2009 with a Record of Decision (ROD) authorizing the commencement of construction. In January 2010, the ATST project transitioned from design and development to the construction phase.

4.5.1 Construction Phase Status and Milestones

The project is following the Project Execution Plan established and reviewed at the NSF-conducted Final Design Review. Commencement of site construction on Haleakalā is tied to the "all permits in place" milestone. After the ROD was signed by the Director, the project submitted an application for a Conservation District Use Permit (CDUP), as required by Hawaiian statute. The Hawai'i Board of Land and Natural Resources (BLNR) voted and approved the CDUP on December 2, 2010. A contested case was immediately filed and the BLNR assigned a Hearings Officer to preside over the case. As of January, 2012, we are awaiting the Hearings Officer's recommendation to the BLNR. Once that is received, we will be scheduled to appear on the BLNR meeting agenda within 30 days for another vote on the CDUP. Site construction will begin immediately after the expected successful conclusion of the contested case.

Construction contracts for the major sub-systems of the telescope and instrumentation systems (e.g., M1 blank and polishing, enclosure, Telescope Mount Assembly, M1 Assembly, instruments, Support Facilities final design), have been issued and are proceeding according to the baseline schedule established at FDR. Major subsystems and their status are described in Appendix E. Risk management analysis continues and is being fed back into the project budgets (e.g., contingency), schedules (e.g., schedule contingency) and planning (e.g., in-process spares, integration, testing, and commissioning (IT&C) planning and staffing). Funds have been budgeted to each of the major work package for the construction phase. Contingency, based upon risk analysis presented at the NSF conducted FDR, is held and managed centrally by project management.

4.5.2 Schedule and Milestone Summary

The engineer responsible for each Work Breakdown Structure (WBS) element has developed detailed plans, including schedules and budgets, for the construction phase. The systems engineering team and project manager have integrated these details into the overall project schedule. Emphasis has been on near-term planning, i.e., subsystem contracting and site construction preparation. However, the planning focus of the ATST construction team is now shifting to detailing the Integration, Test and Commissioning phase, including the final science verification effort. During the initial construction phase, the detailed plans for transitioning to operations that were developed in the D&D phase are being refined and used to continue life cycle planning and help prepare the National Solar Observatory for the operational phase of the ATST.

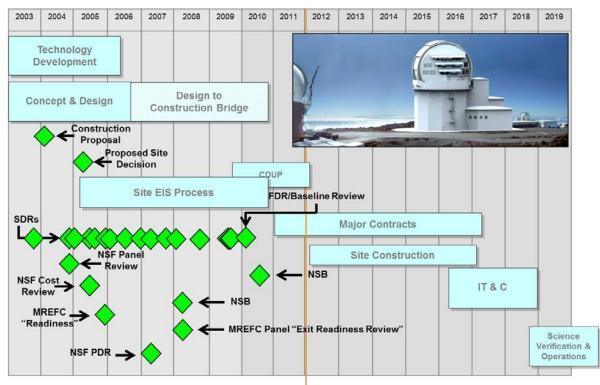


Figure 4.5-1 Top-level construction schedule.

The NSO is engaging in planning of science operations, including telescope operations on Maui and science operations and data center management at NSO headquarters at CU in Boulder. The NSO is already applying significant resources to the effort and will begin ramp up to final operations staffing in 2014.

The top-level ATST construction schedule is shown in figure Figure 4.5-1. Current planning targets calendar year 2018 for obtaining the first scientific data with an ATST instrument. The Project is poised to begin the initial site construction activities (site preparation, excavation, utility building construction, etc) in early 2012 pending the resolution of the permitting process. In addition, final fabrication designs and manufacture of key facility systems (e.g., M1, TMA, Enclosure), are underway. Appendix D lists level 1 milestones for the telescope facility and instrument systems.

4.5.3 Funding

In FY09, funding from the American Recovery and Reinvestment Act of 2009 (ARRA) was made available to the project at the level of \$146M. Funding from the MREFC was made available to the project at the level of \$151,928,000. Table 4.5-1 shows the Funding currently planned by NSF. The first MREFC increment of \$7M was awarded on February 12, 2010 (FY)(funds) with subsequent award amounts of \$13M on June 15, 2010 and \$5M in August 2011. This compares to the MREFC funding requests of \$20M for 2010 and \$17M for 2011. The project is expecting an MREFC allocation of \$10M in 2012 (\$20M requested). As the MREFC funding allocations has varied from the original funding schedule, several different scenarios have been explored to assess the impact on project schedule and costs. Currently, the project can sustain a lower, but flatter funding profile (\$25M per

FY from 2013-2016) without impacting the ongoing design, contracting and construction efforts. Figure 4.5-2 illustrates this funding scenario.

Table 4.5-1 Funds for the Advanced Technology Solar Telescope										
(Dollars in Millions)										
	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	Total
MREFC	\$7.00	\$13.00	\$5.00	\$10.00	\$25.00	\$25.00	\$25.00	\$25.00	\$16.93	\$151.93
ARRA	146.00	-	-	-	-	-	-	-	-	146.00
ATST TOTAL	\$153.00	\$13.00	\$5.00	\$10.00	\$25.00	\$25.00	\$25.00	\$25.00	\$16.93	\$297.93

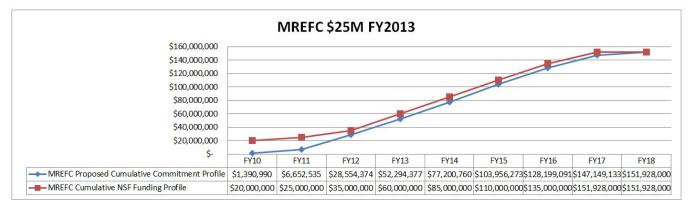


Figure 4.5-2. ATST Cumulative MREFC Commitments vs. Spend Profiles

In 2012, the project will go through an overall review of the cost-to-completion for the project based on updated information on resources, labor and effort since the FDR, and factoring in the unanticipated delays in the start of site construction; the centrally managed project contingency will be synched to the project risk register to be managed throughout the remaining construction activities at a level at/near 20%.

4.6 NSO Transition to ATST Operations

NSO has begun to ramp up for ATST operations, while at the same time beginning the ramp down of current flagship facilities such as the DST and McMath. It should be noted that operations planning, including the implementation of a data center, is responsibility of the NSO and is outside the scope of the ATST construction project (see Section 6). The ATST Director, in addition to directing the ATST construction effort, has responsibility for ATST operations planning during the transition phase and for operations of the ATST after commissioning of the facility. The NSO Data Center will handle processing, archiving, and distribution to the community of both ATST data products and NSO synoptic data products and will be a separately managed entity within the NSO that serves ATST and Synoptic program needs. Science operations of the ATST and the NSO Integrated Synoptic Program (NISP), however, will remain within the responsibility of the ATST and NISP Director, respectively.

A gradual transition of NSO base resources to ATST operations planning has begun and will continue throughout the ATST construction phase. The community supports this effort through focus groups of the SWG. As of 2012, two full-time NSO base science positions have been transferred from support of existing facilities to supporting the development and planning of ATST operations and the NSO

Data Center. Additional NSO science staff members provide part time support for these tasks. These positions report to the ATST Director. The LRP budget includes resources for a significant increase in man power and non-payroll resources for ATST operations and Data Center planning and implementation effort with the goal to be fully and efficiently operational at the end of the commissioning phase. This is reflected in Table 8.1-1 Estimated Personnel Evolution and Table 8.2-1 Long Range Budget Estimates. The Data Center at NSO Headquarters in Boulder, CO will reach a maximum staffing level of 12 FTEs in 2018. This includes staffing for the already well-established Synoptic Data Center component currently operating in Tucson. By jointly serving ATST and Synoptic data handling needs, the Data Center will be able to realize economies of scale. The Data Center will implement the data processing, storage, archiving and dissemination tasks.

4.6.1 Maui Staffing

On Maui, a team of approximately 36 FTEs will support telescope operations. Seven scientific FTEs will provide Resident Astronomers (RA), scientists with expertise in the ATST instrument, wavefront correction system, and data handling. A six-FTE staff of telescope operators led by a chief observer will be responsible for daily operations of the telescope. A 14-FTE engineering and technical staff will maintain the telescope systems and instruments and provide operational and safety support as needed. Computing and system support will be provided by 4 FTEs. An administrative staff will consist of a site business administrator, two administrative assistants (one with Human Resources training), a safety officer and a buyer/clerk. Additional HR and purchasing support will come from the HQ staff and AURA staff in Hilo.

We plan to contract facility support and janitorial services unless the costs are too high. In that case we may hire our own staff for some or all of the services needed to service the facilities.

4.6.2 ATST Staffing at HQ

At NSO Headquarters a science team of 8 FTE will support the ATST science operations. This includes support for the Data Center, the development of second generation instruments. Data Center science support tasks include definition of standard data products (e.g. Milne-Eddington inversions), development of algorithms, such as advanced inversion techniques of polarimetric data, algorithms for removal of residual seeing and basic spectroscopic analysis and interfacing to and support of the user community. Algorithms will be developed in close collaboration with the solar community. Existing algorithms (e.g. Solarsoft, inversion codes) will be implemented as much as possible.

The instrument development program will continue the successful model currently applied at NSO, where NSO scientists either leads the instrument development effort, collaborating closely with university or international partners, or a university PI takes the lead and teams with an NSO scientist(s) in developing the instrument. Several facility instruments have been developed and integrated at the DST in this fashion to the benefit of the broader community.

The ramp-up to full operations staffing for the Data Center and ATST science support will occur during 2012 – 2018. This is achieved by reprogramming existing resources currently supporting DST and Tucson operations and, starting in 2014, applying additional resources for ATST operations ramp-up.

4.6.3 Science Scheduling

In order to achieve the highest possible operational efficiency and guarantee maximized high-impact scientific output NSO will abandon the traditional model of scheduling observing time, in which only one PI has exclusive access to the telescope during a fixed block of observing time and with some help from the observing staff performs the observations. Instead, service observations that allow for flexible scheduling will be implemented. Scientific observing requests will be efficiently pooled, queued and executed only when solar conditions, target availability and seeing conditions, are suitable. Only the expert ATST operations staff will operate the telescope, instruments and all associated support systems. Service time is dynamic and the observatory staff is responsible on a daily basis for real-time decisions regarding what programs out of a scientific merit ranked list are executed and what instruments will be operated. The service mode does not require the physical presence of the proposal PI. Remote participation in observations by the PI is enabled via telecommunication equipment.

The service mode allows making efficient use of target availability, weather conditions and technical readiness and supports a broad range of different programs. This mode is amenable to target of opportunity observations and can be used to perform (long-term) synoptic programs, and does allow for joint/coordinated (campaign) programs or other programs where special time constraints are given (e.g., rocket launch, balloon or space experiment). The service mode also supports maintenance and engineering tasks or special calibration measurements. Those often can be performed during weather conditions that are not suitable for science observations. Service Mode provides flexible scheduling tools that avoid usage of prime observing time for these calibration measurements. To fully support service mode observing, the on-site observatory staff will have a number of key scientific and engineering "actors" that conduct and support the observations. These include the resident astronomer, operators, engineers, instrument scientists, and a wavefront correction scientist. The RA is the final authority for daily scheduling and execution of observations. The RA role is in some ways comparable to the Hinode Chief Observer (CO). Instrument and wavefront correction scientists are expert users of complex instrument and adaptive optics system who ensure that these systems are properly calibrated and operate with consistent performance and according to specification as well as providing support to users in preparing and conducting observations.

The Service Mode is expected to be the predominant observing mode. In addition, the ATST will make available an Access Mode when real-time decisions of and close interactions with the PI are necessary. The Access Mode is particularly tailored to support instrument development efforts, programs that have special-time constraints, and special technical tasks. Hence, access time is offered and encouraged only during limited periods of time and has to be balanced with service mode operations in order to optimize scientific output. During access time, the PI and/or his/her designee and Co-PIs may be either granted physical access to the facility or can participate remotely from the Maui base facility.

In contrast to the PI-Mode based operations of "highly flexible" instrument setups at current facilities, ATST's emphasis on Service Mode operation of facility class instruments in conjunction with an open data policy will enable ATST to provide consistent data products that can be processed, archived and disseminated by the NSO data center.

5 A GLOBAL NETWORK

Since the Sun changes on time scales of less than a second to many millennia, observations need to be as continual as possible for long time periods in order to capture solar phenomena with minimal temporal aliasing, and to ensure that rare events are recorded. A network, such as GONG, has been clearly demonstrated to provide such observations. A network is a set of nearly-identical observing instruments geographically distributed so that gaps from night time, weather and instrumental problems are minimized. While space platforms, such as SOHO and SDO, can also provide nearly-continual solar observations, networks have four distinct advantages: the costs of developing and maintaining a network are roughly a factor of 10 to 15 lower; the network instrumentation can be repaired when it fails; the instrumentation can be upgraded and deployed without incurring the high costs of additional space launches; and the network lifetime is in principle infinite. In addition, a network is very useful for providing data for space weather forecasting. For example, the US Air Force is using GONG data to provide space weather data, and the US Space Weather Prediction Center is using GONG data to drive predictions of geomagnetic storms.

GONG currently supplies one-minute cadence Doppler and longitudinal magnetic field data in the photosphere at a single wavelength (Ni I 676.8 nm) for helioseismology and for studies of rapid changes in the line-of-sight magnetic field. In addition, GONG provides 20-second cadence H-alpha intensity images for detecting flares and filament eruptions. While these data sets are very productive, there are two major missing aspects: vector magnetic field measurements, and multi-spectral observations.

Observations of the vector nature of the solar magnetic field are essential for fully understanding its generation, evolution, and dissipation. Almost every solar magnetic phenomenon, such as flares, CMEs, filament eruptions, the acceleration of the solar wind, irradiance, reconnection, and the formation of the chromosphere and corona requires knowledge of the direction as well as strength of the magnetic field. Currently, no network exists that can acquire vector magnetic field measurements. Thus, much of the information is missing. NSO's SOLIS VSM obtains high-quality measurements of the vector field in the photosphere, but only once a day at a single location. The establishment of a VSM global network would enable synoptic, full-disk observations of the vector field on a nearly continuous 24/7 basis with a cadence of a few minutes. This capability would also complement current solar space missions and provide nearly simultaneous, contextual data for the ATST.

Since the VSM is a multi-spectral instrument, it can provide global chromospheric magnetic field measurements. Knowledge of the chromospheric magnetic field is vital to understand the connection between the corona and the photosphere. Multi-spectral observations would also substantially improve the reliability of helioseismic estimates of bulk flows and wave speed (related to temperature and magnetic fields) below active regions. These estimates are essential for understanding the formation and evolution of active regions. Multi-spectral measurements would provide the wave phases and other parameters as a function of height above the photosphere, which can be used to improve the helioseismic results as well as probe the structure of the solar atmosphere.

In order to provide the data required for significant advances in solar physics, NSO is proposing to develop a next-generation observing network capable of providing images of full-disk Doppler velocity, vector magnetic field and intensity in a variety of wavelengths. Ideally the data would be obtained at a cadence of no longer than 60 seconds, at a spatial resolution of 1" (0.5" pixels), at least 90% of the time for at least a solar magnetic Hale cycle (~ 25 years). Observations would be obtained in at least the Ni I 676.8 nm, Fe I 630.1/630.2 nm, Na D, H- α , Ca K, Ca H He 1083.0 nm, Fe I 617.3 nm and perhaps the Fe I 1500 nm spectral lines. The images would have a format of 4K x 4K. The entrance aperture would be at least 0.5 m in diameter, and the instrument would include adaptive optics or other image enhancement technology; high-speed image post-processing and high-speed real-time data return via the internet. The instruments would be located at least six sites.

6 DATA CENTER

In order to further leverage the substantial national investment in solar physics, NSO will develop a Data Center at its new headquarters location that will be integrated with the NASA-funded Virtual Solar Observatory. The Data Center will archive datasets from both synoptic and high-resolution ATST observations in a common infrastructure, as a cost-effective means to exploit synergies among all NSO programs. It will subsume the current digital library.

The future NSO Data Center staff will be a collaboration of IT, programming, and science expertise. Early phases of planning and designing the data center are in progress, leveraging the expertise of the current NSO data center staff as well as partnerships with space-based missions such as *Hinode* and SDO, and related European efforts. Relocating to the University of Colorado, Boulder (CU) campus will present additional collaborative opportunities with CU and NCAR supercomputing projects. Prototyping of reduction pipelines will utilize DST instrument data. A Data Center Scientist has been hired to lead this team effort.

A NSO Data Center build-up on the CU campus should accommodate existing operational capabilities, with room for substantial expansion into ATST science operations. A 5000 ft² data center is currently being constructed on the ground floor of the planned NSO HQ building on the CU campus. An additional 9000 ft² of data center space is being planned by CU nearby. NSO will establish its own server racks in these spaces in a shared arrangement with other university departments. CU is paying for the facilities construction and recurring maintenance costs, and will charge a user-fee to tenants of the data center based roughly on power consumption. In the short term, CU has expressed willingness to host some NSO computer systems as they are acquired in future annual procurement cycles. This will save in hardware moving costs as most systems currently in production will be ready for retirement by the projected 2015-2016 relocation timeframe.

Assuming an average data rate of 10 TB/day, ATST will collect 3.65 Petabytes in its first year of science operations. This increases the size of all current NSO data archives added together by at least two magnitudes, and presents a formidable challenge for building high performance storage, analysis and distribution infrastructure that meets science requirements, while being cost-effective. The Center for Research Computing (CRC) at CU has received an NSF MRI grant to acquire, deploy and maintain an expandable petascale storage instrument, the CU-Boulder petaLibrary. The petaLibrary will be made available to all CU-Boulder researchers, including NSO, in a "condominium model" at no usage charge other than media. Estimated petaLibrary storage prices in 2011 dollars are \$300/TB for disk, and \$110/TB for tape. These costs are likely to change so long as media costs continue to decline. This could be a cost-effective solution for NSO's long-term storage needs, but specifics about capacity, data access, and performance need to be evaluated.

Build-up of the Data Center will occur in parallel with ATST construction and NSO HQ development. Early investments in the data center at CU should focus on synoptic data migration and test platforms for the ATST. Leveraging continuous advancements in storage and processing technology, the balance of computer hardware investments needed for ATST expansion should

occur on the tail end of the construction phase. The "condominium" storage model at CRC lends itself well to NSO's hardware budgeting, as storage will be purchased on an as-needed basis.

The data produced by ATST will be of much higher volume and significantly more complex than synoptic data. The ATST Data Handling System (DHS) included in the construction proposal provides a common data transfer and storage service for all ATST facility instruments and supports five areas of instrument data requirements: transfer, processing (only allowed if the overall volume is thereby reduced), storage, display for quality assurance, and retrieval. Significant effort has been made to ensure that all data sets are accompanied by the metadata necessary to fully describe its content (such as originating principal investigator etc.) and to guarantee that proper scientific calibration and compliance with VSO is always possible.

The ATST Data Handling System is the interface between the NSO Data Center at Headquarters and the ATST instrumentation. The temporarily stored instrument science & calibration data and related metadata will be transferred from the summit to processing facilities at the ATST Support Facility on Maui and subsequently to NSO Headquarters. The exact amount of storage and processing power to locate on Maui as well as the final transport mechanisms to the Maui Support Facility and NSO HQ will be determined by the NSO Data Scientist and his team during construction and will depend on several factors, including projected data generation rates & transfer costs as well as hardware and personnel costs; several high speed (\geq 1 Gbit) network connections between involved facilities are planned in order to alleviate this problem in part. The ATST support facility on Maui will have sufficient capability to allow ATST staff stationed on Maui to reduce some of the data to further ensure quality and that the objectives of the observing run are being met as well as to conduct their own research.

Any extensive processing on the mostly raw and calibration data occurs at the Data Center located at NSO HQ at CU, which will be equipped with sufficient long-term storage and compute power to a) store the raw data and b) temporarily provide data calibrated to the level desired by the user. The algorithms to achieve the supported levels of calibration are version controlled and applied to the data in supervision of NSO staff; the robustness of the instrument data will determine the level of automation and quality assurance needed, as well as whether there is a 'standard level' of calibration for it. It is expected that many of the data products at the center will be produced using algorithms provided by the community. For example, HAO's Community Spectro-polarimetric Analysis Center (CSAC) is continuously improving inversion techniques and Lockheed has developed a number of pipelining tools for *Hinode*, TRACE, and SDO.

Science and engineering data produced by NSO facilities in general will have a high value and thus be archived either permanently or for extended periods as determined by the NSO data policy which is driven by science requirements. All data with verified scientific value will be stored at the lowest delivered calibration level along with their calibrations in 'on-line' or 'near-line' (tape-robot type) storage systems, for the present and future benefit of the community.

7 EDUCATION AND OUTREACH AND BROADENING PARTICIPATION

NSO conducts a vigorous public affairs and educational outreach program that includes graduate research and training, undergraduate research, teacher research and research-to-classroom experiences, public programs, media information, elements of distance (Internet) learning, and K-12 education. As NSO moves into the ATST era, it plans to expand its outreach programs in several of the STEM areas through proposals and partnerships, including the establishment of effective outreach in Hawai'i by partnering with groups already involved in Hawaiian outreach programs.

The primary NSO EPO objectives and goals are:

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

A full description of NSO's educational and outreach programs and programs to increase diversity is given in the 2011 Annual Progress Report and 2012 Annual Program Plan (APRPP) available at *http://www.nso.edu/sites/www.dev.nso.edu/files/files/docs/APRPP_2011-12.pdf*.

8 IMPLEMENTATION

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

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

The NSO long-range strategy includes a logical and optimal transition from operations and support of the current national solar assets to the era in which several of the primary facilities are supplanted by the ATST. The increased complexity involved in ATST maintenance and operations will require combining resources currently divided among operations in Sunspot and Tucson as well as additional operation staff. The ATST will produce a ten-fold or more increase in the data NSO needs to archive and, unlike for our current flagship telescopes, NSO plans to process ATST data and make it publically available.

In parallel with ATST construction and development, resources will be required for ongoing user support and operation of a scientifically productive synoptic program. Support for the expansion of the SOLIS VSM to a three-site global network will be sought in collaboration with international partners. As ATST ramps up towards its operational phase, NSO will consolidate its staff at a single headquarters location and relocate staff, or hire locally, to support operations on Maui.

8.1 The Evolution of NSO

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

NSO plans call for consolidation of its Tucson and Sunspot staffs into an efficient organization to operate the ATST, conduct synoptic programs, operate a data reduction and distribution center, support forefront research the solar community and its staff, and to more effectively recruit new students into solar astronomy. AURA received seven proposals in response to its solicitation for a new NSO directorate site. After review by an eight-person panel, two proposals were selected for further review and discussion. These are the University of Colorado in Boulder, and the University

of Alabama in Huntsville. After careful consideration of pros and cons of both sites, AURA selected the University of Colorado as offering the best future for NSO.

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

- Starting on-site construction of ATST (2012).
- Development of the next cooperative agreement for operating NSO (2012/2013)
- Establishing the new NSO Directorate site at the University of Colorado, Boulder (2013/2014)
- Relocation of the NSO Staff to Boulder and Maui (2014-2017)
- Relocation of SOLIS to a superior synoptic site at a longitude favorable for a future multi-site network (2015).
- Commissioning of the ATST (2018).
- Divestment of older facilities (2013–2018).

Planning for NSO operations in the ATST era begins with the consideration of existing facilities and capabilities. NSO already has a fully staffed and operating observatory upon whose resources ATST and Synoptic 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.

Ramp-up of operations on Maui needs to occur over a time frame encompassing ATST construction, with a majority of the operational staff in place during the latter part of the commissioning phase. During the early phase of construction, NSO would lease a limited amount of space to house construction engineers, a safety officer, and other necessary personnel. Funds to support space for the construction staff are included in the construction proposal. As NSO operational staffing is required, NSO will have to obtain more space to accommodate approximately 35-40 personnel consisting of technical and science support for the telescope, administrative and computer support, visiting astronomers, and some laboratory and storage space. We refer to this additional space as a base-facility, or remote operations building (ROB). Establishing an operational capability from the ROB has been discussed to reduce travel to and from Haleakalā, but it is not funded in the construction budget.

As ATST construction progresses toward completion, key NSO personnel and NSO base funding will be transferred to support ATST operations on Maui, including administration, telescope operators and scientists for commissioning, contracting, outreach, establishment of a data center, and other functions as needed. These personnel will include both transfers from current NSO facilities and new hires on Maui. While some NSO employees would be willing to transfer, others would inevitably seek other positions or retire.

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

The total NSO staff and how NSO envisions its evolution into the ATST era is shown in Table 8.1-1. In FY 2012 and FY 2013 the staff under HQ is at our current observatories. In FY 2013, however, there may be some early moves to Boulder. The staff is responsible for operating current facilities, providing user support, developing ATST and SOLIS, and conducting outreach programs. The current project team working on ATST along with current observational and technical staff operating the DST and McMP will migrate into many of the staff positions required to operate the ATST. Additional operational staff will be hired locally on Maui.

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

	Table 8.1-1 Estimated Person	nel Evo	lution (F	Y2012-F	Y2019	Time Fi	rame)		
		FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19
HQ, ATST &	Director's Office	2	2.5	2.7	3	3	3	3	3
Synoptic	Administrative Support			1	2	5	5	5	5
Support	Science Staff								
	ATST Science Staff	1	1.7	4	5	7	7	7	8
	ATST Fellow	1	1	1	1				
	Synoptic Science Staff					6	6	6	6
	Data Center			1	2	11	11	12	12
	Instrumentation Prog/Maint			2	4	11	11	11	11
	IT Support				1	2	2	2	2
	Synoptic Program					4	4	4	4
	EPO			2	2	2	2	2	2
	HQ	4	5.2	13.7	20	51	51	52	53
ATST	ATST Construction Project								
	Science Staff								
	ATST PI/Director	1	1	1	1	1	1	1	
	Project Scientist	1	1	1	1	1	1	1	
	Data Handling Scientist	1	1	1	1	1	1	-	
	Engineering/Technical	37	39	44	50	59	47	37	
	ATST Maui Operations								
	Science Staff supporting Ops			1	1.5	2	5	6	7
	Operations Staff			1	1	3	4	6	6
	Administrative Support			1	2	2	5	5	5
	Engineering/Technical				1	6	12	14	14
	IT Support				1	3	4	4	4
	ATST Construction & Maui Ops	40	42	50	59.5	78	80	74	36

		FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19
Sunspot	Scientific Staff								
•	DST Support	3	3	3	1	1	1		
	ATST Data Center Develop.	1	1	1					
	Synoptic Program Support	1	1	1	1				
	DST Observing Support	4	3	3	3	3	2		
	Tech Support	•	Ū	C C	•	Ū	-		
	DST Observing Support	7	6	5	4	2			
	ATST Data Center Delop.	-	1	-		_			
	2nd Gen. Instr. (MCAO)		·	1	1				
	IT Support/AF Obs Support	2	1.5	1.5	1.5				
	Library Support	1	1.5	1.5	1.5				
	Facilities	5	5	5	5	4	2		
	Visitor Center	2	2	2	2	2	2		
	Administrative Support	5	5	5	4	1	1		
	Sunspot	31	29.5	28.5	23.5	13	6		
	· · ·	0.	27.0	20.0	2010	10	Ū		
Tucson	Scientific Staff								
	Deputy Director	1	0.5	0.3					
	McMP Telescope Sci.	1	0.3						
	McMP Operations	2.3	0.5						
	McMP Tech Support	1							
	Tucson	5.3	1.3	0.3					
Synoptic	Salantifia Staffing								
Program	Scientific Staffing	1	1	1	1				
	Assoc. Director Synoptics	4	4	3	3				
	Solar Atmosphere	4	- 2.5	2	2				
	Solar Interior	4 1	2.5	1	2 1				
	Instrument Support	-	1	1	1				
	Synoptic Data Ctr Support	1 0.7							
	Program Manager		1	1 5	1 5				
	Network Operations	5.5	5	5	5				
	Synoptic Data Center								
	Manager	1	1	1	1				
	Operations	2	2	2	2				
	Software Maint. & Develop.	6.5	6.5	6.5	6.5				
	ATST Data Center Develop.	0.5	0.5	0.5	0.5				
	Technical Support	6	5	5	5				
	Administrative Support	1	1	1	1				
	Synoptic Program	34.2	31.5	30.0	30.0				
	Total FTEs	114.5	109.5	122.5	133	142	137	129	89

8.2 Spending Plan

Table 8.2-1 summarizes a long-range funding profile for NSO based on the target provided by the NSF. The staffing levels in the previous section were based on the levels of funding shown in the

Table 8.2-1. Long-Range Budget Estimates (Dollars in Thousands)							
Program	FY12	FY13	FY14	FY15	FY16	FY17	FY18
Director's Office ¹	405	503	555	890	899	765	765
HQ Development + Relocation	22	22	1,610	2,000	800	-	-
HQ Lease and Utilities	-	-	350	1,050	1,150	1,150	1,175
Administrative Support	-	-	180	310	770	760	800
Science Staff	-	-	-	-	-	-	-
ATST Science Staff ²	120	212	613	719	1,312	1,330	1,454
ATST Fellow ³	-		141	127	-	-	-
Synoptic Science Staff	-	-	-	-	875	928	1,013
Data Center/Software/Computing	-	-	121	745	2,405	2,165	1,564
Instrument Program/Maintenance	-	-	500	700	1,850	1,885	2,123
IT Support	-	-	-	520	540	353	390
Synoptic Program	-	-	-	-	1,020	1,100	1,224
EPO	-	-	300	360	300	270	300
ATST Operations	-	-	-	-	-	-	-
Science Staff Supporting Ops	-	-	170	212	370	860	1,473
Operations Staff	-	-	140	154	440	560	794
Administrative Support	-	-	140	260	280	570	723
Engineering/Technical	-	-	-	162	1,080	1,800	2,906
IT Support	-	-	20	350	760	900	620
Mountain Facility Support	-	-	-	-	-	-	2,180
Building Lease	-	-	900	900	900	900	900
Tucson/McMP	565	245	133	30	-	-	-
Synoptic Program	4,043	3,440	3,358	3,481	-	-	-
Sac Peak	2,623	2,299	2,380	2,330	1,472	1,070	-
General NOAO Supp	960	961	970	1,200	1,297	1,100	1,000
Utilities on Kitt Peak	80	60	60	60		-	-
AURA Management Fee	282	260	360	440	480	534	596
Total	9,100	8,000	13,000	17,000	19,000	19,000	22,000

table. NSF funding for the period FY12-FY14 is determined under the current Cooperative Agreement between the NSF and AURA.

¹Assumes that the Deputy Director moves from the Tucson budget to the Director's office at the 50% level in FY 2013, 70% level in FY14 and fully in FY 2015.

²Includes the ATST Associate Director salary starting in FY 2014.

³The ATST fellowship positions is in the Sac Peak budget in 2013, moves to the ATST fellow line in FY 2013, and moves to the ATST scientific staff budgets in FY 2016.

The FY12 figure is what was actually received from NSF which is \$690K less than shown in the Annual Program Plan. FY13 is a cut of 1.1M from the original NSF target. FY14 is reduced by \$2.09M and FY15 by \$2.0M from the target provided previously by NSF. FY15 and beyond will be negotiated in the next Cooperative Agreement. FY14 and beyond include ramp-up of funding for ATST operations. Table 8.2-2 shows the ATST operations and maintenance ramp up and the ramp-down of current O&M funding.

Table 8.2-2 NSF Planned Funding (Dollars in Thousands)							
	FY12	FY13	FY14	FY15	FY16	FY17	FY18
Current O&M	9,100	8,000	8,000	8,000	8,000	5,000	4,000
ATST O&M			5,000	9,000	11,000	14,000	18,000
Total	9,100	8,000	13,000	17,000	19,000	19,000	22,000

8.2.1 Final FY 2012 Budget

The detailed breakdown of the final NSO budget for FY 2012 by work area and functional unit is shown in Table 8.2-3. This is a revision of the budget submitted in the Program Plan for FY 2012 and reflects the latest guidance from NSF. Compared to the target budget at the beginning of FY 2012, it reflects a reduction of \$690K and represents the third consecutive year of level funding.

Table 8.2-3 NSO FY 2012 Revised Spending Plan (Dollars in Thousands)					
	Director's			son	
Expenses	Office	Sunspot	Tuc ¹ + McMP	NISP	Total
Director's, Staff, Committee Support	429				429
Directorate Site Development	16	6			22
Science Staff ²		648	368	1,373	2,389
Science Support/Computing		390	13	1,339	1,742
Instrument Develop./Maint.		793	25	792	1,610
Telescope Operations		345	198	1,120	1,664
Facilities		696			696
Administrative Support		230		199	429
Education and Public Outreach	108	163	26	40	337
NOAO Business Support	45	173	58	576	852
ATST Science ³		220			220
AURA Management Fee	282				282
Program Total	881	3,664	688	5,439	10,672
Revenue					
Programmed Indirects/Carry Over	(24)				(24)
Housing Revenue		(104)			(104)
Meal Revenue		(17)			(17)
NSF REU/RET Funding		(66)	(26)	(40)	(132)
AF Support		(400)		(740)	(1,140)
ATST Fellowship Support		(100)			(100)
Visitor Center Revenue		(55)			(55)
NSF/AST Funds	857	2,922	662	4,659	9,100

¹This column includes McMP operations, Deputy Director salary, and support for downtown operations

²Tuc+McMP column contains Deputy Director and McMP program scientist

³Sunspot column contains scientist time for developing ATST operations, data handling, and ATST fellow

To meet this budget NSO reduced the staff by 5.8 positions. Impacts include less science support for users, slowing of some projects, and reduced support at the NSO synoptic data center.

8.2.2 FY 2013 Preliminary Budget

Table 8.2-4 shows NSO's Preliminary FY 2013 spending plan, conforming to the President's proposed budget of \$8,000K.

			Tuc		
Expenses	Director's Office	Sunspot	Tuc ¹ + McMP	NISP	Total
Director's, Staff, Committee Support	527		•		527
Directorate Site Development	16	6			22
Science Staff ²		559	175	1,168	1,903
Science Support/Computing		347	13	1,339	1,699
Instrument Develop./Maint.		686	5	677	1,369
Telescope Operations		270	71	967	1,308
Facilities		686			696
Administrative Support		230		69	299
Education & Public Outreach	109	163	26	40	337
NOAO Business Support	45	173	58	576	852
ATST Science ³		220	92		312
AURA Management Fee	260				260
Program Total	956	3,340	440	4,837	9,573
Revenue					
Programmed Indirects/Carry Over	(24)				(24)
Housing Revenue		(104)			(104)
Meal Revenue		(17)			(17)
NSF REU/RET Funding		(66)	(26)	(40)	(132)
AF Support		(400)		(741)	(1,141)
ATST Fellowship Support		(100)			(100)
Visitor Center Revenue		(55)			(55)
NSF/AST Funds	932	2,598	414	4,056	8,000

¹This column includes McMP operations and support for downtown operations

²Tuc+McMP column contains 50% of Deputy Director salary, the other 50% is moved to the Director's Office; and 30% of McMP program scientist the other 70% moved to the ATST science staff.

³Sunspot column contains scientist time for developing ATST operations, data handling, and ATST fellow; the Tuc+McMP column contains 70% of McMP program scientist time.

This level of funding is a \$1.1M decrease from this year and \$2,090K less than we had previously developed our long range plan for. In order to fit our program into the \$8M level, we have eliminated nine staff positions. Impacts include reduction of support and early closure of the McMath-Pierce telescope. This means the community loses the ability to observe in the IR beyond 2 microns. It reduces the time to develop a consortium that could take over the McMP. In order to extend the time, we will seek outside funding, including funding from the planetary community, which provides some of the heaviest users. We are also reducing observer support by 25% at the Dunn Solar Telescope, which impacts our use of the DST as an ATST test bed and as the primary source for training ATST users. At this level of funding we have also eliminated most of our R&D funds for the coming year and stop some of the planned upgrades of the current instruments and will concentrate on just maintaining current systems.

APPENDIX A: ATST SCIENCE WORKING GROUP MEMBERS

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

APPENDIX B: ATST TELESCOPE PROPERTIES

The most important capabilities of ATST can be summarized as follows:

- Aperture: 4m
 - Diffraction limited resolution:
 - 430nm 0.022 arcsec
 - 1μ 0.05 arcsec
 - 4μ 0.2 arcsec
 - 12μ 0.6 arcsec
- Gregorian
- Off-Axis
 - o Unobstructed Aperture, no spider diffraction
 - o Clean PSF, High Strehl
- Alt-Az Mount
- High order conventional Adaptive Optics (MCAO ready optical design)
- Internal Seeing Control (thermal control of optics & structure)
- Dust control for low scattered light coronal observations
- Polarimetric sensitivity: > 10⁻⁵
- Polarimetric accuracy: 5×10-4
- Wavelength coverage: 300 nm to 28 micron
- Facility class first-light instrumentation

APPENDIX C: ATST INSTRUMENTATION

C.1 Visual Broadband Imager (VBI)

The Visual Broadband Imager is designed to provide diffraction limited images and movies at a number of wavelengths that image the photosphere and the chromospheres. The VBI will reveal solar structure at unprecedented resolution and capture dynamical processes with high cadence imagery. The instrument is divided into two channels, one for the red (650 nm-860 nm for H α , TiO, and the Ca infrared triplet) and one for the blue (390 nm-490 nm for Ca II K, G-band, blue continuum, and H β). Each beam will feed a single 4K x 4K detector. The ATST team is currently constructing this first-light instrument.

The VBI will take advantage of ATST's high spatial resolution by using a combination of adaptive optics and post-facto image reconstruction. The conventional adaptive optics system will provide partial correction of the image primarily at or near the wavefront sensor field-of-view (FOV). Near real-time image reconstruction algorithms are applied at Haleakalā to provide data volume reduction and feedback to operators and remote participants in observations. The VBI will generate two data streams of up to approximately one gigabyte per second each in order to meet the requirement of one reconstructed image per 3 seconds, which will allow capturing highly dynamic events in particular in the chromosphere. Additionally, in order to compute a reconstruction with accurate photometric properties, this data stream has to be merged with adaptive optics performance data during the reconstruction process.

C.2 Visible Spectro-Polarimeter (ViSP)

The ViSP will provide precision measurements of the full state of polarization (i.e., all four Stokes parameters I, Q, U, and V) simultaneously at diverse wavelengths in the visible spectrum, and fully resolving the spectral profiles of spectrum lines originating in the solar atmosphere. Such measurements provide quantitative diagnostics of the magnetic field vector as a function of height in the solar atmosphere, along with the associated variation of the thermodynamic properties. Furthermore, information about protons and electrons in flares can be deduced from analyzing the polarization of strong lines during flares.

The High Altitude Observatory in Boulder, Colorado is leading the design of the ViSP. This instrument provides high spatial and polarimetric resolution spectra with the capability of scanning a large field of view. Wavelength diversity is a key element of the instrument allowing the ViSP to simultaneously perform spectropolarimetric maps in up to three arbitrarily chosen and widely separated lines in the visible and near-infrared spectral range (380 nm-900 nm). The spectral resolution is 180000. The ViSP team achieved a preliminary design review in January 2011.

The instrument has passed its PDR and is expected to pass its CDR in 2012. Commissioning of the ViSP at the telescope on Haleakalā will commence in 2018. Science verification will conclude at the end of 2018.

C.3 Visible Tunable Filter (VTF)

The central mission of the VTF is to spectrally isolate narrow-bandpass images of the Sun achieving the highest possible spatial and temporal resolution images from the ATST telescope. Observations with this instrument will allow rapid imaging spectrometry, limited Stokes imaging polarimetry,

accurate surface photometry, and spectroheliograms that will result in Doppler velocity maps, transverse flows, and imaging magnetograms that track evolutionary changes of solar activity.

The VTF is a partner contributed and funded instrument. The design effort, and subsequent construction, is being led by the Kiepenheuer Institut für Sonnenphysik in Freiburg, Germany. The VTF will deliver diffraction-limited narrow-band filter images and is capable of vector polarimetry. Its multi-etalon Fabry-Perot filter system operates from 515 nm to 860 nm. The spectral resolution of the Fabry-Perot filter system will be 2.5 pm and thus an order of magnitude better than that of the VBI. The FOV is limited to a maximum of 1 arcmin. The VTF will be able to perform two-dimensional spectroscopy and polarimetry at the diffraction limit. This type of instrument has been and continues to be highly successful at current solar telescopes.

The kick-off meeting for the VTF effort was conducted in 2011. The Conceptual Design Review will be held in April, 2012. PDR and CDR are scheduled for the end of 2012 and 2013, respectively. Commissioning of the VTF at the telescope on Haleakala will commence in 2018. Science verification will conclude at the end of 2018.

C.4 Diffraction Limited Near-IR Spectro-Polarimeter (DL-NIRSP)

The primary purpose of the DL-NIRSP is the study of the solar magnetic fields at high spatial and spectral resolution at near infrared wavelengths. It is an instrument for the analysis and recording of the full polarization state (Stokes I, Q, U and V) of spectral lines originated on the Sun in the near infrared wavelength regime from 900 nm to 2500 nm. While the spatial resolution of the ATST decreases with increasing wavelength, the magnetic resolution of the Zeeman effect increases with increasing wavelength, and so there are advantages to observing at long wavelengths. The DL-NIRSP will address scientific questions, which require very detailed line profile observations and seek to measure small velocities and velocity gradients found in the solar photosphere. A prototype of the DL-NIRSP has just been commissioned at the Dunn Solar Telescope and will provide valuable guidance for the DL-NIRSP design. Figure C-3.1 shows the DL-NIRSP design. The instrument will have a spectral resolving power of up to 200000.

The University of Hawai'i Institute for Astronomy (IfA) is leading the DL-NIRSP development effort. This instrument is capable of diffraction-limited spectropolarimetry in the short wave infrared (900 nm - 2500 nm). The multiple slit design with the capability of observing three simultaneous wavelengths allows the DL-NIRSP to produce rapid cadence spectropolarimetric maps at diverse wavelengths.

The instrument has passed its PDR and is expected to pass its CDR in 2013. Commissioning of the DL-NIRSP at the telescope on Haleakalā will commence in 2018. Science verification will conclude at the end of 2018.

C.5 Cryogenic Near Infrared Spectro-Polarimeter (Cryo-NIRSP)

The primary purpose of the Cryogenic Near-IR Spectro-Polarimeter is the quantitative measurement of the solar magnetic field over a large field-of-view at thermal infrared wavelengths in the solar corona. It is an instrument for the analysis and recording of the full polarization state (Stokes I, Q, U and V) of spectral lines originated on the Sun in the near infrared wavelength regime

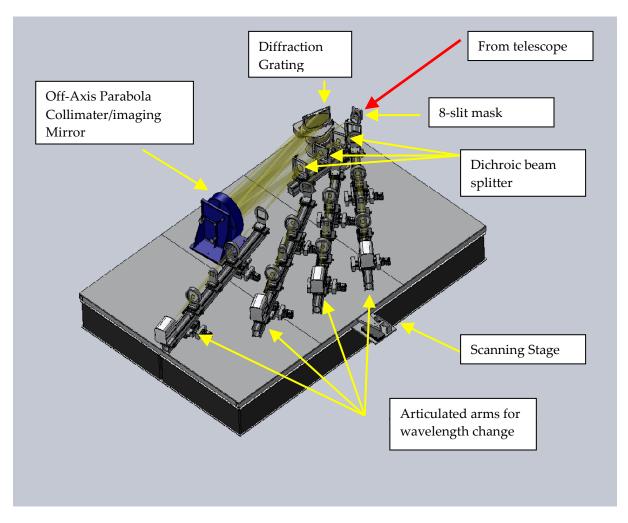


Figure C.3-1 . DL-NIRSP design.

from 1000 nm to 5000 nm. The coronal spectral lines have very low intensity, measured in millionths of the brightness of the solar disk, and have much larger spectroscopic line widths than photospheric lines because the coronal plasma has a temperature in the millions of Kelvin. In some cases where prominences are studied, the spectral lines are much brighter and are cooler, representing chromospheric temperatures of only 8000K.

The University of Hawai'i IfA is developing the Cryogenic NIRSP, an instrument capable of spectropolarimetry from 1000 nm to 5000 nm. The Cryo-NIRSP has a large field of view and, by trading spatial and spectral resolution for signal to noise, is capable of coronal magnetic field measurements in Fe XIII (1075 nm) and Si IX (3935 nm). The spectral resolving power is 30000. The required spatial resolution is 1 arcsec. When operated at higher resolution, it can provide solar surface observations across its bandpass including the important CO bands at 2333 nm and 4666 nm.

The instrument has passed its PDR and is expected to pass its CDR in 2012. Commissioning of the CRYO-NIRSP at the telescope on Haleakalā will commence in 2018. Science verification will conclude at the end of 2018.

APPENDIX D: ATST MILESTONES

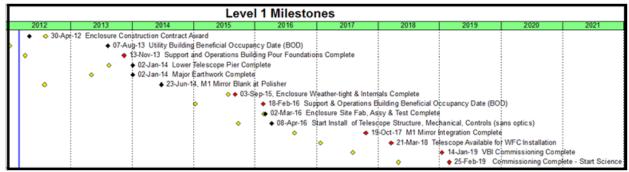


Figure D-1. Level 1 Milestones

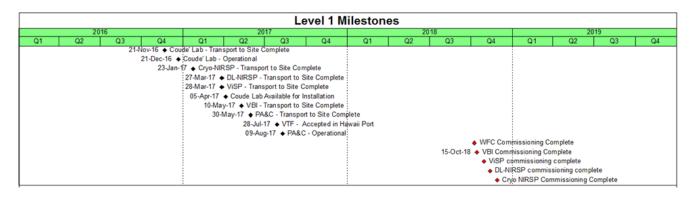


Figure D-2. Instrument Milestones

APPENDIX E: ATST MAJOR SUB-SYSTEMS

E.1 Support Facilities

A Professional Services Sub-award Contract was awarded to M3 Engineering and Technology Corporation on October 15, 2009 to perform Architectural and Engineering Services for the design development of the ATST Support Facilities. This work is now wrapping up. An early construction drawing and specification package—"Civil, Site Utilities, Foundations, & Utility Building"—was completed in August 2011. This early package covers all site construction through the installation of all major site infrastructures, the complete foundation system, and the erection of the Utility Building. The remaining construction drawings and specifications are on schedule to be delivered to the project in early 2012. This latter package will form the basis of RFPs used to bid the remaining support facilities site work, including above-ground pier, lower enclosure support structure, and the operations building. The following major milestones are expected to be achieved during the LRP period and beyond:

- 2011-Aug: Design of Civil, Site Utilities, Foundations and Utility Building
- 2012-Mar: Site Prep and Demolition complete.
- 2012-May: Power/Communications Corridor complete
- 2012-Sep: Roadways complete
- 2013-Mar: Foundations complete for Utility Building
- 2013-May: Utility Building Beneficial Occupancy Date
- 2013-Oct: S&O building foundations complete; lower telescope pier complete
- 2015-Dec: Support & Operations building Beneficial Occupancy Date
- 2016-Jan: Coating and Cleaning facilities available on site
- 2016-Mar: System interconnects for S&O/Mount installed; IT infrastructure complete

E.2: Optical Systems

The ATST is an off-axis all-reflecting Gregorian telescope. During 2010, the project made no changes to the optical design outside of the coudé lab but has continued to improve the design within the coudé lab. The primary mirror has been cast by Schott, Germany and will be shipped to the Optical Sciences Labs in Tucson Arizona in early 2012. Polishing to specifications of the 4m off-axis parabola will begin in 2012. The following major milestones are expected to be achieved during the LRP period and beyond:

- 2011-Oct: M1 Ceramization complete
- 2012-Apr: M1 Acceptance testing complete
- 2012-Oct: M1 Cell Assembly FDR
- 2013-Sep: M1 Polishing complete
- 2014-Feb: Delivery of M1 to site
- 2014-Oct: M1 Cell Assembly Acceptance testing complete
- 2014-Nov: Delivery of M1 Cell Assembly to site
- 2015-May: TEOA Acceptance testing complete
- 2015-Aug: Delivery of TEOA to site
- 2015-Dec: Delivery of Feed/Transfer optics to site

E.3 Telescope Mount Assembly (TMA)

The design-build contract for the Telescope Mount Assembly (TMA), which is under contract with Ingersoll Machine Tools (IMT) in Rockford, IL, is approaching Preliminary Design Review in Dec 2011. The past years work on the design with respect to meeting the TMA's demanding specification has yielded a design that leans heavily on IMT's experience in the world of large machine tools and their design subcontractor MT Mechatronics' experience in both optical and radio telescopes. The resulting TMA design is quite radically different from the original ATST reference design, but meets all interface and functional requirements, and should exceed the reference design's performance capabilities. On successful completion of the preliminary design, the detailed final design stage will process through to October 2012, at which point fabrication will commence. The following major milestones are expected to be achieved during the LRP period and beyond:

- 2011-Dec: TMA PDR
- 2012-Sep: TMA FDR
- 2013-Oct: TMA Fabrication complete
- 2014-Sep: TMA available for site assembly
- 2015-Oct: Coudé structure installation complete
- 2016-Aug: TMA Coudé acceptance testing complete
- 2017-Mar: TMA Mount installation complete

E.4 Enclosure

The design contract for the Enclosure is nearing completion. A successful Preliminary Design Review (PDR) was held in April 2011, and now the remaining design effort will conclude with a Final Design Review (FDR) in January 2012. The design contract with AEC Idom includes an option to fabricate and integrate the Enclosure. A decision to exercise these options will be determined in the near future pending final construction cost estimates. In anticipation of the Project exercising this option, AEC Idom has begun developing pools of bidders for the major work packages of fabrication, testing, shipping, and site integration and test. The following major milestones are expected to be achieved during the LRP period and beyond:

- 2012-Jan: Enclosure FDR
- 2013-Dec: Enclosure ready for site assembly and test
- 2014-May: Enclosure AZ track installation, assembly and test complete
- 2015-Dec: Enclosure site fabrication, assembly and test complete

E.5 Facility Thermal Systems (FTS)

Work on the thermal subsystems continues in three major areas. The first is the Facility Thermal System that is being designed under contract with AEC Idom. This work encompasses such things as the Enclosure plate coil cooling subsystem, passive and active ventilation systems, and air scavenging and dehumidification systems. The PDR for this work was successfully held in September and the completion of detailed construction documents is now in progress. The final design review is scheduled for June 2012.

The second major subsystem is the Coudé Environmental System, which is the equipment and controls required to maintain an environmentally controlled (i.e., "clean") laboratory space inside

the coudé lab (Figure 2). The design of this work is under contract with M3 Engineering along with the third major subsystem--the Facility Plant Equipment. This equipment encompasses such things as chillers, fluid coolers, ice storage tanks, and all the piping and pumps required to supply coolant to the support facility, enclosure, and telescope. The 70% complete construction documents passed a review milestone in early November. The 95% complete review point is scheduled for late January 2012. The following major milestones are expected to be achieved during the LRP period and beyond:

- 2011-Sep: Facility Thermal Systems PDR
- 2012-Jun: Facility Thermal Systems FDR
- 2013-May: Facility Thermal Systems Contractor Mobilization
- 2014-Oct: Facility Control System site assembly begins
- 2015-Mar: Facility Management Systems fabrication, site assembly and test complete
- 2015-Apr: Facility Control System site assembly and test complete
- 2015-May: Facility Plant Equipment systems fabrication, assembly and test complete
- 2016-Mar: Facility Thermal Sub-systems fabrication, assembly and test complete

E.6 Wavefront Correction (WFC)

The ATST wavefront correction system uses deformable and tip-tilt mirrors to improve the delivered image quality by compensating for image distortions introduced by the atmosphere and telescope optics. The system will enable diffraction limited imaging and spectroscopy. The ATST WFC must achieve high Strehl requirements at visible and infrared wavelengths called for in the Science Requirements Document. To do this, the ATST has several correctors and sensors for wavefront correction, including: 1) quasi-static alignment (QSA) for keeping the entire optical path—most importantly M1 and M2—aligned in closed-loop; 2) active optics (aO), which has the main function of keeping the figure of M1 within specifications, compensating for deformation due to gravitational and thermal distortions; 3) tip/tilt devices for image stabilization; and 4) high-order adaptive optics (HOAO) for correcting atmospheric and internal seeing and residual optical aberrations. The following major milestones are expected to be achieved during the LRP period and beyond:

- 2012-Mar: Evaluate WFS Prototype Camera
- 2012-Jun: WFC Fabrication Readiness Review
- 2014-Oct: Deformable Mirror Acceptance testing
- 2014-Dec: DM acceptance testing at NSO/SP
- 2015-Apr: Limb Tracker commissioning on site
- 2016-Feb: WFS camera, real-time system, DM and Tip/Tilt working in lab
- 2016-Aug: HOAO, aO, Context Viewer working in lab2013-Jan: HOAO Ship to site
- 2017-Jan: HOAO Ship to site
- 2018-Mar: aO align optics; test system operation; HOAO WFS testing complete
- 2018-Apr: Context Viewer testing complete

E.7 Software

The software team expanded to six people at the start of construction phase funding, with additional team members focused on the Instrument Control System (ICS), the Data Handling System (DHS), and the Virtual Camera Controller (VCC). The DHS, ICS, and Observatory Control System (OCS)

are under construction and beginning to meet the major requirements of their respective first releases, all due near the end of 2011 or beginning of 2012. The VCC has begun its design work in conjunction with the work on the camera requirements, hardware, and data handling.

The Telescope Control System is now under contract, along with the software development of the enclosure control system. This contract has a preliminary design review in October 2010. Contracts for the software control of the telescope mount assembly, M1 assembly, and Top End Optical Assembly are to be issued later in 2010.

The Common Services Framework has released its first construction-ready version. Team members are now supporting contractors and developers in its use through technical forums and on-site classes. Additional features are planned for the next formal release in June 2011. The following major milestones are expected to be achieved during the LRP period and beyond:

- 2011-Oct: Telescope Control System Simulator available
- 2013-Feb: Telescope Control System delivered
- 2014-Sep: Data Storage System testing complete
- 2015-May: OCS site acceptance testing complete
- 2016-Jan: ICS software delivered
- 2016-Feb: Camera Software delivered
- 2016-Apr: DHS data processing pipeline testing
- 2017-Jun; Global Interlock System installation and testing complete

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APPENDIX G: ACRONYM GLOSSARY

ADAPT	Air Force Data Assimilative Photospheric flux Transport
AFRL	Air Force Research Laboratory
AFWA	Air Force Weather Agency
AIA	Atmospheric Imaging Assembly (NASA)
APRPP	Annual Progress Report and Program Plan
aO	Active Optics
AO	Adaptive Optics
ARRA	American Recovery and Reinvestment Act
ATST	Advanced Technology Solar Telescope
AURA	Association of Universities for Research in Astronomy, Inc.
BBSO	Big Bear Solar Observatory
BLNR	Board of Land and Natural Resources (Hawai'i)
CDR	Conceptual Design Review
CDUA	Conservation District Use Application
CDUP	Conservation District Use Permit
CfAO	Center for Adaptive Optics
CMEs	Coronal Mass Ejections
CO	Chief Observer
CRC	Center for Research Computing (University of Colorado)
Cryo-NIRSP	Cryogenic Near-Infrared Spectropolarimeter
CSAC	Community Spectro-polarimetric Analysis Center (HAO)
CU	University of Colorado, Boulder
D&D	Design & Development
DHS	Data Handling System
DL-NIRSP	Diffraction-Limited Near-IR Spectro-Polarimeter
DLSP	Diffraction-Limited Spectro-Polarimeter
DM	Deformable Mirror
DoD	Department of Defense
DST	Dunn Solar Telescope
EAST	European Association for Solar Telescopes
EIS	Environmental Impact Statement
EPO	Educational and Public Outreach
ESF	Evans Solar Facility
EST	European Solar Telescope
FDP	Full-Disk Patrol (SOLIS)
FDR	Final Design Review
FIRS	Facility Infrared Spectropolarimeter
FOV	Field of View
FTE	Full Time Equivalent
FTS	Facility Thermal Systems (ATST)
FTS	Fourier Transform Spectrometer
FY	Fiscal Year
GB	Giga Bytes

GCM	Global Circulation Model
GONG	Global Oscillation Network Group
HAO	High Altitude Observatory
HO	Haleakalā High Altitude Observatory Site
HOAO	High-Order Adaptic Optics
HQ	Headquarters
HR	Human Resources
IBIS	Interferometric BIdimensional Spectrometer (Arcetri Observatory)
ICS	Instrument Control System
IfA	Institute for Astronomy (University of Hawai'i)
IR	Infrared
ISOON	Improved Solar Observing Optical Network
ISS	Integrated Sunlight Spectrometer (SOLIS)
IT&C	Integration, Testing, & Commissioning
KIS	Kiepenheuer Institut fuer Sonnenphysik (Germany)
KI3 KPVT	
	Kitt Peak Vacuum Telescope
LCROSS	Lunar Crater Observation and Sensing Satellite (NASA)
LRP	Long Range Plan
	Local Thermodynamic Equilibrium
LWS	Living With a Star (NASA)
McMP	McMath-Pierce Solar Telescope
MCAO	Multi-Conjugate Adaptive Optics
MHD	Magnetohydrodynamic
MREFC	Major Research Equipment Facilities Construction (NSF)
MRI	Major Research Instrumentation (NSF)
NAC	NSO Array Camera
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NHPA	National Historic Preservation Act
NISP	NSO Integrated Synoptic Program
NJIT	New Jersey Institute of Technology
NLTE	Non-Local Thermodynamic Equilibrium
NOAA	National Oceanic and Atmospheric Administration
NOAO	National Optical Astronomy Observatory
NSB	National Science Board (NSF)
NSF	National Science Foundation
NSF/AST	National Science Foundation, Division of Astronomical Sciences
NSO	National Solar Observatory
NSO/SP	National Solar Observatory Sacramento Peak
NSO/T	National Solar Observatory Tucson
NST	New Solar Telescope (NJIT)
NWNH	New Worlds, New Horizons in Astronomy & Astrophysics (NRC Committee Report)
PAARE	Partnerships in Astronomy & Astrophysics Research and Education (NSF)
OCD	Operations Concept Document
OCS	Observatory Controls
PDR	Preliminary Design Review
PSPT	Precision Solar Photometric Telescope

QSA	Quasi-Static Alignment
RA	Resident Astronomer
RET	Research Experiences for Teachers (NSF)
REU	Research Experiences for Undergraduates (NSF)
RISE/PSPT	Radiative Inputs from Sun to Earth/Precision Solar Photometric Telescope
ROB	Remote Operations Building
ROD	Record of Decision
ROSA	Rapid Oscillations in the Solar Atmosphere
SDO	Solar Dynamics Observatory (NASA)
SOC	Solar Observatory Council (AURA)
SOHO	Solar and Heliospheric Observatory
SOLIS	Synoptic Optical Long-term Investigations of the Sun
SONG	Stellar Oscillation Network Group
SORCE	Solar Radiation and Climate Experiment (NASA)
SPINOR	Spectro-Polarimeter for Infrared and Optical Regions
SRA	Summer Research Assistant
SRD	Science Requirements Document
SST	Swedish Solar Telescope
SWG	Science Working Group (ATST)
SWPC	Space Weather Prediction Center
STEM	Science Technology Engineering and Mathematics
STEREO	Solar TErrestrial RElations Observatory (NASA)
SWPC	Space Weather Prediction Center
TAC	Telescope Time Allocation Committee
ТВ	Tera Bytes
TCS	Telescope Control System
TEOA	Top End Optical Assembly
TMA	Telescope Mount Assembly
TRACE	Transition Region and Coronal Explorer
USAF	United States Air Force
VBI	Visible Broadband Imager (ATST)
VCC	Virtual Camera Controller
ViSP	Visible Spectro-Polarimeter (ATST)
VSM	Vector Spectromagnetograph (SOLIS)
VSO	Virtual Solar Observatory
VTF	Visible Tunable Filter (ATST)
WBS	Work Breakdown Structure
WFC	Wavefront Correction
WWW	World Wide Web