National Solar Observatory

Response to the
National Science Foundation, Division of Astronomical Sciences
Review of Senior Facilities

August 2005

TABLE OF CONTENTS

FOREWARD
EXECUTIVE SUMMARY **1**
1 Introduction **8**
2 Community Input **8**
3 Facilities — Support to the Community **10**
3.1 NSO/Sacramento Peak, Sunspot, NM **10**
3.1.1 The Richard B. Dunn Solar Telescope **10**
3.1.2 Evans Solar Facility **12**
3.1.3 Hilltop Solar Facility **13**
3.1.4 ISOON **14**
3.1.5 Instrument Program at Sacramento Peak **14**
3.1.6 Science Program at Sacramento Peak **14**
3.1.7 Education and Public Outreach and Workshops **14**
3.2 NSO/Kitt Peak, Tucson Arizona **15**
3.2.1 McMath-Pierce Solar Telescope **15**
3.2.2 SOLIS **17**
3.2.3 NSO/GONG, Tucson **18**
3.2.4 Science Program NSO/Tucson **19**
3.2.5 Instrument Program NSO/Tucson **20**
3.2.6 Education and Public Outreach NSO/Tucson **20**
3.3 Virtual Solar Observatory **20**
4 Metrics and Performance Goals **21**
4.1 Leadership in Solar Physics **22**
4.2 Service to the Solar Community **24**
4.3 Publications **25**
4.4 Education and Outreach **26**
4.5 Data Archives and Web Usage **28**
4.6 Telescope Usage Metrics **30**
5 Partnerships and the Solar Observing System **34**
5.1 Community Partnerships **34**
5.2 Synergy between Theory and Observations **35**
5.3 Synergy with Non-NSO Facilities **36**
5.4 Software Provided to the Community **37**
6 Costs **38**
6.1 Spending Breakdown by Location & Facility **39**
6.1.1 Sacramento Peak **39**
6.1.2 Tucson/Kitt Peak **41**
6.1.3 GONG **42**
6.2 NSO Relocation and ATST Operational Costs **43**
7 Conclusions **44**
APPENDIX A SCIENCE THEMES **45**
APPENDIX B DUNN SOLAR TELESCOPE **49**
APPENDIX C MCMATH-PIERCE SOLAR TELESCOPE **58**
APPENDIX D SOLIS **68**
APPENDIX E GONG **71**
APPENDIX F ATST **73**
APPENDIX G NSO STAFFING & STUDENT & TEACHER PROGRAMS
APPENDIX H COMMUNITY INPUT
APPENDIX I ACRONYM GLOSSARY

Foreword

Solar physics is entering a new period in which the coupling of advanced instruments and detailed modeling are challenging what we think we know about the Sun and solar processes that govern the interplanetary space and affect life on Earth. 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: What causes sunspots? Why does the Sun have a magnetic field? How does the Sun produce cycles of varying activity? How does the Sun produce violent explosions? Answers to these questions will help us understand and someday predict the influence of the Sun on Earth and space weather and the role of the Sun and its variability in the evolution of life in planetary systems.

Striking new data and images from space missions have given solar physics high public visibility and revealed a wealth of new phenomena and information about the complexity and dynamics of the corona and chromosphere. More often than not, detailed and flexible ground-based observations are what clarified processes and challenged theories. A recent international workshop on *Solar MHD: Theory and Observations* clearly revealed that precision spectral polarimetric observations provide the information on velocities and fields needed to compare with theoretical predictions. Examples presented at the workshop included theories for the structure of sunspots and models of magnetoconvection and its relationship to chromospheric structure. Measurements with the Advanced Stokes Polarimeter and the Diffraction-Limited Spectropolarimeter at the Dunn Solar Telescope reveal problems with MHD models for these phenomena. The ASP and DLSP show that chromospheric fields and heating mechanisms do not behave in the force-free manner that MHD models predict. McMath-Pierce Solar Telescope IR measurements of cool molecular clouds in the chromosphere are at odds with existing chromospheric heating models. When the much more powerful Advanced Technology Solar Telescope comes on line, it will help answer many of the unresolved questions and undoubtedly reveal even more difficulties with our models and theories of solar processes and challenge theorists and modelers to revise our understanding of the Sun.

The National Solar Observatory's current and planned suite of telescopes and instruments addresses the Sun as a global system, from interior through corona, and represents the entirety of ground-based facilities freely available to US astronomers on a competitive peer-reviewed basis. NSO facilities provide the only high-resolution, diffraction-limited spectropolarimeters; the only access to the thermal IR, and the only synoptic helioseismic, coronal emission line, and vector magnetic field data. NSO facilities also serve as test beds and development labs for instrumentation operated by other groups. Numerous examples are given in Section 3 and the individual telescope appendices.

Ground-based solar observers are a distinct, important minority of practicing solar astronomers. Their impact is high because of the powerful diagnostic observations that complex ground–based instruments can obtain, and because of the continuity of ground-based synoptic observations that let us understand the Sun as a variable star.

The solar community has worked with NSO to develop a forward-looking plan that will provide the assets needed to tackle unsolved questions governing the Sun’s behavior. The value of these assets will be maximized by synergistic operations with space and other ground-based instruments. Older facilities will be closed as their data are no longer needed and as newer ones are brought on line. This report to the Senior Review summarizes our roadmap, showing the evolutionary path to meeting the science requirements. The Executive Summary reviews the whole program, the main body addresses NSF questions concerning metrics and cost, and the appendices present science themes and the roles of our current and planned primary facilities in accomplishing those themes.

Executive Summary

The National Solar Observatory (NSO) has worked closely with the solar community to establish a road map for ground-based O/IR solar physics that is both evolutionary and revolutionary. The major goals of the NSO road map include:

- Solve the mysteries associated with the generation, structure and dynamics of the surface magnetic fields through the development of the next generation high-resolution facility: the Advanced Technology Solar Telescope (ATST) and the implementation of diffraction-limited imaging at its existing high-resolution telescopes;
- Understand the magnetic origins of solar variability through the enhancement of the NSO synoptic program to include full-disk and active region vector magnetograms at unprecedented precisions followed by extension into a three-station synoptic network (SOLIS);
- Map the interior dynamics of the Sun and linkages to solar variability by upgrading and operating the Global Oscillation Network Group (GONG) system so that high-spatial frequency oscillations can be observed in order to probe the nature of structures just below the solar surface as well as in the deep interior;
- Enhance community data mining through participation in the creation and operation of a Virtual Solar Observatory (VSO); and
- Enhance NSO's public and educational outreach programs through focused and effective work by its scientific and technical staff.

In parallel with the achievement of these principal goals, the NSO structure will evolve in order to consolidate its scientific staff at a single headquarters, ideally, on or near a university campus. In this way, the NSO staff can contribute locally to the academic program in solar physics while serving the research and educational goals of the broader scientific community through its forefront capabilities. The cost of this consolidation is discussed in Section 6.

The NSO plan to achieve these goals is in direct response to the community-wide National Research Council (NRC)/National Academy of Science Astronomy (NAS) and Astrophysics Survey Committee's decadal report entitled "Astronomy and Astrophysics in the New Millennium" (Decadal Survey). This report, which serves as a guidepost for the future in modern astrophysics, was preceded by the NAS/NRC Task Group on Ground-based Solar Research report "Ground-based Solar Research: An Assessment and Strategy For the Future" (Parker Report). The community goals for national ground-based facilities were specified in the Decadal Survey and/or Parker Report and assigned high priority. The subsequent NRC/NAS Solar and Space Science Decadal Survey strongly endorsed and expanded the justification for these new NSO facilities, programs and capabilities from the perspective of the solar-terrestrial and space physics community.

The solar community has charged the National Solar Observatory with the design and construction of the 4-meter Advanced Technology Solar Telescope. The ATST, with its 4-meter aperture, will have 2.5 times the spatial resolution and over six times the light gathering power of the next largest solar telescope for O/IR observations. Thus, the ATST will be uniquely capable of achieving the highest possible resolution for solar observations simultaneously in the spatial, spectral and temporal domains required to understand magnetic fields and address the solar science themes of the Decadal surveys (see Appendix F). The ATST will enable observational solar physics to cross the threshold into the parameter domain that defines current theoretical models that have now advanced beyond the limits of testing and verification by the solar telescopes of today.

Road Map — The Evolution of Solar Facilities

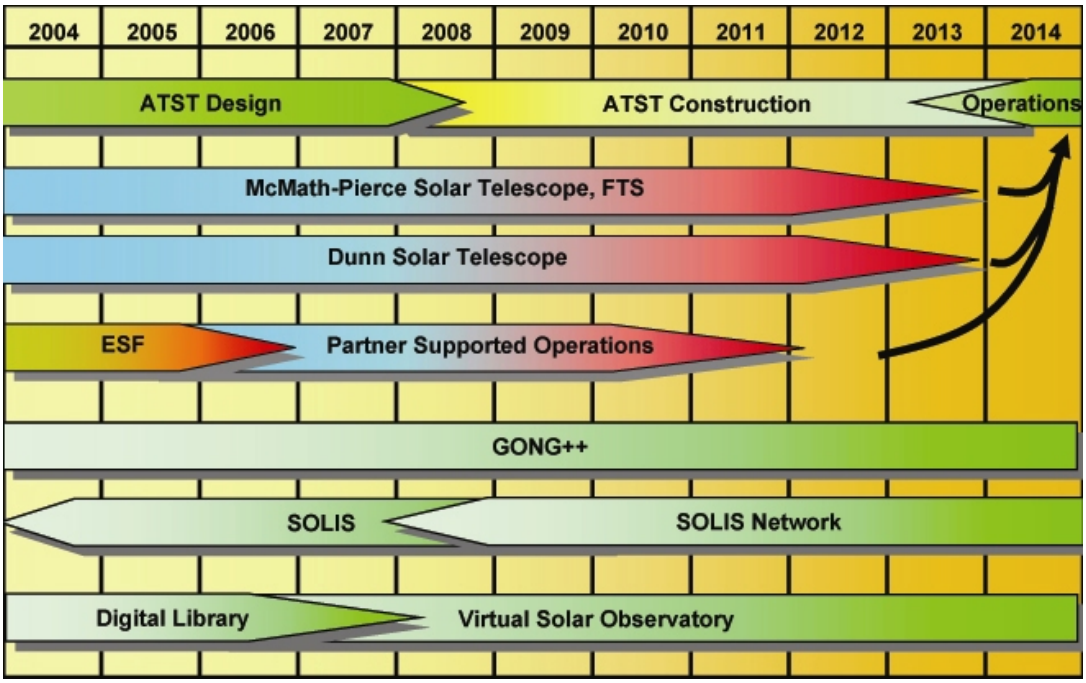


Figure 1. *Evolution of the NSO facilities showing the replacement of the Dunn Solar Telescope and the McMath-Pierce Solar Telescope by the ATST. NSO operational support of the Dunn Solar Telescope and the McMath-Pierce Solar Telescope will be reallocated to the ATST when it commences full operations.*

Figure 1 is a road map showing the planned evolution of NSO facilities. The National Solar Observatory Long-Range Plan calls for the phased reallocation of existing facilities support to our new capabilities as they become available. As illustrated in Figure 1, we have discontinued synoptic programs over the past few years at the Evans and Hilltop facilities at Sacramento Peak, and at the Vacuum Telescope on Kitt Peak, as the Synoptic Optical Long-term Investigations of the Sun (SOLIS) and the Improved Solar Observing Optical Network (ISOON), respectively, have commenced operations. The NSO Long-Range Plan clearly shows a phasing out of operations at both the Dunn Solar Telescope (DST) and the McMath-Pierce Solar Telescope (McMP) when the Advanced Technology Solar Telescope is completed and operational. This will generate a funding wedge for the support of ATST operations.

We illustrate in Figure 2 the fraction of the NSO base program dedicated to the support of initiatives specified in the Astronomy Decadal Survey and the Parker Committee report. Table 1 provides the actual funding used

Table 1. *NSF Funding for NSO Operations. The shaded area represents current programs that will be phased out as new assets come on line. The table does not include soft-money contracts and grants, the AURA fee, or funds received from NSF in direct support of the ATST design and development effort or ATST construction funds. The row labeled "ATST" contains the funds NSO has reprogrammed from its base to provide support to ATST development.*

Fiscal Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Director	354	363	374	385	397	409	421	434	447	460
Tucson	1,988	2,008	2,059	2,071	2,083	2,145	2,210	2,276	1,172	
Sac Peak	1,876	1,887	1,976	1,985	2,045	2,106	2,170	2,235	1,151	
GONG	137									
GONG+/++	2,595	2,701	2,767	2,850	2,936	3,024	3,115	3,208	3,304	3,404
SOLIS	313	322	532	591	616	700	750	773	796	820
ATST	657	701	997	1,130	1,214	1,250	1,288	1,327	3,689	6,193
Total	7,920	7,982	8,705	9,012	9,291	9,635	9,953	10,252	10,559	10,876

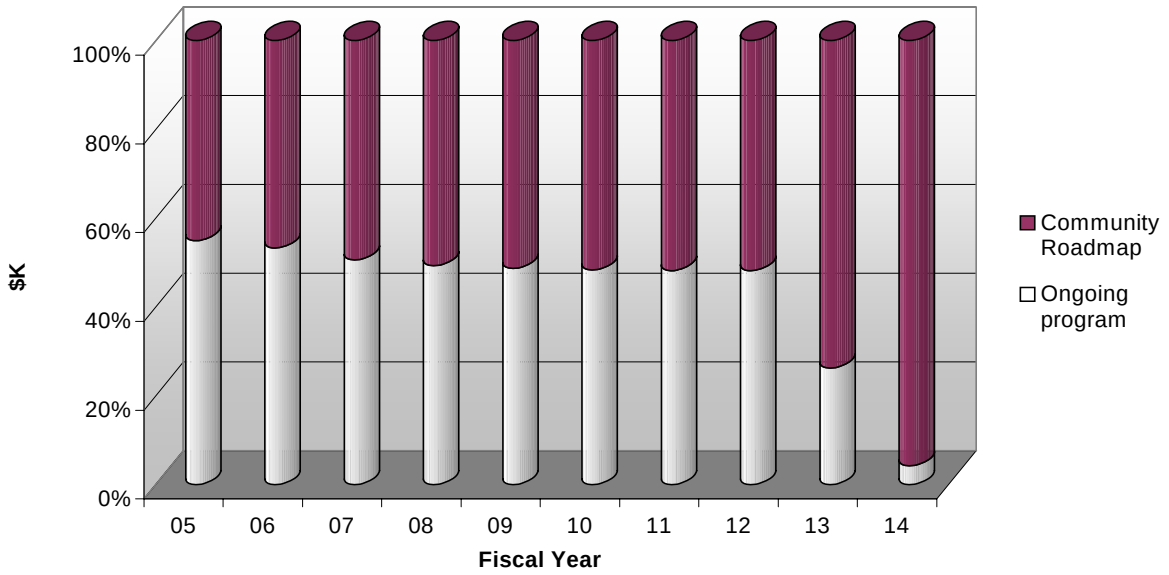


Figure 2. *Fraction of NSO base budget supporting the priorities of the community road maps laid out in the Decadal Surveys (ATST, SOLIS Network) and Parker Committee reports (ATST, GONG++ and SOLIS) for ground-based solar physics are shown. The graph only includes NSF base support to the NSO program. It does not include the ATST D&D, ATST construction, partner, contract or grant funding. It assumes 3% inflation growth in the out years and assumes those funds supporting the DST and McMP transfer to ATST. This would provide about $6M for ATST operations. In the ATST construction proposal, the total ATST operational cost is estimated at about $10M-$12M.*

to generate Figure 2. As seen in Figure 2, the NSO has reprogrammed a considerable fraction of its resources in order to implement its long-range plan and achieve the goals of ground-based, O/IR solar physics as specified through community road mapping efforts in the Parker report and Astronomy and Solar and Space Physics Decadal Surveys. The NSO's inclusive approach to its long-range plan involved organizing and leading a consortium of 22 institutions and universities to produce a Design and Development Proposal for the ATST. Efforts at existing facilities are approved on the basis of how well they will support the transition to the new facilities. As these new capabilities become operational, the replaced facilities are closed or transitioned to non-NSF Astronomy Division funding sources. In the meantime, the NSO will continue to serve the scientific goals of the solar community at its major solar telescope facilities in a manner that is consistent with the scientific and development goals for the ATST.

In brief summary, the NSO, in partnership and in consultation with the solar community, continues to make substantial progress in the execution of its road map (Fig. 1). The goal of ultimately providing unrivaled high-resolution and coronal observing capabilities with the ATST has progressed rapidly The Construction Proposal for the ATST, which was based on a thorough Design & Development Study, received outstanding reviews and now only awaits approval at the Major Research Equipment Facilities Construction (MREFC) level at the NSF. The NSO's implementation of state-of-the-art synoptic facilities through SOLIS and the GONG++ network is nearly complete. Calibration of SOLIS full-disk vector magnetograms is also approaching completion and they should become available via the Web through the NSO Digital Library and the Virtual Solar Observatory by the fall of 2005. Cross calibration between the older Sun-as-a-star spectral line surveys and the SOLIS Integrated Sunlight Spectrometer (ISS) will be performed over the next several months, allowing for the integration of the old and new data. This will yield a continuous record of cycle variations in the Sun seen as a star. GONG near-real-time data links and data pipeline are near completion, and the preliminary data are available at the GONG Web site or via the NSO Digital Library and the VSO. Adaptive optics systems have been installed and commissioned for general use at the major solar telescope facilities of the NSO. Advanced instrumentation for ultra-high precision polarimetry at the diffraction limit of

its telescopes in the visible and the infrared is in the implementation stage as are needed upgrades of the obsolete telescope control systems.

Bridges to the ATST: The Solar Telescopes of the NSO

Solar observing programs often differ from their nighttime counterparts. The need to obtain a unique data set to further our understanding of solar processes drives complex and flexible instrumental setups at solar telescopes. This in turn requires heavy involvement of the user in customized instrument definition and layout. Successfully obtaining data often requires strong support from the in-house science staff and thus many observing runs are collaborations between visiting and staff scientists. Most solar observing programs desire to study the evolution and structure of solar magnetic fields and dynamics over several days. Observing time on NSO telescopes is normally allocated in blocks of 10-14 days. New and scientifically interesting discoveries are mostly achieved by looking at the Sun in different ways than before, either in previously inaccessible wavelengths at higher spatial, spectral and temporal resolution, or in particular, by finding different combinations of wavelengths to probe different layers in the solar atmosphere simultaneously. For these reasons few solar telescopes have standard observing programs with fixed instrument configurations. Instead, solar observing is very much a hands-on experience, where the observer is heavily involved in a specialized and individual instrument setup, and where specific targets on the solar disk are selected on the basis of opportunity.

Exceptions are solar synoptic programs, which typically utilize fixed instrumentation to perform daily observations of the whole solar disk in order to establish a well-calibrated long-term database.

The ***Richard B. Dunn Solar Telescope*** is the premier US high-resolution facility and the world's best-instrumented telescope for diffraction-limited polarimetry. With the development of high-order adaptive optics (AO) systems at Sac Peak the DST is now a diffraction-limited solar telescope, which has greatly increased user demand and enhanced its scientific output. It has two identical AO systems, well matched to the seeing conditions at the DST, which feed two different instrument ports. These ports accommodate a variety of facility-class instrumentation, such as the Diffraction-Limited Spectro-Polarimeter (DLSP) that just came online, and the new Spectropolarimeter for Infrared and Optical Regions (SPINOR), as well as experimental setups and visitor instruments such as the Italian Interferometric BI-dimensional Spectrometer (IBIS). This has made the DST the most powerful facility available in terms of post-focus instrumentation. It supports observations that will drive ATST high-resolution requirements at visible and near-infrared wavelengths, and refine ATST science goals. The DST also supports the development of future technologies such as multi-conjugate AO (MCAO). The first successful on-sky MCAO experiment was recently performed at the DST. The DST supports the US and international high-resolution and polarimetry communities and is often used in collaboration with space missions to develop global pictures of magnetic field evolution. While competing European telescopes have emerged, they have not supplanted the need for the DST. Indeed, many Europeans still compete for time on the DST and provide instruments such as IBIS (Italy) and ROSA (high-speed camera for Rapid Observations of the Solar Atmosphere (Ireland)) that are available to all users. The 1-meter Swedish Solar Telescope (SST) is providing high-resolution imaging and polarimetry with a geographic separation of seven hours from the DST. The geographic separation enables collaborations that extend our ability to follow magnetic evolution over longer periods, substantially enhancing the probability of observing the build-up and triggering of solar activity events. The SST is operated over a limited observing season and time must be purchased. Currently it is fully utilized by various European and US groups that can pay for time and/or contribute instruments. The ready access and support available at the DST is not available at these European facilities. The DST will continue to play the major role in supporting US high-resolution spectro-polarimetry and the development of instruments needed for progress in this important field, and these instruments will serve as prototypes for ATST instrumentation. The road map calls for divesting NSO of the DST when the ATST is completed and operational.

The ***McMath-Pierce Solar Telescope*** is currently the largest optical solar telescope in the world, with a diameter of 1.6-m. It is primarily used for IR and thermal IR observations, where it is much easier to compensate for seeing. It also houses the Fourier Transform Spectrometer (FTS). Its reflective optics enable observations over a wide range of wavelengths without obstruction by refractive elements. Thus, it is uniquely

capable of panchromatic, flux-limiting studies of the Sun. In particular, it is the only solar telescope in the world on which investigations in the relatively unexplored infrared domain beyond 2.5 microns are routinely accomplished. The East and West Auxiliary telescopes are among the largest solar telescopes (both with 0.9-m diameter and 0.8-m clear aperture) and share the same all-reflective, unobstructed design of the main telescope. This unique telescope, equipped with a superb high-resolution grating spectrograph and the world's finest Fourier Transform Spectrometer, has recently had an adaptive optics system incorporated into the optical path. With the new AO system coupled with the InSb-based detector of the NSO Array Camera (NAC) for ultra-high precision polarimetry in the infrared at the diffraction limit, and the completion in 2006 of the first Advanced Image Slicer (AIS) Integral Field Unit (IFU) for a solar telescope, the McMath-Pierce will likely produce the best mid-infrared solar observations ever achieved. The NAC system is also planned to be a bridge to the ATST near-infrared instrumentation. The NAC dewar is flexible with plenty of internal space available, and can accommodate upgrades for use with the ATST first-light instrumentation. The ATST will also require IFUs for its suite of instruments. Thus, this effort is the first step in developing IFUs for the ATST.

Because of its utility at longer wavelengths, the McMath-Pierce solar telescope is fully complementary to the Dunn Solar Telescope and currently without counterpart in the world. The German Gregor solar telescope and the New Jersey Institute of Technology (NJIT) New Solar Telescope (NST) will be of similar aperture. Both will be located at excellent sites, the Gregor on Tenerife in the Canaries and the NST at Big Bear Solar Observatory in California. The start date for the Gregor is uncertain, pending the resolution of issues involving the production of its unique silicon-carbide mirror. The NST will be used primarily for space weather and dedicated support of the Solar Dynamics Observatory (SDO) and other space missions. At this time it is not yet know how much public access there will be, although NJIT plans to make their data public. NSO has contributed to both telescopes through the cooperative development of adaptive optics systems and will continue discussing US public access with their developers.

Our Variable Sun: The Synoptic Facilities of the NSO

The one constant feature of the Sun is that it's not constant! As a national center, the NSO provides the continuity and stability of operation required to provide the scientific community with advanced observations of solar variability at unparalleled quality over solar-cycle time scales. These crucial data serve the missions and objectives of a variety of national priorities, extending from the study of fundamental processes in astrophysical plasmas to space weather and astronaut safety.

The new ***SOLIS (Synoptic Optical Long-term Investigations of the Sun)*** suite of instruments is now yielding daily, full-disk observations at unprecedented sensitivities of heretofore-unseen patterns of magnetic fields on the Sun. SOLIS was installed inside the existing structure of the Kitt Peak Vacuum Tower Telescope (KPVT), thus replacing the KPVT and launching the new era for the "KPST" (Kitt Peak SOLIS Tower). The synoptic magnetograms acquired by the KPVT since 1973, which continue to play a major role in studies of solar magnetic activity, will now be extended by SOLIS with its much higher sensitivity. In addition to continuing the synoptic magnetograms observed by the KPVT, SOLIS also provides full-disk and active region vector magnetograms. Once these data are calibrated and released on a regular basis, they will revolutionize our ability to model chromospheric and coronal fields and contribute to the advancement of our understanding of the dynamics of magnetic fields on the Sun.

The Decadal Survey assigned its primary recommendation for a small-size, ground-based facility to an expansion of SOLIS to a three-site network to enable nearly continuous full-disk vector magnetic field observation. This recommendation is included in the main report under small initiatives. Once the SOLIS Vector Spectromagnetograph (VSM) is routinely producing full-disk vector magnetograms, the NSO plans to lead the development of a proposal for a SOLIS/VSM network in collaboration with international partners.

The NSO ***Global Oscillation Network Group*** explores the rapidly-varying solar interior in order to understand i) the astrophysical phenomena in the solar and stellar contexts; ii) the role of interior structures and flows in the creation of solar and stellar surface magnetic activity; and iii) how these structures and flows give rise to "space weather." GONG observations revealed that the resonant mode frequencies varied with the solar magnetic activity cycle, and that these variations reflected real structural changes of the solar interior, which

are related to the origin of solar magnetic fields. In addition to global, resonant-mode seismology of the Sun as a whole, running-wave seismology with spatial resolution of a few degrees and temporal resolution of a day or less became possible, enabling the study of significant time-varying structures. This discovery gave rise to a new requirement from the solar physics community to study these structures for a full magnetic solar cycle of 22 years. Furthermore, it was recommended that magnetograms be obtained continuously at the same cadence as the velocity images, i.e., once per minute. The high temporal resolution of the localized, line-of-sight GONG magnetograms complement the very high quality, full-disk SOLIS vector magnetograms that are obtained at a lower cadence.

This new program of continuous, local helioseismology in conjunction with the acquisition of magnetograms began routine operations in 2001. Near-real-time acquisition of the data from the GONG stations via the Internet is available, which has already enabled provision of images of the farside of the Sun for predictive purposes, and which soon will make all of the scientific products available with little or no delay. GONG continues to work closely with the SOHO helioseismology experiments, and with the forthcoming SDO/HMI.

The ***Evans Solar Facility*** (ESF) on Sacramento Peak houses a 48-cm coronagraph and a 10-inch coelostat. Due to funding pressures, NSO terminated most of its support for this telescope in 2002. Three positions were abolished. The US Air Force group at Sac Peak relies on the ESF for studying coronal heating and variability and therefore provides funds for a part-time observer and some maintenance efforts. The AF group requires only a half-day of ESF time, so the telescope is available to other users, but only if they provide their own support. Currently the High Altitude Observatory (HAO) is planning to develop a corona magnetometer using the ESF. The NSO chromospheric monitoring program, which takes about one hour, three times per week, will continue until approximately six months of overlap is obtained with the SOLIS Integrated Sunlight Spectrometer, at which point chromospheric monitoring with the ESF will terminate. Existing NSO staff currently support this program part-time.

The ***Hilltop Solar Facility*** houses a sunspot drawing telescope, an H-alpha and white-light flare patrol, and a full-disk coronal telescope, the Coronal One-Shot (COS). The Hilltop also contains offices and an optical laboratory used for developing filter systems. The USAF Improved Solar Observing Optical Network (ISOON) telescope has supplanted the flare patrol, and the COS has been modified and is now operated by HAO. The ESF observers operated the Hilltop for many years. When NSO abolished the ESF positions, the DST observers operated the flare patrol until ISOON came online. The Hilltop still provides a live H-alpha image used for target selection at the DST, but maintenance efforts have been reduced to a bare minimum.

Digital Library and the Virtual Solar Observatory

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

In order to leverage further the substantial national investment in solar physics, NSO is participating in the development of a Virtual Solar Observatory, the European Grid of Solar Observations (EGSO), and the Collaborative Sun-Earth Connection (CoSEC). The solar physics community is actively involved in the planning and management of the VSO. Although most of the funding for the VSO has thus far been provided through NASA proposals, NSO is making a substantial in-house contribution of manpower.

Educational Outreach

Figure 3. *Summer students and teachers visiting SOLIS.*

Because of its accessibility to the public and to students of all grades, the Sun provides an ideal context for conveying many of the concepts in astronomy to a broad audience. NSO's outreach program has been an extremely effective tool for sharing the excitement of solar physics with the general public and recruiting the current generation of solar astronomers. The NSO is committed to increasing its role in outreach programs at all levels. Current programs include participation in Project ASTRO, the Southwest Consortium of Observatories for Public Education (SCOPE), the NSF Research Experiences for Undergraduates (REU), Research Experiences for Teachers (RET), and Research-Based Science Education (RBSE) programs, as well as local challenge programs, science fairs, and career days. NSO also operates a Visitor Center with many hands-on exhibits, and maintains a Web site with a solar tutorial, Web-based experiments that K-12 students can perform using the NSO on-line Digital Library and development of classroom activities and materials. In addition, NSO has a long tradition of training graduate students and postdoctoral fellows in both solar physics and instrumentation. Many of today's practicing solar astronomers and leaders have participated in NSO student programs. We will continue and strengthen these programs as recommended in the Decadal Survey.

Productivity

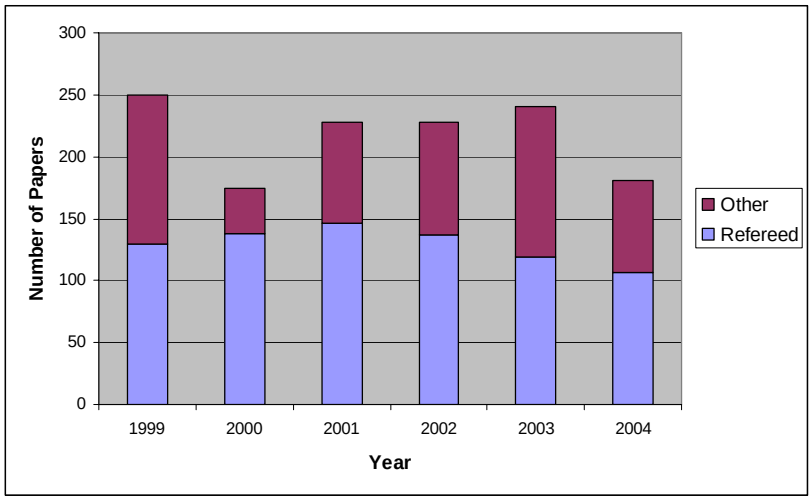


Figure 4. *Total NSO papers divided into refereed and conference proceedings. See Section 4 for detailed break down of publications by facility.*

The scientific productivity of NSO facilities continues to be a major contributor to solar research at a very reasonable cost. However, because NSO distributes data through many outlets, we are unable to track all uses of our data. The NSO annual reports summarize staff and visitor publications that we were able to track based on NSO observations and data, which average approximately 217 per year. Figure 4 shows the distribution from 1999-2004. This gives a cost per paper of about $37K based on the NSO operational budget of ~$8M/year. For comparison, the Swedish Solar Telescope program costs approximately $90K/paper. A survey of papers published in the *Astrophysical Journal* in 2003 show that 39% of solar ground-based (optical + radio) papers contained therein are based on NSO data. This number rose to about 45% in the first 5 months of 2004. A similar survey of *Solar Physics* shows that 25% of the papers based on ground-based data in 2003 are based on NSO data. Papers based on more than one data source were split by estimating the fraction of data from each source.

1 Introduction

The Sun exhibits many enigmatic phenomena that defy explanation. Research in solar physics is a critical part of our 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. The interplay of these aspects of physics creates an astounding 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 in the search for new planetary systems that may be the sites for life in the universe.

The National Solar Observatory operates telescopes and instruments on behalf of and often in collaboration with the US and International solar communities. The NSO science staff supports these functions and also conducts cutting-edge scientific research both independently and in collaboration with members of the community. Staff research ensures that NSO scientists are strongly vested in the quality of both the telescopes and the instruments. Major scientific thrusts supported by NSO facilities and research include understanding the interior structure and dynamics of the Sun, solar magnetic variability that leads to solar activity and irradiance variations, and the Sun-as-a-star capable of supporting life and impacting the terrestrial and space environments. These thrusts lead to the science programs described in Appendix A.

NSO currently operates telescopes at Sacramento Peak in Sunspot, New Mexico, on Kitt Peak near Tucson, Arizona, and it operates a network of solar oscillation telescopes at six sites around the world—the Big Bear Solar Observatory (BBSO) in California, the High Altitude Observatory at Mauna Loa in Hawaii, the Learmonth Solar Observatory in Western Australia, the Udaipur Solar Observatory in India, the Observatorio del Teide in the Canary Islands, Spain, and the Cerro Tololo Inter-American Observatory in Chile. The network provides 24-hour coverage of solar oscillations and magnetic fields. NSO operations of the Richard B. Dunn Solar Telescope on Sacramento Peak and the McMath-Pierce Solar Telescope on Kitt Peak support high-resolution studies of solar magnetism in the visible and infrared, the GONG telescopes support studies of the solar interior, and the SOLIS telescopes support studies of magnetic field evolution and space-weather studies. The Evans Solar Facility and Hilltop Facility on Sacramento Peak support studies of coronal heating and magnetism.

NSO staff members are located in Sunspot, NM and Tucson, AZ. The director currently resides in Sunspot and spends time at both sites. A deputy director resides in Tucson and is responsible for Tucson operations. This split provides effective support for NSO operations in the most cost effective manner. When the Advanced Technology Solar Telescope begins operations, NSO will divest itself of both the Dunn Solar Telescope and the McMath Pierce Solar Telescope either through finding other groups interested in assuming operations, or through closure. Telescope closure costs are estimated in Section 6.

NSO receives its primary funding from the National Science Foundation. The Air Force solar research group is collocated with NSO at Sunspot and they provide funding that helps support operations of Sacramento Peak. Grants from NASA, as well as NSF/Chemistry, help support operations on Kitt Peak and development of a Virtual Solar Observatory.

2 Community Input

National, community-wide study groups have compiled key goals for solar physics in recent years as well as outline a community vision for the NSO. The most recent ground-based perspective is found in the 1999 NAS/NRC report on "Ground-Based Solar Research: An Assessment and Strategy for the Future," often referred to as the Parker report. NSF and NASA have had the NRC and the Space Studies Board convene the Astronomy and Astrophysics Survey Committee (AASC) at the beginning of each decade to determine the most important directions for astrophysical research during the next decade (Decadal Survey). The 2001 NRC Decadal Survey and its associated panel report on solar astronomy have outlined the major questions to be

addressed by observations and modelers. More recently, NSF and NASA commissioned the Solar and Space Physics Survey Committee to assess solar and space physics. Their report, "The Sun to the Earth – and Beyond: A Decadal Research Strategy in Solar and Space Physics brings the perspective of another community to bear on the need for solar observations.

The NSO long-range plan was developed to meet the needs of the solar community as represented in the Astronomy Decadal Survey, the NSF/NRC Parker report, the Solar and Space Sciences Decadal Survey and the NSO users. The primary recommendations to NSF (and to NSO) coming out of the public hearings and deliberations of the Parker committee included: complete the fabrication of SOLIS and provide funding for data analyses; upgrade GONG to a 1024 × 1024 camera system and operate over a whole solar activity cycle (GONG++) while provide funding for data analysis in the U.S.; and begin development of a 3-4 meter advanced solar telescope. The latter recommendation included strengthening the NSO adaptive optics program, demonstrating AO on meter-class telescopes, designing the advanced solar telescope and conducting a thorough site testing program. With NSF support and redirection of its base funding, NSO has responded to all of these recommendations. In collaboration with the New Jersey Institute of Technology and the Kiepenheuer Institute for Solar Physics, NSO developed an MRI proposal and obtained funding for adaptive optics. NSO also devoted a large fraction of its internal budget to AO. Two of the SOLIS instruments are on line and the final instrument will go on line this fall. The GONG++ system became fully operational in 2003. Concepts for an advanced solar telescope were developed and NSO devoted part of its internal funding to building instrumentation for site testing.

The primary Astronomy Decadal survey recommendations for solar were to construct the Advanced Technology Solar Telescope and to extend SOLIS into a three-station network. These recommendations followed several public meetings of the solar panel and main body of the committee to gather public inputs. NSO has responded by submitting the ATST construction proposal and seeking both national and international partners to help fund it. NSO fielded a suite of site testing instruments in collaboration with the University of Hawaii and the High Altitude Observatory, and conducted a community wide site testing campaign. Based on the success of the initial SOLIS instruments, NSO will develop a proposal and seek partners to help develop a SOLIS network.

The Solar and Space Physics Decadal Survey, while not directly advising NSF/Astronomy, made several recommendations for NSO's input into the Sun-Earth system. They see the ATST as a prerequisite to the solar and heliospheric panels' recommendations for new programs. They state that "… Overlapping investigations by the Solar Dynamics Observatory, the Advanced Technology Solar Telescope and the Magnetospheric MultiScale (MMS), together with the start of the Frequency Agile Solar Radio array (FASR) will form the intellectual basis for a comprehensive study of magnetic reconnection in the dense plasma of the solar atmospheric and the tenuous plasma of geospace." They also emphasize the importance of existing NSO facilities to four of their five research themes.

To further vet its plans with the community, NSO presents its long-range plan to the Solar Physics Division of the AAS at their annual business meeting, opening it for discussion. These meetings have shown strong endorsement of the NSO future plans as well as the need to continue operating the current flagship facilities in a manner that insures a smooth transition into the future.

The NSO Users' Committee consists of 9-10 community representatives who meet two-to-three times per year to discuss NSO's current operations and plans for future facilities. NSO responds to their inputs, which include the observational and instrumentation needs they express on behalf of the community. The AURA Board, through its Solar Observatory Council (SOC), reviews NSO long-range and program plans to ensure that the plans are well managed and are addressing the fundamental science requirements of the solar community and the nation. The Board and SOC track the NSO's progress in fulfilling the plans laid out in the Decadal Surveys.

NSO has science working groups and science advisory committees for the various programs and projects that it conducts. Examples include the ATST Advisory Committee, the ATST Science Working Group, the ATST Site Survey Working Group, the GONG Science Advisory Committee, the GONG Data Users'

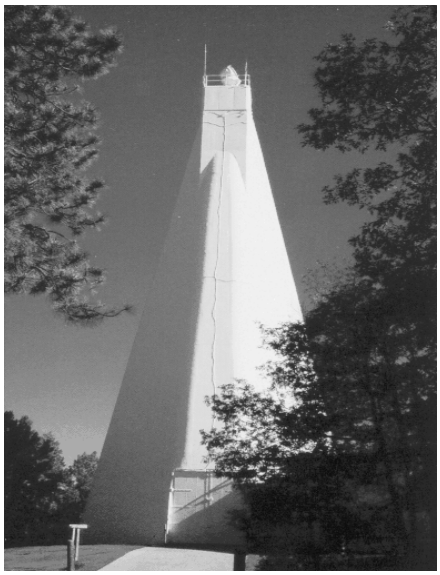
Committee, the GONG Magnetogram Users' Group, and the SOLIS Science Advisory Group. Inputs from these groups are included in our response to the Senior Review.

3 Facilities — Support to the Community

This section provides a list and separate description of each NSO facility. Progress in solar physics, however, requires the Sun to be studied as a global system, thus the various facilities need to work in concert, each providing a unique aspect of the solar process that can be fit into a comprehensive view of the Sun. NSO and visiting scientists often collaborate with facilities at the other sites to obtain a comprehensive view of the solar phenomena under investigation. Additionally, users of NSO facilities collaborate with other ground assets and space missions to extend both temporal and spectral coverage of solar phenomena.

3.1 NSO/Sacramento Peak, Sunspot, NM

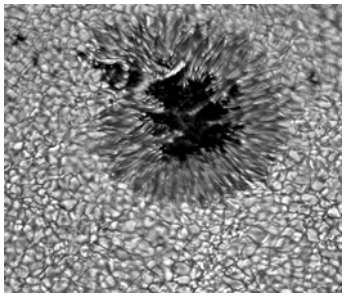
Program Components at NSO/SP



- Richard B. Dunn Solar Telescope (DST)
- Evans Solar Facility (ESF) and Hilltop Facility
- Science Program
- Instrument Program
- Education and Outreach Program, Visitor Center
- Annual NSO/SP Workshops
- Support Functions

3.1.1 The Richard B. Dunn Solar Telescope

The 76-cm Dunn Solar Telescope on Sacramento Peak is optimized for high-resolution imaging. It is the major US high-resolution and polarimetric facility. With the advent of adaptive optics correction, it is again the world's premier high-resolution solar telescope because of its wealth of focal plane instrumentation. The DST, which sits at an altitude of 2804 meters, is an evacuated tower telescope with a 76 cm entrance window. The evacuated light path eliminates internal telescope seeing. The image enhancement program over the past few years has included: active control of the temperature of the entrance window to minimize image distortion; high speed correlation trackers to remove image motion and jitter; and most recently two high-order adaptive optics systems that provide diffraction-limited seeing under moderate to poor conditions and deliver images to several optical benches housing both fixed and modifiable instruments. Recent science results using the Dunn Solar facility include:



- Locations where the *p*-modes are excited by strong downflows
- Reconnection and submergence of magnetic flux in the photosphere
- Observations of magnetic reconnection signatures in the chromosphere
- Sub-arcsecond convective motions inside magnetic pores and sunspots
- The existence of weak granular fields
- H-alpha fine structure in solar flares (0.2")
- Vector magnetic maps of prominences

3.1.1.1 DST Instruments

Adaptive Optics

- Two high-order systems, each with its own wave front sensor and 97 actuators
- Corrects 74 degrees of freedom
- Produces diffraction-limited images in fair to good seeing conditions

Precision Measurements of Solar Magnetic Fields
- Advanced Stokes Polarimeter (ASP)
- Diffraction-Limited Spectro-Polarimeter (DLSP)

Narrowband Tunable Filters
- Universal Birefringent Filter (UBF) 0.3 – 2.2 μm
- Dual etalon, near-IR tunable filter 1.0-1.7 μm
- Interferometric BI-dimensional Spectrometer (IBIS)

Near-Infrared
- 128 × 128 video CCD 1-2.5 μm
- 256 × 256 array, 1-5 μm
- High-resolution spectroscopy
- Full vector polarimetry capabilities

High-Resolution Spectrographs
- Vertical Echelle Spectrograph
- Horizontal Spectrograph
- Solar spectroscopy from 0.3 to 2.2 μm

Multiple CCD Cameras
- Simultaneous imaging at several wavelengths
- Simultaneous spectroscopy and imaging

3.1.1.2 DST Scientific Usage

Examples of the type of research that are best supported by the DST include:
- Magneto-convection, flux tube formation
- Sunspot and magnetic pore structure and evolution
- Stokes polarimetry of surface features
- Causes of filament eruptions and CME triggers
- Origins of solar flares

Examples of research programs carried out with the NSO telescopes are given in Appendix A. Specific DST science programs are presented in Appendix B. Having adaptive optics systems that can now regularly deliver diffraction-limited images over extended periods to a suite of instruments designed to take full advantage of the full resolution of the DST is increasing the demand for time. They have opened up discovery space not just in the spatial domain, but also in the temporal and polarimetric domains. Temporal sequences at the diffraction limit are helping to unravel the interaction between flows and magnetic field. AO makes longer exposures possible, hence more photons and better sensitivity available for accurate measurements of field strengths, locations and evolution. Figure 3-1 plots the changes in the DST subscription rate. The increased demand (time requested/time available) beginning in 2003 is primarily due to the discovery space opened by AO.

When the DLSP is officially released to the user community and the Spectro-Polarimeter for Infrared and Optical Regions (SPINOR) is on line, we expect to see the demand increase again.

3.1.1.3 DST Future Plans

- Spectro-Polarimeter for Infrared and Optical Regions (SPINOR)
- Queue observing mode to enhance coordination with Solar-B and Solar Dynamics Observatory (SDO) and take advantage of fixed diffraction-limited polarimetric systems
- Upgraded control system
- Joint NSO/University of Hawaii IR camera and spectrograph
- Closure or divestment when ATST is commissioned

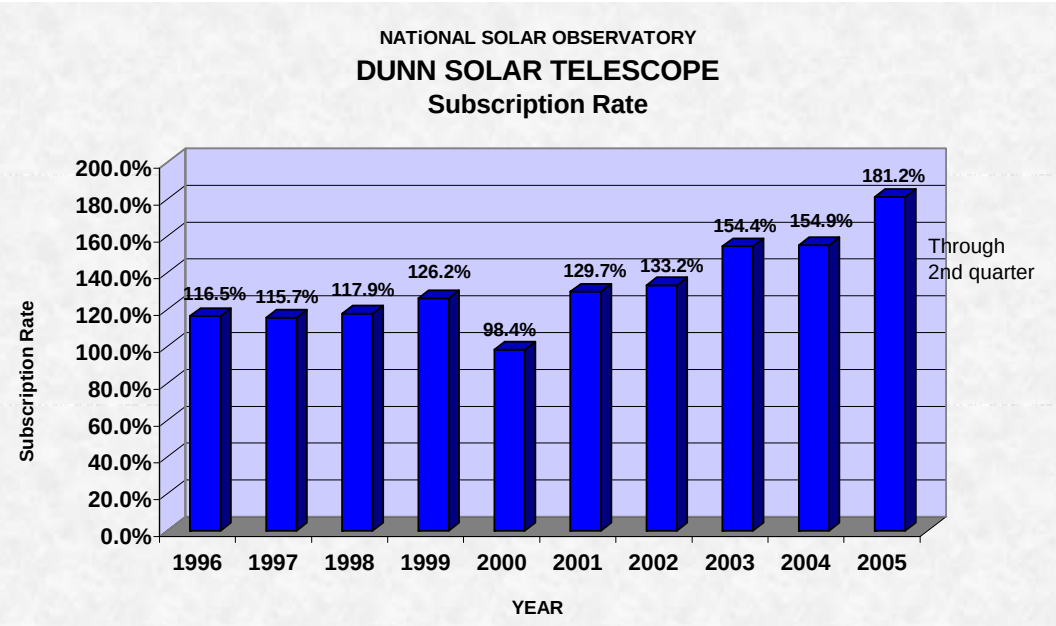


Figure 3-1. *Subscription rate is computed by dividing the number of hours requested vs. the number of hours available in a year.*

3.1.1.4 DST Cost of Operation

The DST currently has three full-time observers who set up experiments, operate the telescope, ensure proper collection of data and participate in the telescope maintenance. Maintenance of the DST and its instrumentation draws from NSO technical staff and facilities staff. The technical staff, comprising 11 FTEs, also supports the development of new instrumentation. While it is somewhat flexible depending on need, approximately 4 FTEs are devoted to DST maintenance and the rest to instrumentation. The facilities staff has five craftsmen with various skills. Over the course of a year the DST uses 1.5 FTEs. By assigning part of the utilities and site costs to the DST, we estimate the annual operating budget to be $958K.

3.1.2 Evans Solar Facility

The Evans Solar Facility provides a 40-cm coronagraph as well as a 30-cm coelostat. It is still the best-instrumented coronagraph in the world. Recent experiments include a visible and IR coronal polarimeter, which has produced tantalizing observations of coronal magnetic fields and inspired considerable effort in this area including the University of Hawaii Solar-C experiment and the HAO upgrade of the Coronal One-Shot telescope in the Hilltop Facilty. Examples of some science results based on ESF data include:

- Limits on electric fields in the solar atmosphere
- Rush to the poles in the density of coronal emissions
- Extended solar cycle in coronal emissions
- Demonstration of coronal polarimetry
- The viability of measuring stellar differential rotation
- Limitation on chromospheric and coronal heating over the solar cycle

3.1.2.1 ESF Instrumentation

- Universal spectrograph
- Spectroheliograph
- Littrow spectrograph
- Chopping coronal photometer
- Bench for PI experiments

3.1.2.2 ESF Future Plans

Because of budgetary pressure and a declining user base resulting from coronal scientists moving toward space-missions, NSO eliminated its observing staff at the Evans. The facility remains open to scientists who can provide their own support. NSO still provides some minimal maintenance as some of the older systems break down. The USAF conducts daily measurements of coronal emission lines by providing funding for a part-time observer and some funds for maintenance. NSO operates a Ca II K-line synoptic program in disk-integrated light that now has operated for two solar cycles to study chromospheric variability and the differential rotation of the Sun when viewed as a star. This program is currently being cross-calibrated with the SOLIS Integrated Sunlight Spectrometer. Once this cross-calibration is complete (about 6 months), the ESF program will be discontinued. At that point NSO will no longer operate any programs in the facility and only externally funded programs will be conducted.

3.1.2.3 ESF Cost of Operation

NSO currently expends about 0.5 FTE on maintenance. Utilities are approximately $20K per year. The Ca K-line program uses about three hours per week of staff time. Thus total costs are estimated at $90K/year. This is offset by funding provided by the Air Force.

3.1.2.4 Air Force ESF Coronal Emission Line Program

The coronal emission line data are

- published online and used for space weather prediction and research by over 60 customers world wide. (Last year the coronal data on the Web site were accessed from outside our local area network approximately 100,000 times.)
- inter-calibrated with data from SOHO and other space missions to produce a long-term record of solar variability.
- used to determine the relationship between the 18-year cycle of activity that is observed in the solar corona and variations of the rotation of the convection zone of the Sun known as torsional oscillations.
- used to predict solar maximum and solar minimum.
- used to measure coronal temperatures. The polar temperature varies cyclically from approximately 1.3 to 1.7 millions of Kelvins. The temperatures are similar in both hemispheres. The temperature near solar minimum decreases strongly from mid-latitudes to the poles. The temperature of the corona above 80 degrees latitude generally follows the sunspot cycle, with minima in 1985 and 1995–1996 (cf. 1986 and 1996 for the smoothed sunspot number, Rz) and maxima in 1989 and 2000 (cf. 1989 and 2000 for Rz). The temperature of the corona above 30 degrees latitude at solar maximum is nearly uniform, i.e., there is little latitude-dependence.

3.1.3 Hilltop Solar Facility

The Hilltop Facility houses the white-light and H-alpha flare patrols and the coronal one-shot coronagraph. In addition, it has a 10-cm coelostat that feeds an optical bench currently used as a laboratory for developing narrowband filters. The Improved Solar Observing Optical Network project conducted by the Air Force Research Laboratory personnel at Sunspot has replaced the flare patrol and NSO no longer collects this data. The ISOON data are being archived and are partially available online. The High Altitude Observatory has modified the coronal one-shot by adding a tunable filter and is now operating daily to measure coronal magnetic fields. HAO provides their own support. DST observers open the facility on a daily basis. The H-alpha telescope is used to provide a live image for monitoring activity in real time and for selecting targets at the DST.

3.1.3.1 Hilltop Cost of Operation

The DST observers use about 10 minutes per day opening and closing the facility. Approximately 0.1 FTE goes into maintenance. Because the Hilltop houses the narrowband laboratory and offices, utility costs support these as well as the telescopes. The overall cost of operating the telescopes is estimated at $17K/year.

3.1.4 ISOON

The ISOON telescope was intended by the Air Force to be part of a network of flare patrol and prediction instruments. While the network is on hold pending a decision by the Air Force, the ISOON station at Sacramento Peak is in full operation. ISOON provides high-quality real-time data in white-light, H-alpha and He 10830. The Air Force provides all of the operating costs. NSO and the AFRL group are discussing combining SOLIS and ISOON into a network where ISOON provides the full-disk imagery and SOLIS provides the full disk-vector magnetograms.

3.1.5 Instrument Program at Sacramento Peak

Sacramento Peak houses mechanical and electronic shops and several laboratories where instrument development is conducted. In their latter stages, many of the instrument development programs apply for telescope time primarily on the DST. Recently completed programs include three high-order adaptive optics systems, two of which were installed on the DST and one on the Big Bear Solar Observatory 64-cm telescope. These systems were partially supported by an NSF Major Research Instrumentation grant in collaboration with the New Jersey Institute of Technology. The Diffraction-Limited Spectro-Polarimeter was developed in collaboration with HAO and is now installed at the DST. Another joint program with HAO, the Spectro-Polarimeter for Infrared and Optical Regions (SPINOR) is being developed and should be ready for users in 2006.

3.1.6 Science Program at Sacramento Peak

The research conducted by scientists at Sacramento Peak is described in Appendices A and B. In addition to research, science staff are deeply involved in defining and developing instrumentation. They also develop tools for data reduction, analysis and interpretation, which are made available to visiting scientists. All of the scientists on the Sacramento Peak staff are contributing effort to the ATST. This includes both science definition and instrument design. They also provide supervision for students working on NSO instruments and data and participate in other outreach programs.

3.1.7 Education and Public Outreach and Workshops

NSO conducts a robust outreach program at Sacramento Peak. Typically 10 to 14 scientists and teachers spend the summer at the Peak. These consists of 4-5 REU students, 1-2 Air Force sponsored space scholars, 3-5 graduated students and 2 RET teachers. Staff scientists hold adjunct university positions and supervise theses students. There are currently 3 students doing their thesis on NSO data and instruments resident at the Sac Peak. The staff presents talks and seminars at local schools and at the Lodestar Planetarium in Albuquerque. The Visitor Center provides daily tours and talks to the public and has a number of hands on exhibits. Typically 15-20 school groups visit the Sac Peak each year and are given talks and tours. The NSO workshop series draws 60-100 scientists each year to Sunspot. The proceedings are published by the Astronomical Society of the Pacific and are a valuable tool for understanding the state-of-the-art in many areas of solar physics. More specifics on outreach are given in Section 4 on metrics.

3.2 NSO/Kitt Peak, Tucson Arizona

Program Components in Tucson

- McMath-Pierce Solar Telescope (McMP)
- Synoptic Optical Long-term Investigation of the Sun (SOLIS)
- Global Oscillation Network Group (GONG)
- Science Program
- Instrumentation Program
- Educational Outreach

3.2.1 McMath-Pierce Solar Telescope

The McMath-Pierce main telescope on Kitt Peak, Arizona, at an altitude of 2096 m is the largest unobstructed-aperture optical telescope in the world with a diameter of 1.6 m. The East and West Auxiliary telescopes are among the largest solar telescopes (both with 0.9-m diameter and 0.8-m clear aperture) and share the same all-reflective, unobstructed design of the main telescope. The light path is thermally controlled to minimize internal seeing. The large light-gathering power, the extended wavelength range from the UV to the far IR, and the well-behaved polarization characteristics of the telescopes make them unique instruments and have stimulated extensive solar and night-time research. The McMath-Pierce facility is scheduled for observing for more hours than any other large NOAO telescope because it is used both day and night. The existing post-focus instruments are state-of the-art. The Fourier Transform Spectrometer is a unique national resource in wide demand by atmospheric physicists and chemists as well as astronomers. Recent science results at the McMath-Pierce facility include:

- Fine structure in sunspot penumbrae at 0.1 arcsec spatial resolution in the visible
- Rapid Evershed flow in cool magnetic plasma in sunspots seen in Ti lines at 2.2 μm and CN at 1.6 μm
- Cool cloudlets in the solar chromosphere due to convective overshooting seen in CO at 4.7 μm
- Quantum interference between fine-structure components seen in coherent scattering polarization
- Spatial variation of solar background magnetic field from Hanle effect measurements

3.2.1.1 McMath-Pierce Instruments

High-Precision Visible Polarimetry

- ZIMPOL I (ETHZ) vector polarimeter, 0.45-1.1 μm detects polarization below 10^{-5}

Near-Infrared

- 256 × 256 InSb array, 1-5 μm
- High-resolution spectroscopy
- Full vector polarimetry capabilities (1-2 μm)
- Fabry-Perot for 1.56 μm
- 1024 × 1024 InSb 1-5 μm (2005)

Thermal Infrared

- 6-15 μm imaging (NASA)
- 12 μm vector polarimeter (NASA)

High-resolution Spectrographs

- Solar spectroscopy from 0.3 to 12 μm
- Stellar spectroscopy in the visible

Fourier Transform Spectrometer (FTS)

- 1-m path difference
- High-resolution spectroscopy from 0.3 to 20 μm
- Astronomical objects, Earth's atmosphere, and laboratory sources

3.2.1.2 McMP Features

- Adaptive optics in the infrared
- Active optics at all wavelengths
- Telescope control system upgrade (2005-2006)
- Control systems, open air operation, off-axis design, spacious laboratory environment, and IR instrumentation are preludes to ATST instruments, science, and operations in the infrared
- Educational outreach (REU/RET, TLRBSE, etc.)

3.2.1.3 McMP Scientific Usage

Examples of the type of research best supported at the McMP include:

- Observations of the upper photosphere and chromosphere at IR wavelengths ≥2.2 μm
- Chromospheric structure
- Polarimetry requiring large photon fluxes
- Coronal spectral diagnostics in the IR
- Solar cycle spectral variations
- Terrestrial atmospheric spectral lines
- Solar system synoptic studies of planets, asteroids, and comets
- Laboratory spectroscopy of atoms and molecules of astrophysical interest

Specific research programs carried out with the McMath-Pierce are given in Appendix C. The implementation of the NSO Array Camera (NAC), based on a large-format InSb array, and utilized in conjunction with the AO system now in general use at the McMath-Pierce, is expected to produce new science results that will not be replicated at any other observatory.

3.2.1.4 McMP Future Plans

- Commission the large-format NSO Array Camera for advanced applications in mid-IR spectral imaging and polarimetry
- Complete and commission in 2006 the joint NJIT/NSO Advanced Image Slicer (AIS) Integral Field Unit (IFU) to enable 2-D spectral imaging of the Sun, optimized for IR wavelengths
- Upgrade the Telescope Control System
- Continue operations of the Fourier Transform Spectrometer for the solar, laboratory chemistry, and upper atmospheric communities
- Continue and enhance educational outreach programs such as TLRBSE
- Closure or divestment when ATST is commissioned

3.2.1.5 McMP Cost of Operation

The McMP currently has one full-time observer and two soft-money support personnel. The latter are supported by funds from NSF/Chemistry and NASA. Technical support is provided by 1.75 FTEs who are stationed in Tucson. In addition the MCMP receives approximately 1.5 FTEs of support from the technical staff on Kitt Peak.

3.2.2 SOLIS

The Synoptic Optical Long-term Investigations of the Sun (SOLIS) is a new facility designed to provide unique, modern observations of physical processes on the Sun that require sustained observations over a long time period. It replaces facilities built in the 1970s and is designed to operate on a continuing basis until about 2030.

3.2.2.1 SOLIS Science Impact

Long-term SOLIS observations of the most important astronomical object to humanity will provide fundamental data to help answer the following questions. The first question is one of 125 major unsolved science questions listed in the 1 July 2005 issue of *Science*.

- What drives the solar magnetic cycle? SOLIS provides unique, 'gold-standard' magnetic observations, including new full-disk vector field measurements, used to characterize and study the physics of the 22-year magnetic cycle that drives solar activity and variability. Many of the measurements are not available from any other source.

- How is energy stored and released in the solar atmosphere? SOLIS provides both unique data for space weather forecasting and also direct observations of the structures (filaments, coronal holes) and events (flares and disk manifestations of coronal mass ejections) that shape the heliosphere and spawn space weather.

- How does the solar radiative and non-radiative output vary? SOLIS continues a three-decade record of monitoring the variations of disk-averaged spectrum lines that are sensitive to long-term changes of the solar interior and surface.

Why is SOLIS needed to address these questions? SOLIS includes the only instrument in the world that produces regular full-disk measurements of the vector magnetic field. An instrument being built for flight on the Solar Dynamics Observatory will provide 5 years of similar measurements after a successful 2008 launch, but it does not utilize the full information available in polarized spectrum line profiles. This complete information is vital for proper extraction of magnetic fields from complicated line profiles sometimes associated with solar activity. SOLIS magnetograms combine high-sensitivity, high accuracy, wide field and adequate spatial resolution unmatched by any other instrument. This has enabled, for the first time, synoptic studies of weak magnetic fields thought to be generated near the solar surface that may play a role in the cycle of solar activity. SOLIS also provides unmatched measurements of the chromospheric magnetic field which have revealed large-scale, mainly horizontal fields covering large areas of the Sun's chromosphere surrounding active regions and also associated with filaments. SOLIS data are now being used to forecast solar wind speed near earth using both an old method involving a potential field outward extrapolation of the surface magnetic field and a new method based on the appearance of coronal holes in helium observations. SOLIS is unique in providing complete helium line profile information that allows superior identification of coronal hole locations.

3.2.2.2 SOLIS Instrument and Synoptic Data

Vector Spectromagnetograph (VSM)

- Helium-filled 50-cm f/6 telescope
- Grating spectrograph with 2048" × 1" field
- CMOS hybrid cameras with 1" pixels
- Full-disk photospheric vector magnetograms in 24 minutes (3 per day)
- Deep full-disk longitudinal photospheric magnetogram (1 per day)
- Chromospheric full-disk magnetogram (3 per day)
- Helium 1083 nm full-disk coronal proxy (3 per day)

Full Disk Patrol (FDP)

- 14 cm f/21 achromatic refractor with 2048" × 2048" field
- CCD cameras with 2048 × 2048 1" pixels
- Liquid-crystal tunable filters from 390 to 1083 nm
- H-alpha core and wing intensity and velocity (1 per minute)
- He 1083 nm core and wing intensity and velocity (1 per minute)
- Continuum (6 per hour)
- Ca II K core and wing (1 per 3 hours)

Integrated Sunlight Spectrometer (ISS)

- 8-mm aperture feeding full disk to fiber optic light feed with movable CCD sensor
- f/15 double pass grating spectrograph
- 1024 × 512 CCD sensor; movable for accurate calibration
- High-accuracy profiles of many spectrum lines; R~300,000
- Two sequences per day

Observing Modes and Data Access

- Scheduler-driven, semi-autonomous operation
- Time available for special, user-requested observations
- Completely open data policy
- Data available over the Internet

3.2.2.3 SOLIS Costs

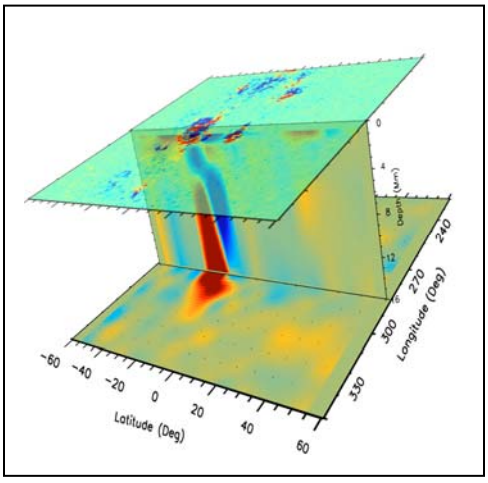
NSO is just beginning to ramp up SOLIS operations. Two NSO FTEs are now fully devoted to SOLIS and part-time support from the NSO/Tucson technical staff is provided. SOLIS also has support for two and one-half soft-money position from a NASA Living With a Star (LWS) grant. In addition, because of its location on Kitt Peak, and like the McMP, it receives support from the NOAO mountain staff. The current NSO contribution is $429K, while the current soft-money support is $199K. NSO plans to continue the ramp up with an estimated cost of $750K for full operations and science support.

3.2.3 NSO/GONG, Tucson

The new, improved Global Oscillation Network Group program explores the rapidly evolving sub-surface dynamics of the solar plasma and magnetic field, to understand the origins of stellar magnetism and "space weather."

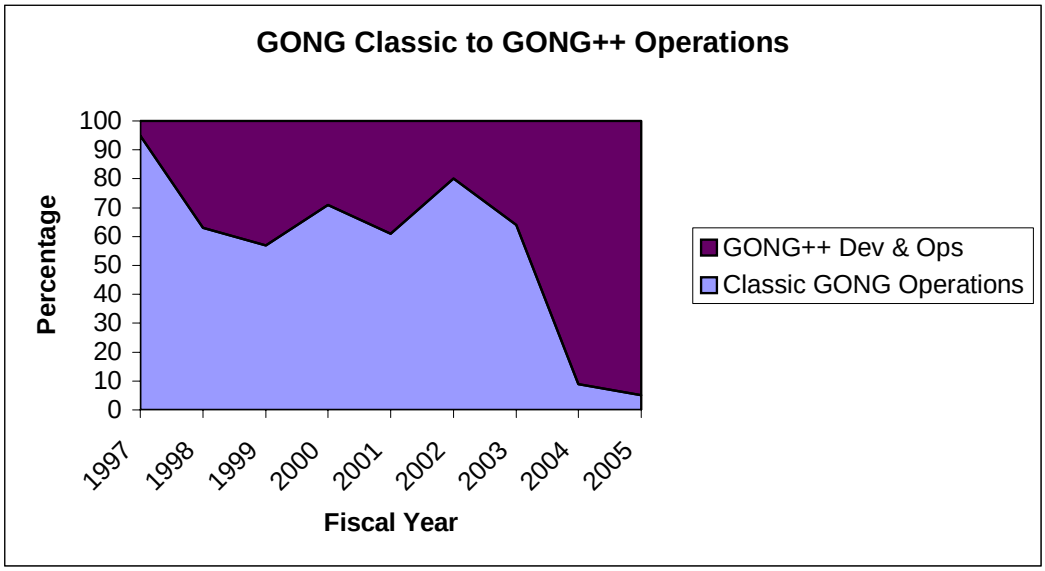
GONG's Transition to GONG++

From inception (1984), through the startup of the GONG Classic network (October 1995), through the GONG+ camera upgrade (network complete July 2001), up to merging full-resolution images (May 2003; first Opus version of the GONG++ pipeline merge), the focus of the GONG Program was to produce global helioseismology data products: time series, power spectra, and frequencies. In parallel with the breakthrough of local helioseismology (2000)—ring diagram analysis, time distance, and holography—the GONG Program began developing its transition from GONG Classic to GONG++.



Distribution of enstrophy in the first 16 Mm below a concentration of magnetic energy measured by GONG++

As of 2005, the majority of the effort and budget is focused on GONG++ and the processing, archive, and dissemination of local data products. Currently, only about 1.0 FTE is used to process and generate Classic GONG data products.



3.2.3.1 GONG++ Science/Methodology – Local Helioseismology & Changing Surface Magnetic Flux

- Structure and dynamics of local concentrations of magnetic field
- Changing meridional and torsional flows
- Changing structure of the convection zone and tachocline
- Dynamics of the surface magnetic field and coronal response
- Builds on the success of the original GONG study of the global structure of the solar interior
- Exploits the discovery of running wave seismology, in addition to standing waves previously used.

3.2.3.2 GONG++ Instrument, Data, & Analysis

- 1024 × 1024 velocity, intensity, and magnetic flux images, 60-second cadence
- 1 TB per week processed to calibrated data, analyzed to data products such as *p*-mode frequencies and science products such as internal rotation and surface flow maps
- All data available publicly online

3.2.3.3 GONG ++ Future

- NRC Decadal Survey says run for at least a solar cycle
- Near-real-time data recovery and science to support prediction
- New communities for local helioseismology, high cadence magnetic flux, and space weather

3.2.3.4 GONG Costs

GONG collects data from the six sites around the world and provides the science community with processed data. The Data Management and Acquisition Center handles this aspect. A technical team maintains the GONG sites and a strong scientific staff insures data quality in addition to their own research. The overall cost is about $3.1M per year.

3.2.4 Science Program NSO/Tucson

The NSO scientific staff inTucson are significantly involved in the support of, and collaborative community leadership in, major ground-based O/IR initiatives in solar physics. In particular, staff members are leading SOLIS completion and commissioning, including the development of reduction and analysis algorithms; the upgrading of the GONG instrumentation and the enhancement of its science productivity through the development of advanced analysis methods; leading or supporting the introduction of forefront IR instrumentation at the McMath-Pierce telescope; carrying out research programs in solar physics, solar-stellar astrophysics, and supporting programs in laboratory spectroscopy. The Tucson staff are contributing to the

ATST effort through science definition, instrument design and site evaluation. They also supervise undergraduate and graduate students in research, in addition to postdocs.

3.2.5 Instrument Program NSO/Tucson

SOLIS instrument development and the upgrade of the GONG cameras have dominated instrumentation activities in Tucson during the past several years. This work is carried out with NSO base resources, ETS resources shared with the NOAO and through vendor contracts. In addition, the scientific staff develops tools for data reduction, analysis and interpretation that are, in turn, made available to the community of users, including students. At the McMath-Pierce, recently completed instrumentation includes an AO system optimized for infrared observations; the joint NSO/CSUN IR camera; and the soon-to-be commissioned NSO Array Camera. The latter will become the workhorse IR instrument at the McMath-Pierce for forefront research in the IR. In addition, the joint NJIT/NSO Integral Field Unit, to be completed in 2006, will deliver will be the first instrument of its kind for a solar telescope. The AIS IFU will enable simultaneous sampling of the AO-corrected field at the McMath-Pierce for 3-dimensional spectroscopy and polarimetry.

3.2.6 Education and Public Outreach NSO/Tucson

NSO/Tucson has a strong outreach program, typically hosting 3 or 4 REU students, 2 RET teachers and 1 or 2 graduate students during the summer. The scientific and technical staff have made significant contributions to the TLRBSE program and for the past three years have hosted observing programs for the TLRBSE teachers at the McMath-Pierce. Tucson staff developed and regularly update the Research in Active Solar Longitudes (RASL) and Data and Activities for Solar Learning (DASL) programs that are used as a source for educational labs and projects at the K-12 level. Staff scientists give guest lectures at the University of Arizona for graduate or undergraduate courses in Physics and/or Astronomy, and both scientific and technical staff participate in Project ASTRO and give presentations on solar and stellar astronomy at Tucson elementary and secondary schools. More specifics are given in Section 4 on metrics and in Appendix C.

3.3 Virtual Solar Observatory

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

Over the next few years, NSO should make major strides toward becoming a central component of both the VSO and EGSO. Both of these community-wide systems should be on-line in the next five years. In addition, the NSO archives should be observatory-wide with components at both sites. These components should link together enhanced pipeline processing systems similar to those now available as the Improved Solar Observing Optical Network (ISOON) and GONG++; massive storage systems based on the initial SOLIS system; an instrument-driven pipeline and PI data capture systems at all NSO observing facilities; and a large-scale photographic digitization system. The details for this expansion have been discussed in the NSO Data Plan (see *http://www.nso.edu/general/docs/*).

4 Metrics and Performance Goals

The cooperative agreement between NSF and AURA, spanning 2003-2007, contains the performance and metric goals listed in Table 4-1. We are now in the third year of that agreement and NSO along with the solar community it supports have made progress in all areas.

Table 4-1. List of Metrics

Area	Metrics
Leadership in Solar Physics	1. ATST a. Completion of ATST site survey b. Completion of ATST D&D phase c. Development of funding partnerships for the ATST d. Submission & approval of ATST construction proposal
	2. SOLIS a. Completion and deployment of SOLIS b. Formation of partnerships for SOLIS network c. Adding SOLIS data to digital library and archive
	3. GONG a. Implementation of GONG+ cameras b. Implementation of GONG++ data reduction
	4. ADAPTIVE OPTICS a. Develop high-order system b. Place on all major facilities
	5. IMPLEMENT STATE-OF-THE-ART INSTRUMENTATION a. Develop infrared detectors, filters, and spectrographs b. Implement narrowband filters c. Develop Advanced Stokes Polarimeter II
Service to Solar Community	1. Provide observing time to the national and international solar community a. Increase support for remote observations b. Increase capability to provide quick-look and partially reduced data c. Increase joint space/ground observing collaborations
	2. Provide solar data to the solar, solar-terrestrial, atmospheric, space-weather and global climate communities a. Provide long-term synoptic observations of cyclic variation b. Provide solar activity observations c. Provide background observations for space missions
Scientific Productivity	1. Publications a. Refereed journals b. Other publications
	2. Presentations a. Invited talks b. Meeting presentations
Education and Outreach	1. Help train the future generation of solar astronomers a. Increase the number of graduate students trained b. Increase the number of postdoctoral candidates working at the NSO c. Improve the coordination with university programs
	2. Increasing the effective of our of k-12 programs a. Increase the number of teachers participating in our RET program b. Increase the number of classroom exercises transitioned and supported c. Continued participation in local and minority schools
	3. Public relations a. Increase effectiveness of Web site b. Continue to upgrade Visitor Center c. Increase PR activities, press releases, support for NSF PR

While solar and nighttime programs have many overlapping metrics, there are also some very different metrics in each area that also measure the impact of a program. Some of these metrics—important to include for solar, but often hard to measure—include NSO support to a wide variety of non-astronomy users. Since our data are widely distributed through the NSO Digital Library and now the VSO, we often find by accident publications using NSO data in space weather journals, geosciences journals, and climate journals. NSO data are also published in the Solar Geophysical Data reports by NOAA/NGDC and are used by many customers for various modeling and forecasting efforts. One might think, this is operational, not science, and thus not NSF's business. However, the skill or lack of skill these models exhibit drives both research and the demand for new techniques, models, instruments and data. Their accuracy reflects our understanding of the physics governing the Sun and the solar-terrestrial system.

Another metric that is important is the coherence of long-term synoptic data sets. Things like torsional oscillations, sheared flows in the tachocline, emergence patterns of active regions, and evolution of magnetic structure, all play fundament roles in understanding the Sun and other stellar systems. The data needed to understand them must often be collected over several solar cycles. Having the continuity of observations provided by programs like SOLIS and GONG is critical. NSO has been very effective at maintaining these continuous data sets. Their scientific importance is moving to the forefront as we begin to have sufficient data to tackle solar dynamo issues. This type of data does not produce the rapid-fire publications that observing new things does, but in the end the discoveries obtained by carefully mining these data may be more important. (e.g., awarding of the AAS Hale Prize to both Bob Howard and Jack Harvey for their long-term efforts in these areas).

Below we briefly address progress in each of these areas given in Table 4-1 (labeled 1a, 1b, etc.). Also included are responses to the metrics provided by the NSF Astronomy Division.

4.1 Leadership in Solar Physics

1. ATST

1a. **Completion of the ATST site survey:** NSO, along with the University of Hawaii, the New Jersey Institute of Technology, the High Altitude Observatory, the Instituto de Astrofisica de Canarias, (IAC), and the University of Mexico conducted one of the most thorough surveys of potential solar sites. The survey involved developing new, innovative instrumentation for measuring daytime seeing (SDIMM – Solar Differential Image Motion Monitor and SHABAR – Shadow Band Ranger) and sky conditions for coronal observations (SBM – Sky Brightness Monitor), exploring a broad base of existing data, and developing algorithms to derive the Fried parameter (r_0) as a function of height. The survey resulted in the selection of Haleakala on Maui, Hawaii as the prime site for the ATST.

1b. Completion of the ATST D&D phase: NSO and its collaborators have developed a robust design for the ATST and are ready to begin the construction phase as soon as NSF Major Research Equipment Facilities Construction (MREFC) approval is obtained. NSO will continue to refine the design and engage potential vendors in the design completion as funding permits.

1c. Development of funding partnerships for the ATST: NSO has engaged the international community in the ATST project from its inception. A group of 14 European nations developed an ATST proposal for the European Union Framework 6 Program, which, unfortunately, in spite of strong ratings, was not funded. The consortium is currently seeking other opportunities. The German Kiepenheuer Institute for Solar Physics has established a memorandum of agreement with NSO to participate both through direct funding and through in-kind instrumentation contributions. Their intention is to obtain a commitment from the German government for $10M. A proposal is currently being written to their funding agency to be submitted in early August 2005. Regardless of the proposal outcome, their in-kind contribution is estimated at $5M. The IAC is similarly planning to obtain Spanish involvement at a comparable level. We have met with the Spanish Science Ministry and obtained their commitment to participate. The Italian solar community is currently developing a proposal to support their participation. Although no dollar amounts have been specified, they expect to obtain a contribution of about $5M. The Air Force Research Laboratory/Air Force Office of Scientific Research has indicated they will purchase the mirror and help pay for its polishing ($11M) when MREFC approval is

obtained. We continue to seek further participation and will visit Japan and meet with key scientists this November.

1d. Submission and approval of the ATST construction proposal: NSO submitted the ATST construction proposal in January 2004. It is currently working its way through the approval process.

2. SOLIS

2a. Completion and deployment of SOLIS: Two of the the three major SOLIS instruments are in operation on Kitt Peak. The third instrument is being completed and expected to be deployed on the SOLIS mount by the end of 2005.

2b. Formation of partnerships for SOLIS network: Tentative approaches have been made to potential foreign partners in a SOLIS network. There is some interest in joining a SOLIS network with an ISOON deployment.

2c. Adding SOLIS data to digital library and archive: Reduced SOLIS data are made available to the public via direct FTP, the NSO Digital Library and the Virtual Solar Observatory

3. GONG

3a. Implementation of GONG+ cameras: The GONG hardware upgrade was completed in 2003 and is now in full operation.

3b. Implementation of GONG++ data reduction: The GONG data pipeline was streamlined and upgraded to handle the larger data flux, including near-real-time magnetograms, and the data products are going out to the community. The streamlined data processing has substantially decreased the cost of data handling, and the freed resources have been applied to scientific support.

4. Adaptive Optics

4a. Develop high-order system: The first solar adaptive optics systems designed to fully compensate a solar telescope was brought on line by NSO in 2003 at the Dunn Solar Telescope. A second system was installed by NSO at the Big Bear Solar Observatory. A third system was developed for a second port at the DST. A fourth system, optimized for the near and thermal IR was developed and installed on the McMath-Pierce solar telescope. All AO systems at the NSO have been commissioned for general use.

4b. Place on all major facilities: Currently all instrumentation at the DST and at the McMP can be fed with AO. The advent of AO has greatly increased user demand for DST time. NSO, through its partnership with the High Altitude Observatory, the University of Hawaii and the Arcetri Observatory in Italy, is currently developing diffraction-limited spectroscopic and imaging Stokes polarimeters that fully exploit the diffraction-limited images delivered by the AO systems.

5. Implement State-of-the-Art Instrumentation

5a. Develop infrared detectors, filters, and spectrographs: A joint University of Hawaii/NSO IR camera was completed and used both on the Hawaii Solar-C telescope and at the DST. An advanced, large-format (1024 × 1024) InSb infrared array camera is now in the commissioning phase at the McMath-Pierce. The Integral Field Unit (IFU), an advanced image slicer for AO-corrected imaging spectroscopy in the infrared, is currently being built in collaboration with the New Jersey Institute of Technology.

5b. Implement narrowband filters: The Italian Interferometric BIdimensional Spectrometer (IBIS) filter developed by the Arcetri Observatory group was installed at the DST and is being upgraded for polarimetry.

5c. Develop Advanced Stokes Polarimeter II: The Diffraction-Limited Specto-Polarimeter (DLSP) is completed and is now a dedicated user instrument. SPINOR has had its shake-down run and will be finalized in 2005/6.

Both the McMath-Pierce and the Dunn Solar Telescope also serve as test beds for new instruments. Recent examples at the McMP include Flare Genesis testing and the Tunable Heterodyne Infrared Spectrometer (THIS), which is a second-generation IR heterodyne spectrometer designed for the Stratospheric Observatory for Infrared Astronomy (SOFIA). Recent examples at the DST, in addition to SPINOR, include a fiber-optic image slicing spectrograph being developed under a University of Hawaii/NSO MRI proposal, experiments by Arcetri Observatory and HAO to make IBIS an imaging polarimeter. Also, the Southwest Research Institute has recently used the DST to test a new technology, stereoscopic spectral imaging, that promises to enable studies of the high frequency wave field in the chromosphere and of small scale, rapid magnetic evolution in the photosphere.

4.2 Service to the Solar Community

1a. Increase support for remote observations: We have begun testing modes at the DST for conducting observations without the PI present. The DLSP and associated imaging camera's will remain in a permanent set-up that can be used to support space-missions and to implement observations requiring particular solar activity conditions and/or targets or particular seeing conditions. All data obtained in this fashion will become public and made available through the NSO Digital Library and Virtual Solar Observatory. A remote observing mode has been used routinely utilizing the DS-3 line from Kitt Peak and Web-cam set-ups combined with remote control of the telescope. The knowledgeable on-site technical support staff is available to work with, set up and operate instrumentation for visiting researchers. This often alleviates the necessity for the observers to travel to the observatory.

1b. Increase capability to provide quick-look and partially reduced data: A new data handling pipeline, storage and quick-look was implemented for the DST. It gives the users a broad array of media on which to take their data home and provides real-time access to the data to evaluate the observations as they are being made. At the McMP, software for data reduction of typical observations is readily available. Computers with several common software reduction packages (IDL, Maxim DL, IRAF) as well as in-house programs are available to visiting researchers at the telescope. Quick-look SOLIS data are available minutes after an observation is completed.

1c. Increase joint space/ground observing collaborations: Joint observing runs with space missions such as SOHO, TRACE and RHESSI are the norm at the DST. SOLIS data are used in conjunction with most space missions. In addition to solar missions, the McMath-Pierce is often used to support solar-system space missions, such as the recent Deep Impact cometary mission. Statistics for DST observations in 2003, 2004 and 2005 indicate that over 50% of the scheduled science runs were conducted jointly with space and other ground observatories.

2. Provide solar data to the solar, solar-terrestrial, atmospheric, space-weather and global climate communities

2a. Provide long-term synoptic observations of cyclic variation: NSO has a long-term program (1974 to date) at the McMath-Pierce and Evans Solar Facility of synoptic spectroscopic observations of the Sun as a star in key spectral diagnostics in the visible and IR (e.g., Ca II H and K, H-alpha, photospheric lines) over the solar cycle. This is to be continued with the SOLIS Integrated Sunlight Spectrometer following a period of overlapping observations for calibration purposes so that continuity of the data-sets can be maintained. Long-term programs of monitoring coronal emissions and chromospheric variability at the Evans Solar Facility are online through the NSO Digital Library and available in the NSO film library. KPVT and SOLIS data are available to the community now, and correction of older KPVT data is currently underway.

2b. Provide solar activity observations: Currently NSO provides archival data sets for the H-alpha and white-light flare patrol, spectroheliograms from the Evans, coronal hole observations from the ESF, and KPVT magnetograms. These programs are being replaced by better data products from SOLIS/ISOON.

2c. Provide background observations for space missions: In addition to the synoptic programs, which are often used to place space mission observations in context, the DST gives scheduling priority to observers with time on SOHO, TRACE, RHESSI and other space missions.

4.3 Publications

Tracking of publications is made less difficult by the free dissemination of data over the Web through the NSO Digital Library and more recently the Virtual Solar Observatory. While many authors are diligent about giving proper credit, NSO data occasionally appear in publications with no reference to NSO.

Table 4-2. NSO Publications by Facility

	1999	2000	2001	2002	2003	2004	2005	Total	Citation Count
Refereed Staff DST	3	4	3	7	4	10	2	33	235
Refereed Staff McMP (Solar, including FTS)	7	3	1	8	4	0	1	24	122
Refereed Staff McMP (Nighttime)	2	1	2	2	0	0	1	8	34
Refereed Staff KPVT	6	8	2	1	8	5	1	31	151
Refereed Staff GONG	6	8	4	9	7	4	0	38	206
Refereed Staff ESF	0	3	1	0	2	0	0	6	49
Refereed Staff Hilltop	0	1	0	1	0	0	0	2	24
Refereed Staff ISOON	0	1	0	0	2	0	0	3	4
Refereed Staff ATST	0	0	0	1	1	4	0	6	5
Refereed Staff SOLIS	0	1	0	0	2	0	0	3	0
Refereed Staff Other NSO Instr.	1	5	4	7	8	2	0	27	186
Refereed Staff No NSO Data	6	8	18	9	14	11	1	67	249
Refereed Staff Papers SubTotal	31	43	35	45	52	36	6	248	1265
Refereed Visitor DST	7	13	13	9	12	9	6	69	578
Refereed Visitor McMP (Solar, including FTS)	13	16	24	16	7	10	0	86	808
Refereed Visitor McMP (Nighttime)	2	0	2	5	1	4	1	15	67
Refereed Visitor KPVT	43	37	45	43	30	30	8	236	1356
Refereed Visitor GONG	21	27	18	12	10	11	1	100	585
Refereed Visitor ESF	1	0	3	0	1	3	0	8	8
Refereed Visitor Hilltop	1	0	0	0	0	0	0	1	0
Refereed Visitor ISOON	0	0	0	0	1	0	0	1	0
Refereed Visitor ATST	0	0	0	0	0	1	0	1	2
Refereed VisitorSOLIS	0	0	0	0	0	0	0	0	0
Refereed Visitor Other NSO Instr.	6	2	0	0	3	2	0	13	95
Refereed Visitor No NSO Data	5	0	6	7	2	1	0	21	52
Refereed Visitor Papers SubTotal	99	95	111	92	67	71	16	551	3551
			TOTAL REFEREED PAPERS					799	4816
Un-Refereed Staff DST	12	6	6	6	16	12	0	58	47
Un-Refereed Staff McMP (Solar, including FTS)	2	0	4	4	1	0	3	14	12
Un-Refereed Staff McMP (Nighttime)	2	0	0	0	0	0	0	2	1
Un-Refereed Staff KPVT	1	1	1	0	2	0	0	5	2
Un-Refereed Staff GONG	9	1	12	9	15	20	0	66	29
Un-Refereed Staff ESF	5	2	3	3	1	2	0	16	5
Un-Refereed Staff Hilltop	1	0	0	1	0	0	0	2	6
Un-Refereed Staff ISOON	0	0	2	0	0	1	0	3	0
Un-Refereed Staff ATST	0	0	2	2	15	8	0	27	10
Un-Refereed Staff SOLIS	2	3	2	4	7	4	0	22	0
Un-Refereed Staff Other NSO Instr.	0	1	1	4	0	3	0	9	5
Un-Refereed Staff No NSO Data	7	4	8	9	12	8	2	50	18
Un-Refereed Staff Papers SubTotal	41	18	41	42	69	58	5	274	87
Un-Refereed Visitor DST	20	2	3	6	2	2	1	36	46
Un-Refereed Visitor McMP (Solar, including FTS)	5	3	2	4	4	0	0	18	79
Refereed Visitor McMP (Nighttime)	0	0	0	0	0	0	1	1	0
Un-Refereed Visitor KPVT	10	4	9	20	4	5	0	52	27
Un-Refereed Visitor GONG	35	5	22	13	34	6	0	115	69
Un-Refereed Visitor ESF	0	3	0	0	2	0	0	5	0
Un-Refereed Visitor Hilltop	0	0	0	0	0	0	0	0	0
Un-Refereed Visitor ISOON	0	0	0	0	0	0	0	0	0
Un-Refereed Visitor ATST	0	0	0	1	1	1	0	3	0
Un-Refereed VisitorSOLIS	0	0	0	0	0	0	0	0	0
Un-Refereed Visitor Other NSO Instr.	5	2	0	0	3	1	0	11	76
Un-Refereed Visitor No NSO Data	4	0	5	5	2	1	0	17	42
Un-Refereed Visitor Papers SubTotal	79	19	41	49	52	16	2	258	339
				TOTAL UN-REFEREED PAPERS				532	426
								Papers	Citation Count
					TOTALS			1331	5242

Table 4-2 provides a partial list of refereed and un-refereed NSO staff and visitor papers published since 1999, separated by facility. Papers using data from two or more sources are prorated based on the amount of data. Many NSO instrument papers are published in the Proceedings of the SPIE. While these are often refereed, all have been listed as un-refereed papers.

4.4 Education and Outreach

1. Help train the future generation of solar astronomers

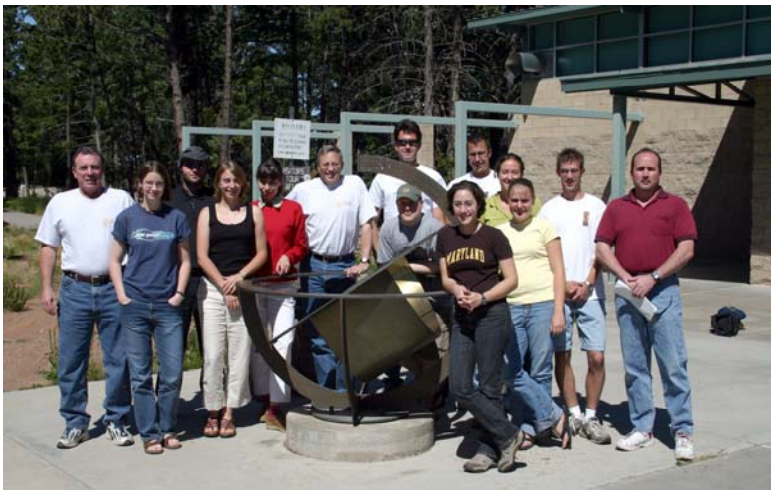


Figure 4.4-1. *2004 REU students, RET teachers, and summer graduate students outside the NSO Visitor Center at Sacramento Peak.*

NSO has conducted strong students programs since its inception in 1983. Prior to the formation of NSO, its predecessors, Sacramento Peak Observatory and the solar component of Kitt Peak National Observatory, both had strong programs for students. NSO has continued to enhance its program over the years. It has participated in both the REU and RET programs from their beginnings. Prior to the RET program, NSO hosted high school teachers every summer through the New Mexico Summer Teacher Enrichment Program. A large fraction of active solar astronomers are alumni of the NSO summer programs. More than 30% of the participants in the program have been female, with this number growing to ~45% over the past several years. Appendix G provides a complete listing of student- and RET/teacher- program participants since 1999. What follows are some recent examples of the program's effectiveness.

1a. Increase the number of graduate students trained: Three thesis students are currently working at NSO/SP. Two are doing instrumental PhDs and one is working on chromospheric structure. This summer NSO is hosting eight REUs, four RETS, two Air Force Space Scholars, and five graduate students. Some recent examples of the program's effectiveness include: Sarah Jaeggli, a former REU student, is entering graduate school at the University of Hawaii with the intention of doing a PhD thesis involving solar infrared instrumentation. As an undergraduate at the University of Arizona, Sarah worked with Matt Penn on data from the NSO/CSUN IR camera at the McMath-Pierce. 2004 REU student Stuart Robbins worked with Carl Henney and Jack Harvey on developing an empirical model for forecasting solar wind driven geomagnetic events. He will start graduate school in solar physics at the University of Colorado this fall. Andrew Medlin worked on his MS degree on chromospheric diagnostics with K.S. Balasubramaniam and is now employed at NASA Goddard. Dave Byers did his PhD on the causes of solar activity with K.S. Balasubramaniam and Steve Keil and is now in charge of the AFOSR space research program.

In the nighttime solar system programs, nine undergraduates have been trained with majors in astronomy, physics, mechanical and electrical engineering, and computer sciences. Currently, several Masters students and one PhD student will be using McMath-Pierce data obtained during Deep Impact monitoring. The NASA Astrobiology Institute (NAI) Astrobiology Program now holds an annual workshop for graduate students on Kitt Peak that includes demonstration solar observing labs at the McMath-Pierce.

1b. Increase the number of postdoctoral candidates working at NSO: Although NSO has not been able to increase its base support for postdoctoral candidates, NSO scientists have been effective at obtaining grants to support postdoctoral positions. The adaptive optics program has hosted several research fellows as part of its MRI grant from the NSF. The ATST D&D effort supports two research fellows, partially cost shared with

AURA. GONG and SOLIS have obtained NASA funding to support several research fellows. A complete NSO staffing table is in Appendix G, with the source of support given.

1c. Improve the coordination with university programs: NSO and the University of Arizona are currently coordinating the selection of a new faculty position in solar physics at the university under the auspices of an NSF Faculty Initiative Award. A number of NSO scientific staff hold adjunct positions at Universities and participate to a limited extent in their undergraduate teaching programs and as advisors in graduate student PhD thesis research. Currently NSO staff are serving as thesis advisors for students at Utah State University, the New Jersey Institute of Technology, the University of Alabama in Huntsville, and the New Mexico Institute of Technology.

2. Increasing the effectiveness of our K-12 programs.

NSO currently hosts four RET teachers each summer who work closely with the staff and REU students on both research projects and outreach. They are listed in the table in Appendix G, including demographics.

NSO presented teacher workshops on Data and Activities for Solar Learning (DASL), Real Research in the Classroom (RASL) at the National Association of Science Teachers annual convention. NSO also exhibited at the National Association of Science Teachers and American Indian Science and Engineering Society annual conventions.

As part of the ATST project, NSO is doing extensive work to develop two curriculum projects. Both are being designed as flexible projects that can be deployed as traveling museum exhibits or traveling classroom activities. Magnetic Carpet Ride will provide education modules and public programs that emphasize the magnetic nature of the Sun and solar activities and that tie in with the rise of sunspot Cycle 24 (2007-08), the centennial of Hale's 1908 discovery of magnetism in sunspots, and the International Heliophysical Year (2007). The Goldilocks Star will build on a new research initiative by NSO to characterize the activity cycles of stars that might host planets suitable for life in the context of our Sun's variability. Students will be made aware of the Sun as a star and of its activity cycles as a point of comparison in the hunt for stars that are stable enough to allow evolution of life, as we know it. The Global Oscillation Network Group, working with French partners, is developing an education CD using GONG data from the 2003 Transit of Mercury and the 2004 Transit of Venus. Classroom activities now available include Data and Activities for Solar Learning (DASL), Real Research in the Classroom (RASL), and Computer-based Exercises for the Classroom: The Period of Rotation of the Sun, produced by Project CLEA in collaboration with the GONG Program.

NSO is a participant in the Southwestern Consortium of Observatories for Public Education (SCOPE) and in Project ASTRO, Astronomers and Educators as Partners for Learning. Approximately 30 teachers per year visit Sacramento Peak as part of co-sponsored workshops (ASTRO, etc.). NSO is designing a solar system scale model that will stretch from Sunspot, NM, to Alamogordo, and that will provide highway markers at appropriate locations along NM6563 and lead the public to the Sunspot Astronomy and Visitor Center and an 18-foot-diameter walkthrough model of the Sun. NSO has provided five lecturers on the Sun to the Lodestar Planetarium in Albuquerque. NSO provided mentors for students at Cloudcroft (NM) High School in astronomy for the 2005 Science Olympiad 2005 and administered the regional test. NSO staff serve as judges science fairs for Alamogordo and Tucson.

3. Public Relations

The NSO Web site supports both outreach and data distribution. The statistics for data distribution are presented in the Section 4.5. Our site, Ask Mr. Sunspot, handles public on-line queries about the Sun and other astronomical topics. It keeps a complete archive of questions asked and answers. NSO also provides press releases and images on the web for media, educational, and public use.

The NSO Visitor Center on Sacramento Peak houses solar, general astronomy and forest displays showing how the sun affects forestation. There are numerous hands on displays covering everything from the size scale of the solar system to properties of infrared and polarized light including a spectrograph fed by a live solar beam. Approximately 20,000 visitors per year visit the Center and take both guided and self-guided tours of

the telescope facilities. Another 8,000-9,000 tour the facilities without registering (estimated from the number of brochures distributed). Approximately 1,000 school students, museum members, and other groups per year participated in special talks and tours arranged ahead of time.

NSO also participates in the visitor program on Kitt Peak by providing displays and various exhibits. Kitt Peak typically hosts 50,000+ visitors per year. The McMath-Pierce is the only telescope they can see in operation. Currently the NSO staff are collaborating with the NOAO EPO staff in the installation of a new automated telescope in the old Razdow dome on Kitt Peak in order to feed live solar images to the Kitt Peak Visitor Center.

The NSO staff participates in PR activities, press releases and NSF PR. Some examples include:

- Display at the "NSF Symposium on the Future of Ground-Based Astronomy" in October 2003.
- Developed posters and handouts for use at the Coalition for National Science Funding Science at Work exhibition held June 21, 2005, on Capitol Hill.
- Developed Einstein and the Sun poster and matching teacher handouts for the International Year of Physics.
- 24 press releases over the last 2-1/2 years highlighting NSO observations, science papers, and ATST.
- Provided solar images for four different science texts here and abroad (Japan, Poland).
- Hosted tour and dinner for the New Mexico section of the National Science Writers Association.
- Several NSO scientists did extensive interviews for *An Astronomer's Universe,* an education film.
- NSO provided images and information to a July 2004 issue of *National Geographic*

4.5 Data Archives and Web Usage

NSO maintains a digital library as well as extensive film archives that currently span nearly three solar cycles. Data in these archives are freely distributed and will be a major element of the Virtual Solar Observatory. Table 4.5-1 gives the current holdings of the digital library and the estimated increase in these holdings over the next two years. The number of bytes in the film library represents an estimate of converting the film to digital form. Although NSO has written proposals to convert the whole library, so far the resources have not been available. Parts of the film library have been converted to digital by individual PIs with their own grants. When this occurs, the data are added to the digital library.

We have included an estimate of the number of film images stored at NSO/Sac Peak from our flare patrol and Evans Spectroheliograph. While these are not available in digital form, they qualify as being readily available since anyone who asks is given access.

Table 4.5-1. Data Archive Sizes for NSO in GigaBytes

Data Source	FY 2002	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007
GONG	7,336	26,843	46,518	76,349	108,504	149,210
KPVT	118	137	137	137	137	137
SOLIS	-	-	1	19	7,374	14,729
ISOON	-	-	50	100	1,378	2,655
FTS	81	84	87	91	94	97
Evans/Coronal Maps	1	1	1	1	1	1
SMEI	-	2	4	6	8	11
DST	-	-	-	-	-	100
TOTAL	7,536	27,067	46,798	76,703	117,496	166,940
Film (Estimated No. of Images)	246,375	254,953	263,530	272,108	280,685	289,263

We have some very small data sets that are nonetheless extremely useful. For example, at the Evans we also store the Ca II K-line profiles (100 spectral scans per run (~3 times a week now, almost daily from 1976-

1999)), each covering 60 angstroms at 5 mA resolution. While we archive these, most people prefer to have just the parameters. The parameter data are publicly available with currently 20 or so users accessing them monthly. These data are also stored at the NGDC. However, the entire CaK parameter file is only 0.23 GB (but each byte is extremely valuable!). Another example is the sunspot parameters that Bob Howard and co-workers measured from historic glass plates obtained at Kodaikanal, India.

Principal Investigator data from both the McMath-Pierce and the Dunn Solar Telescope are *not* included in these totals, as PI's take their data with them and copies are not kept by NSO. This situation will soon be rectified. An example of the amount of PI data typically involved is an October 2004 run of Steve Keil's: 7000 GB of data were produced, which he has shared with Roudier, Molidij, Schmieder and other colleagues from other institutions.

NSO data archives can be accessed in several different ways. Almost all of the data can be reached via the digital library or the Virtual Solar Observatory the drive engines of which are maintained in Tucson. In addition, the FTP site at Sunspot can be accessed directly and some current images and movies from ISOON are available at the Sunspot web site. NSO also exports data to the NGDC site for inclusion in their solar data reports and archive. Thus, NSO data can often be used without us being directly informed. In any case, Table 4.5-2 contains the download statistics for NSO data, and Figure 4.5-1 shows those statistics in graphical form.

Table 4.5-2. Total Data Downloaded from NSO FTP and Web Sites (Gbytes)

Domain	2001	2002	2003	2004
Science	109.50	291.31	293.68	1269.38
Public	99.69	156.86	178.87	299.88
Foreign	53.35	80.57	42.31	124.43
Unresolved	20.14	56.42	37.17	131.67
TOTAL	**282.68**	**585.16**	**552.03**	**1825.36**

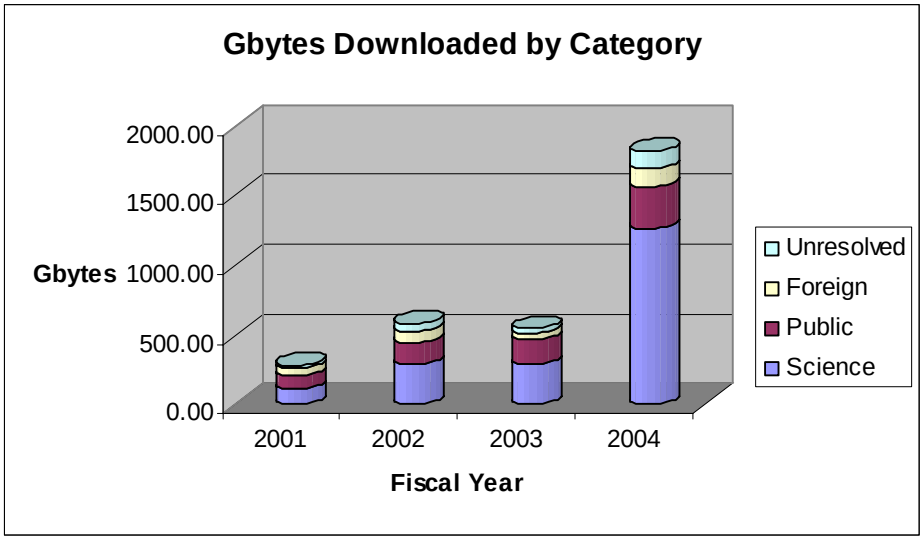


Figure 4.5-1. *Gbytes downloaded by category. "Science" includes* .edu, .gov, and .mil*. "Public" includes* .org, .com, .net. *International downloads are placed in "Foreign." Occasionally the URL cannot be determined; these are placed in "Unresolved."*

There is a definite trend of increased usage. GONG++, SOLIS, and ISOON have greatly increased the number of data files being downloaded. As we start placing DST data into the archive, we expect to see a further increase in FTP traffic.

4.6 Telescope Usage Metrics

The classical telescope metrics of number of proposals received vs. number of awards are inadequate to measure the impact of solar telescopes or their usage. Most requests for time are for observing runs of two weeks or more, often involving simultaneous use of two or more telescopes. NSO attempts to accommodate almost all requests, sometimes asking the proposer to use a different telescope, almost always giving them less time than requested. Only occasionally do we turn down a proposal either because it is scientifically unjustified or does not mesh with the NSO capabilities. Most users are well versed in the telescope capabilities. Only the DST is oversubscribed in the classical sense of more time being requested than is available (see Figure 3-1).

We track the number of unique science projects and the institutions of the investigators. Because many runs require unique and complex setups, visiting scientists often collaborate with the in-house staff. Progress in solar physics generally requires looking at the Sun in unique ways and a considerable fraction of telescope time is devoted to engineering new instrumentation. With the advent of some powerful space missions, such as SOHO, TRACE and RHESSI, the demand for simultaneous ground-based measurements has increased. This is pushing NSO toward more queue-based, fixed-instrument observing modes such as those planned for the DLSP on the DST.

Figure 4.6-1 shows the break down of PI observing programs by type and facility from the beginning of FY 1999 to the present. Most users of the KPVT (now SOLIS), Hilltop and ESF are efficiently served by regular synoptic data from these facilities and only rarely require unusual data via the PI route. As SOLIS operations evolve and stabilize, we plan to introduce a PI mode that will be interleaved with the normal synoptic observations, taking advantage of SOLIS' planned remote observing capabilities.

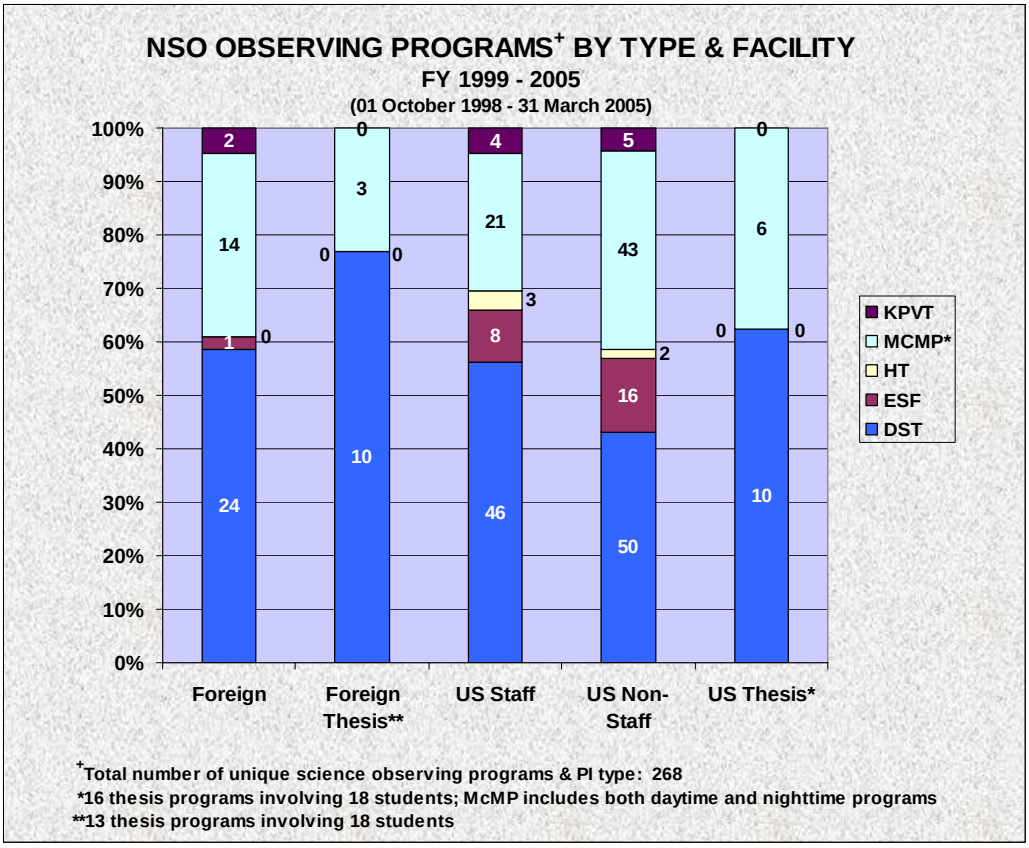


Figure 4.6-1. *Unique science observing programs and PI types by facility.*

Figure 4.6-2 shows the co-PI distribution by facility and whether they are staff, non-staff or foreign. For the period covered, there were 268 PIs and 417 co-PI's using the facilities. The much larger number of synoptic data users is not included here. The Web statistics in Section 4.5 give some feel for the number of users accessing NSO synoptic programs.

Figures 4.6-3 gives the status of users (PI and co-PI) and their institutional representation. Finally, the demographics for US and foreign users are presented in Figures 4.6-4a and 4b.

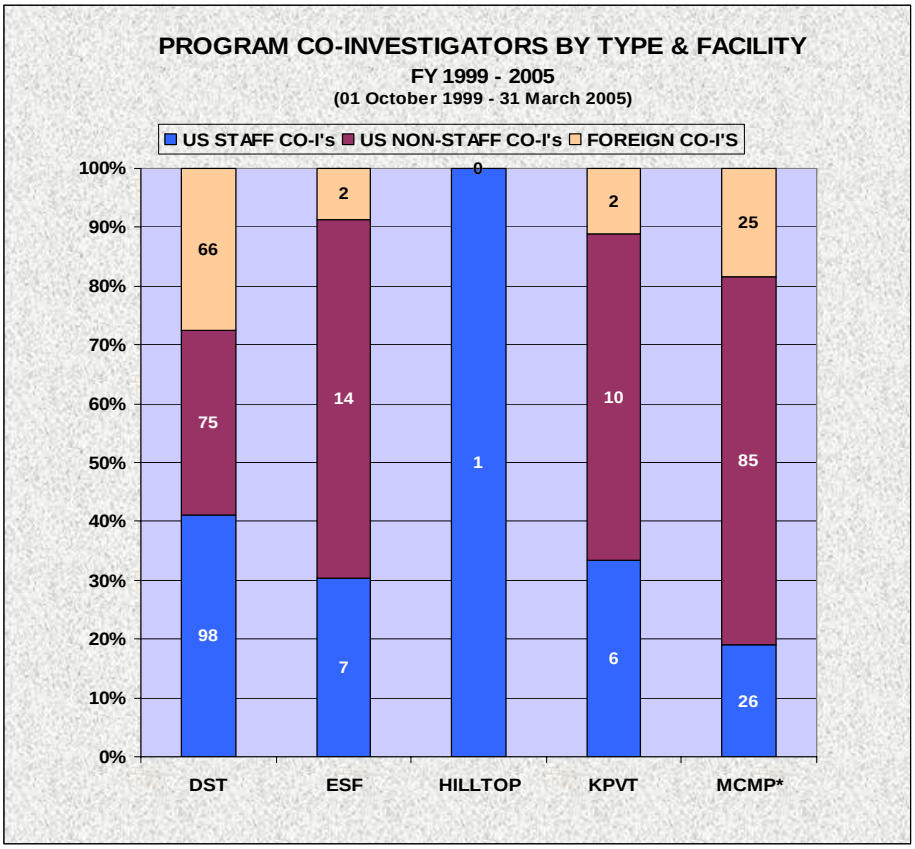


Figure 4.6-2. *Co-PI's by facility.*

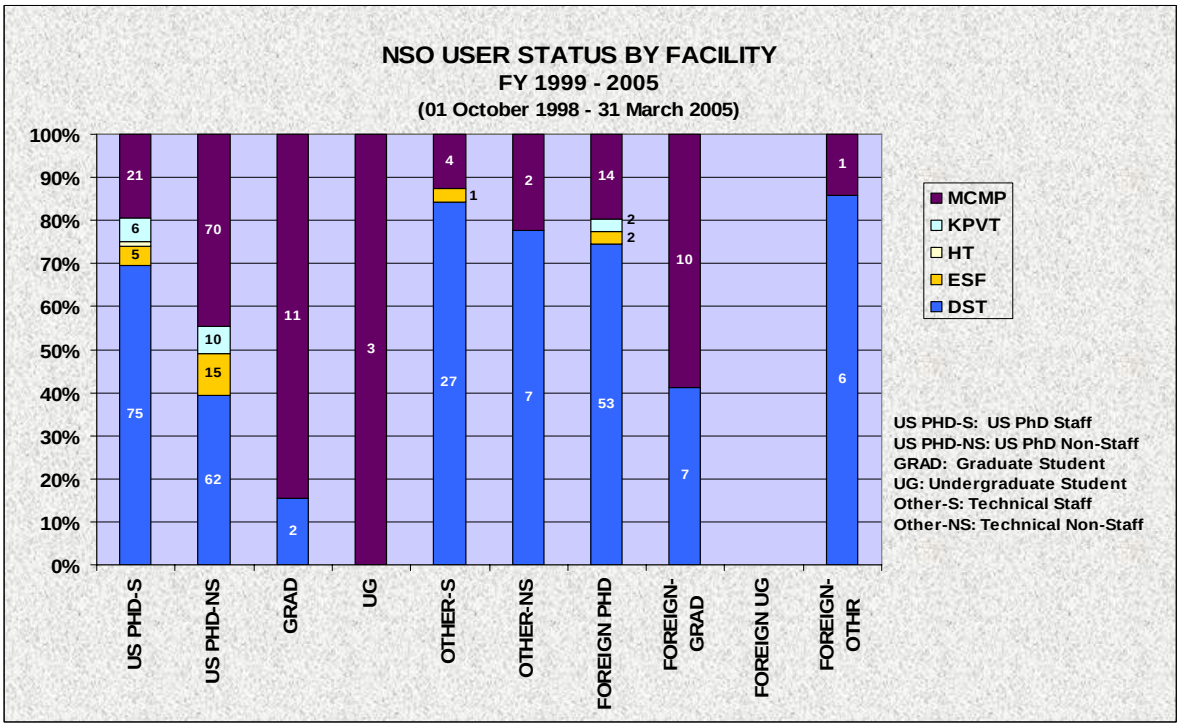


Figure 4.6-3. *Status of users by facility.*

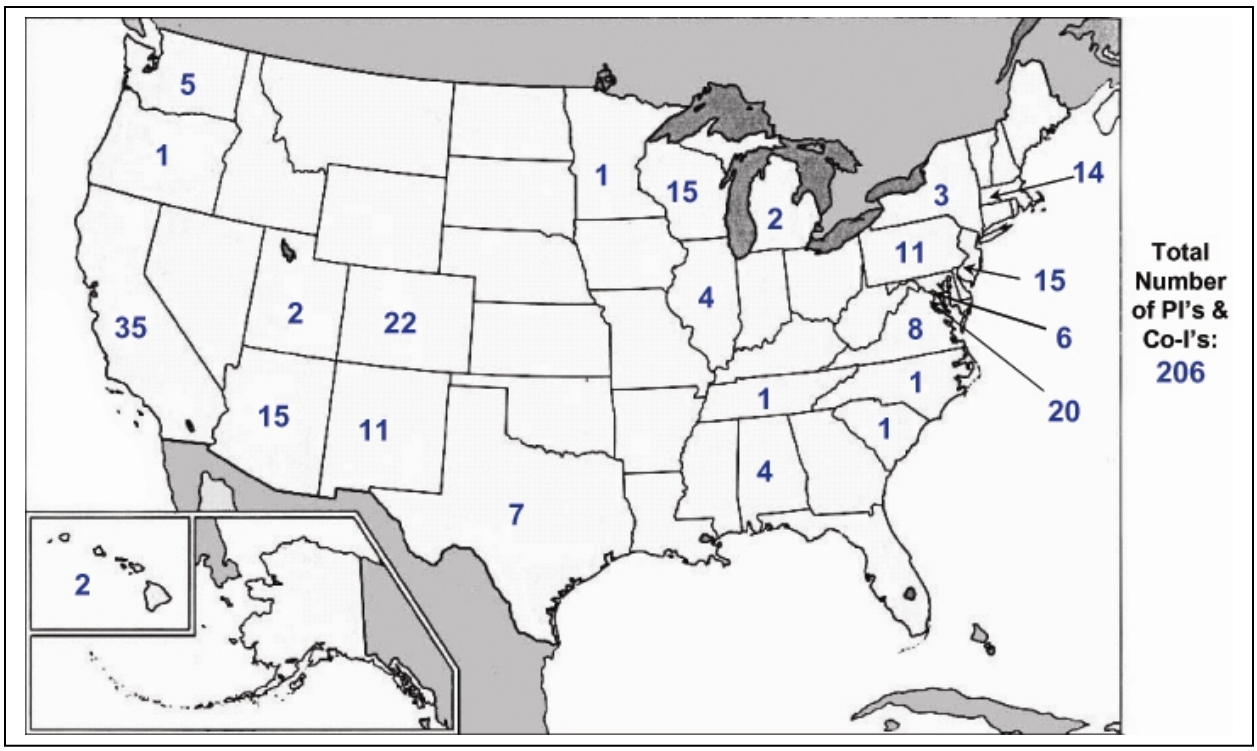


Figure 4.6-4a. *User demographics. US PI's and Co-I's do not include NSO or NOAO staff.*

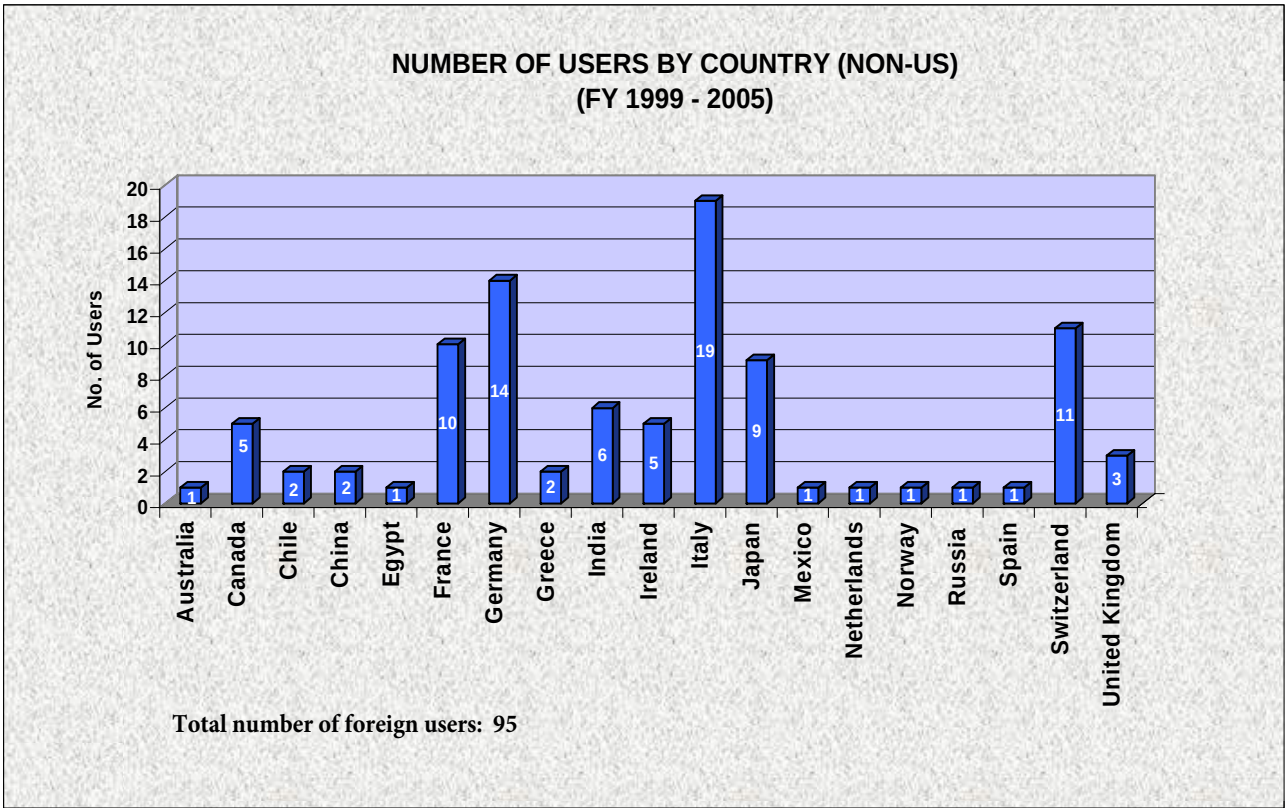


Figure 4.6-4b. *Foreign user demographics.*

Community usage of NSO facilities is realized via many different mechanisms, in addition to the investigator actually going to the telescope, and the systems approach to current solar physics problems leads to a very significant reliance on synoptic datasets, key programs, and heavily processed data, in addition to exploring new observing methodologies at the telescope. For example, NSO serves virtually all of the helioseismology community since most researchers in this field use GONG as the principal data source, or in collaboration with other data, in their papers. None of these users applies for telescope time or goes to the telescope. The same applies to the several decades of KPVT data, or its successor SOLIS, to the ESF synoptic coronal emission line data and the Ca K-line monitoring of the Sun-as-a-star data, and the Hilltop (no ISOON) flare patrol.

In the Parker report on ground-based solar physics it was estimated that about 200 US universities had 1, occasionally 2 solar faculty with only a few (3-4) having more. As noted in that report, almost all of these support their research with NASA grants to reduce and look at data from space missions or related theory. Many of these researchers use ground-based data, but only if obtained at no expense to them (i.e., no travel to the observatory) from sources such as the NSO Digital Library. They rely on the NSO and private observatories to collect and process the data and make it available.

Currently there are ~500 members of the Solar Physics Division (SPD) of the AAS. The membership has grown by 75 members since 2000, primarily because of the new research supporting opportunities offered by space missions such as TRACE and SOHO. We expect similar growth with the advent of ATST, provided that adequate research support is made available. Of the 500 SPD members, we estimate approximately 90-110 are active ground-based observers. If we consider PI's + co-PI's, NSO serves about 110 scientists through scheduled observing runs per year. One should also keep in mind, for example, that only about 20-30 observing runs per year are scheduled on NSO's primary telescopes because of the 10-14 days normally allocated to each proposal due to the extensive instrumentation set-up times that are part of observing the same object in innovative ways virtually every observing run.

Thus, while ground-based data plays a crucial role in the progress of solar physics, only a small number of solar astronomers are active ground-based observers, and NSO serves a substantial fraction (>50%) of these.

5 Partnerships and the Solar Observing System

NSO facilities are a unique component of a set of national and international telescopes for studying the Sun. Although there is no formal system, the majority of observations at NSO facilities are coordinated with or used in conjunction with data from other observatories and space missions. To obtain 24-hour coverage from the ground, data from facilities in Asia, Europe, and North and South America are often combined. Ground-space collaborations often need many ground sites to ensure the availability of data over 24-hour periods. Ground observations, with their more flexible and often more capable instruments, provide more detailed observations that are often needed to interpret space-based measurements or to follow-up on discoveries made with space instruments.

Some of the unique roles played by NSO telescopes include: accurate polarimetry of solar structures at several heights in the atmosphere, simultaneous narrowband imaging and spectroscopy in multiple spectral lines.
Because solar physics plays a role in several disciplines (e.g., astrophysics, space-weather, solar-terrestrial physics), NSO often forms partnerships with other groups, some of which are collocated at NSO sites. Partnerships exist for operations, instrumentation and outreach programs.

5.1 Community Partnerships

Through its operation of the entirety of US ground-based solar facilities freely available to US astronomers on a competitive peer-reviewed basis and its ongoing synoptic programs, NSO is clearly important to the solar community. In turn, NSO must work closely with the solar community and provide leadership to strengthen solar research, renew solar facilities and to develop the next generation of solar instrumentation. Some past examples of NSO meeting this responsibility include development of GONG and enhancement of the GONG network, development of solar adaptive optics in collaboration with NJIT and the Kiepenheuer Institute, development of multi-conjugate adaptive optics, development of infrared observing capabilities in collaboration with the University of Hawaii, California State University-Northridge, and NASA, and participation in the development of advanced Stokes polarimeters in collaboration with HAO. Table 5-1 lists several ongoing joint projects and development efforts.

NSO sponsored several community workshops and forged an alliance of 22 institutions to develop a proposal for the design of the ATST and its instrumentation. NSO will continue to work closely with this group in leading the successful completion of the design and transition to construction of the telescope. A series of workshops on ATST science operations will begin this fall to provide guidance for developing a sound plan for exploiting the full potential of the ATST. NSO is developing partnerships with several European nations. Germany has sign an MOU with NSO for their participation in ATST and Italy, Spain and France are developing similar MOUs. Scientists from all of these countries have contributed to the ATST science definition, design and to the site survey.

NSO's strategic planning embraces the interdisciplinary nature and dual objectives of solar physics: in that it is both basic science and applied research. Likewise, NSO's relationships to its users reflect the diversity and richness of the communities they represent—solar and stellar astronomy, space plasma physics, solar-terrestrial relationships, space weather prediction, terrestrial atmospheric chemistry, and more. Table 5-2 is a summary of the current partnerships that provide operational support. NSO's long-standing relationship with the US Air Force space science group will continue into the ATST era. The Air Force Office of Scientific Research (AFOSR) a desires to keep their basic solar research program collocated with NSO and has indicated that they will help purchase and polish the mirror for the ATST.

In accepting this significant responsibility, NSO has forged partnerships that strengthen its scientific and observational programs while satisfying partner needs. These partnerships range from long-term "residential" relationships to the cooperative development of individual instruments. In return, funding and collocated personnel from the partners permit NSO to operate a wider variety of instruments for longer periods that it could otherwise afford.

Table 5-1. Joint Development Efforts	
Telescope/Instrument/Project	***Collaborators***
Advanced Technology Solar Telescope	HAO, U. Hawaii, U. Chicago, NJIT, Montana State U., Princeton U., Harvard/Smithsonian, UC-San Diego, UCLA, U. Colorado, NASA/GSFC, NASA/MSFC, Caltech, Michigan State U., U. Rochester, Stanford U., Lockheed-Martin, Southwest Research Institute, Colorado Research Associates, Cal State Northridge
Adaptive Optics	NJIT, Kiepenheuer Institute, AFRL
Diffraction-Limited Stokes Polarimeter ((DLSP)	HAO
Spectro-Polarimeter for Infrared and Optical Regions (SPINOR)	HAO
Narrowband Filters and Polarimeters	Arcetri Observatory, U. Alabama, Kiepenheuer Institute
Synoptic Solar Measurements	USAF, NASA
Fourier Transform Spectrometer	NASA
Advanced Integrated Field Unit	NJIT
IR Spectrograph and Cameras	U. Hawaii, Cal State Northridge

Table 5-2. Current NSO Partnerships	
Partner	***Program***
Air Force Research Laboratory	Solar Activity Research at NSO/SP; Telescope Operations; Adaptive Optics; Instrument Development; 6 Scientists Stationed at NSO/SP; Daily Coronal Emission Line Measurements; Provides Operational Funding: $450K-Base and Various Amounts for Instrument Development.
NASA	- Operational Funding for SOLIS: 2 Asst. Scientists; 1 Postdoctoral Research Asst.; 0.5 Instrument/Observing Specialist. - McMath-Pierce: Support for Operation of the FTS; Upper Atmospheric Research. - Funding for 2 GONG research fellows
NSF Chemistry	FTS Support

5.2 Synergy between Theory and Observations

Developments in theoretical modeling and high-resolution observations go hand in hand. One cannot exist successfully without the other. Observations of high spatial, spectral, and temporal resolution are needed to verify detailed predictions by analytical and more and more prominently numerical modeling. High quality models are required not only to interpret observations, but also to investigate what critical observations should be performed to distinguish between competing physical models.

At NSO we have developed an extensive radiative transfer code that can be used to calculate theoretical spectra from state-of-the-art numerical models in many different spectral diagnostics. This includes photospheric atomic and molecular lines in Local Thermodynamic Equilibrium (LTE), chromospheric lines under general Non-LTE conditions and with Partial Frequency Redistribution (PFD) if necessary, the effects of polarization in these lines caused by magnetic fields, and the effects of radiative transfer in multi-dimensional geometry. Spectra calculated through the numerical models cannot only be compared to observed spectra to assess the realism of the observations; they provide insight into the diagnostic characteristics of a given spectral feature.

We work with several groups that perform state-of-the-art simulations of solar magneto-convection, and make our numerical transfer code available to the community through the Web.

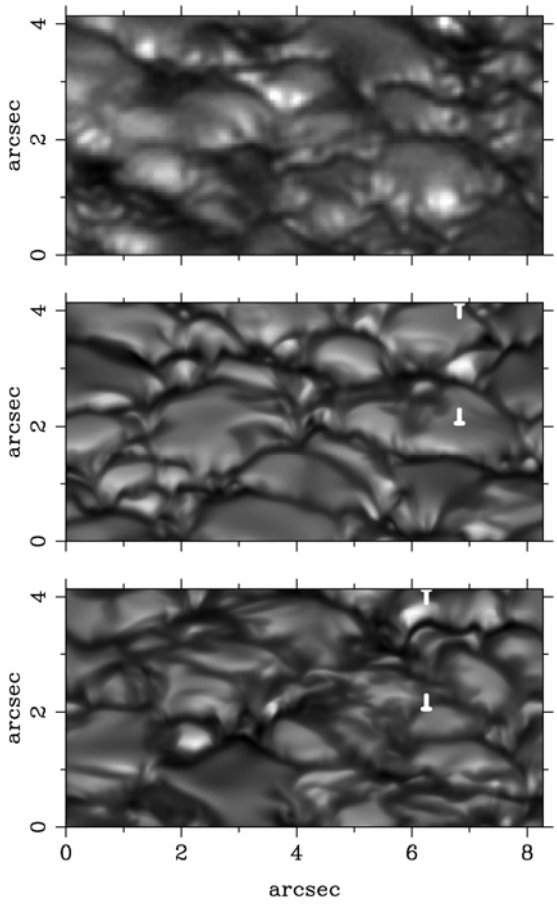


Figure 5-1. *Comparing simulations with observations, models of solar faculae. Observations (top) are compared with simulations at 488 nm and at a heliocentric angle of 60º with an average vertical magnetic field of 400 G (middle panel) and 200 G (lower panel). The upward direction is towards the solar limb. White marks point out two prominent faculae in the simulations. No attempt has been made to degrade the simulations to match the resolution of the observations. (Keller, Schussler, Vogler & Sakharov, ApJ 907, L59.)*

5.3 Synergy with Non-NSO Facilities

As noted, many if not most observing proposals at NSO involve collaborations with other facilities. For example, in 2004 60% of the science proposals for time on the DST have involved collaborations with other facilities and space missions. 16% of the proposals on the McMP have involved similar collaborations. Synoptic data from SOLIS is almost always used in the same fashion. Some recent examples include a program to understand photospheric dynamics around sunspot and filaments leading to filament eruptions and flares. Participating telescopes include the DST and ISOON on Sacramento Peak, SOLIS on Kitt Peak, the Dutch Open Telescope on La Palma, Spain, the Paris Observatory, Meudon Observatory, and Pic du Midi Observatory in France, THEMIS on Tennerife, Spain, and from space, TRACE images, SOHO/MDI magnetograms and CDS spectra. They observed for three weeks in October 2004 and will repeat for three weeks in September 2005. The DST produced high-speed time sequences simultaneously in H-alpha, white-light, and the G-band. During the next run, DST vector magnetograms will also be obtained with the Italian Interferometric BIdimensional Interferometric Spectrometer (IBIS) at the DST.

From 2003-present, NSO scientists have conducted collaborative studies with colleagues from US and non-US organizations to investigate: a relationship between X-ray luminosity and magnetic flux, the helicity properties of solar active regions, the cyclic variation of helicity, coronal heating associated with emerging active regions, the role of kink instability in CMEs, chirality patterns in chromospheric filaments, the relationship between photospheric and coronal electric currents, the relationship between twist and tilt of active regions, a comparison of photospheric and coronal magnetic fields derived from radio observations, transequatorial loops, and properties of coronal bright points. In addition to NSO facilities, these projects used data from the following instruments: ISOON/USAF, Yohkoh/SXT, stellar observations, SOHO/EIT, SOHO/MDI, WIND,

Mees Solar Observatory/Haleakala Stokes Polarimeter, H-alpha full-disk telescope/Big Bear Solar Observatory, NASA/MSFC vector magnetograph, Siberian Solar Radio Telescope, and the Nobeyama Radio Telescope.

In collaboration with several theorists, modelers and data analysts, drawn from USAF/AFRL, NASA, Helio Research Inc. and the University of Colorado, NSO scientists have searched for chromospheric signatures of mass ejections. They propose an explanation for the mechanisms by which the chromosphere responds to large-scale loop eruptions and resulting transient coronal holes and CMEs. The data were obtained from ISOON, at Sacramento Peak and SOHO instruments MDI, LASCO and EIT. They discovered sequential, wave-like chromospheric brightenings, which are accompanied by EIT flare waves, the eruption of transequatorial loops, and mass ejections. Their model describes these sequential brightenings in the chromosphere as magnetic foot-points of field lines that extend into the corona. They are energized in a sequence of magnetic reconnections that occur when coronal fields tear away from the chromosphere during an eruption of the transequatorial CME. These results are presented in a paper: "Sequential Chromospheric Brightenings beneath a Transequatorial CME" by Balasubramaniam et al. to appear in *The Astrophysical Journal*, 630, September 2005 issue.

Scientific research using infrared spectroscopy, polarimetry and imaging with the McMath-Piece telescope has been used in conjunction with several space- and ground based missions. These include the study of comet impact on Jupiter and studies of solar active region filaments. Another example of the synergy between ground- and space-based observations can be seen in "An Erupting Active Region Filament: Three-Dimensional Trajectory and Hydrogen Column Density" (Penn, 2000, *Solar Physics*, 197, 313). Here large field-of-view, high-cadence spectropolarimetry in the near infrared (around the He I line at 1083 nm) from the ground is combined with smaller field-of-view spectroscopy of the EUV He II 30.4 nm line (and others) from the SOHO spacecraft to study the velocity and column density of an erupting filament.

GONG is unique in providing full time, high-resolution helioseismic science. The ESA/NASA SOHO spacecraft's Michelson Doppler Imager provides comparable resolution data, free from atmospheric distortions, but because of limitations in the download capacity it is available only two months per year; in addition the satellite is now beyond its nominal mission and has been subject to prolonged outages in the past. The two programs work extremely closely with one another—the biennial GONG meeting is now a joint GONG/SOHO meeting, the MDI PI is on the GONG Scientific Advisory Committee, the chair of GONG's Data Users' Group is the MDI data scientist, and a key member of the MDI science team is on the GONG Magnetogram Users' Group—and the subtleties of the data and subsequent analysis are such that intercomparisons are constantly carried out. Other ground-based helioseismology efforts include the BiSON integrated sunlight, sun-as-a-star, network which does only the very lowest order global modes, the ECHO two-site moderate resolution network, and occasional observations at Mount Wilson and the South Pole. NASA's Solar Dynamics Observatory (SDO) is under development and a key component will be the Helioseismic and Magnetic Imager (HMI) which should provide 4096^2 data starting in 2009. Working close to the noise limit imposed by the Sun, instrumental systematics introduce subtle effect and the only way to detect them is by a separate observation—a key part of the scientific process—in addition to which given the strong scientific community and the growing interest in a real predictive capability offered by helioseismology, it is not prudent to put all of the world's eggs in a single, fragile basket.

When the ATST comes on line, it will open a new realm of synergistic studies. Figure 2.2 in Appendix F provides a synopsis of some of the possible types of synergies.

5.4 Software Provided to the Community

The GONG Reduction and Analysis Package (GRASP) is the collection of IRAF-based routines and scripts used for the GONG global helioseismology processing, and it is provided to the community, where several groups rely very heavily upon it.

Local correlation tracking software developed at NSO is now in wide use throughout the solar community. Distribution has been by request from individual PIs to the NSO staff. ISOON is using tracking algorithms developed by NSO scientists as a standard tool in their reductions.

Virtual Solar Observatory inquiry tools are being developed at NSO in collaboration with NASA, Stanford University, and Montana State University and are being distributed to all institutions with archives of solar data. Site Survey software was distributed to all of the institution participating in the ATST site survey and is now being used along with the instruments at other observatories at their request. As mentioned earlier, the NSO developed radiative transfer code is available on the Web.

Many data reduction and analysis programs written in IDL are given to visiting scientists so they may quickly assess the data they are collecting. These packages are often taken back and implemented at their home institutions. Examples include flat fielding algorithms for spectrograms (which is often very difficult to achieve). Flat fielding algorithms based on the actual images (rather than flat fields) were developed at NSO and are now used on ISOON and at other observatories including the HAO/PSPT, Rome/PSPT, THEMIS, Pic du Midi, and the Swedish Solar Telescope on La Palma

6 Costs

At both of its operating locations on Sacramento Peak and in Tucson, NSO conducts several different operations. The NSO annual program plan breaks out costs by both location and work break down function. In the following sections we have allocated costs to various facilities and programs. This process contains uncertainty because of changing maintenance and user requirements, evolving instrument programs, and shifting emphasis of the science staff between ongoing operations and projects.

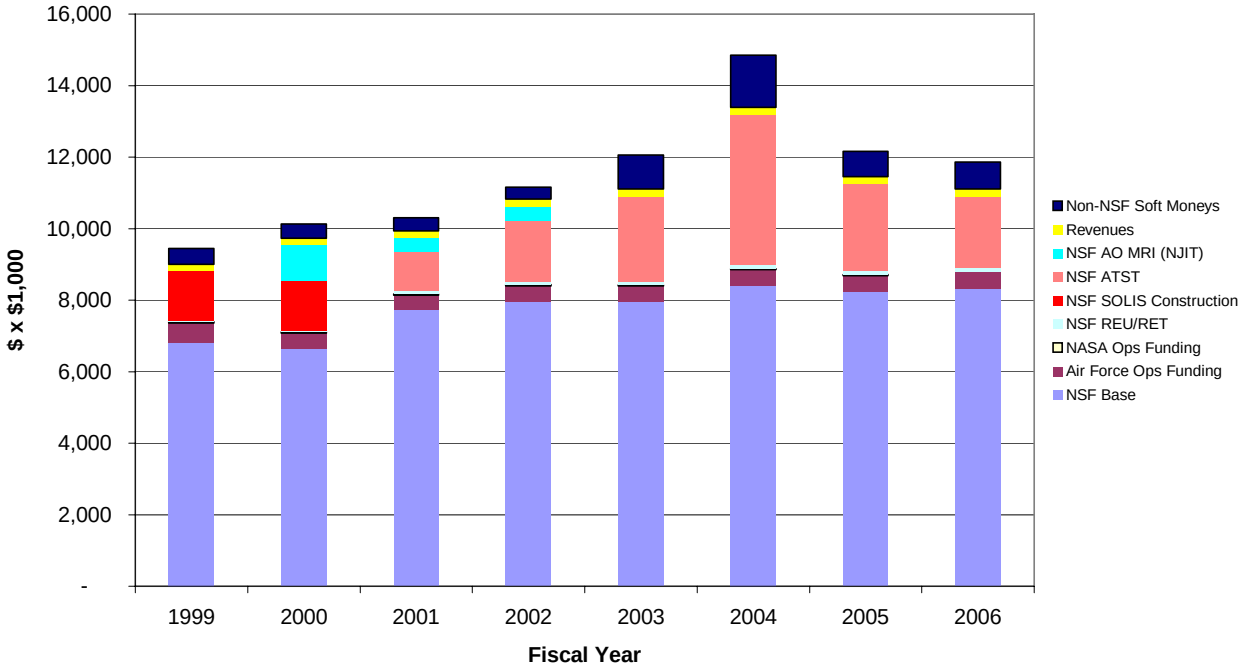


Figure 6-1. *Income from all funding sources.*

Table 6-1 lists all the funds received by NSO from 1999 to the present by funding source. These values are plotted in Figure 6-1. Funds labeled "NSF Base" are the funds used to support users through ongoing facilities operations, instrument programs, scientific support, and outreach. Air Force operational funding is used at Sacramento Peak to support the resident AF staff and ESF operations and is added to the general operation fund. In addition to the direct funds received from the Air Force, AF personnel stationed at NSO provide

manpower to various projects such as the ATST design and site survey efforts and to the NSO EPO program. Similarly, the "NASA Ops" funding supports the KPVT and now SOLIS operations. The REU/RET funds are received via a proposal to NSF that is resubmitted every five years. SOLIS construction funds were received as part of a facilities renewal proposal. NSF ATST funds were obtained through a community proposal to NSF for the ATST Design and Development (D&D) effort spanning the period 2001-2005. The 2006 ATST funds are bridge funding for continuing the design effort into construction. The ATST D&D funds support the ATST design/engineering team and efforts at partner universities and the HAO for instrument designs. The MRI funds were part of a joint proposal to the NSF/MRI program with NJIT. NSO matched these funds with approximately $1M from its base funding to develop the adaptive optics systems now in use at the DST and Big Bear Solar Observatory. Revenues include funds earned at Sacramento Peak from housing rentals, Visitor Center operations, and the kitchen. Finally, non-NSF soft monies include funding received from various proposals to NASA, other divisions at NSF, and other funding agencies and are listed in the tables in the following section.

Table 6-1. NSO Income from All Funding Sources

Fiscal Year	1999	2000	2001	2002	2003	2004	2005	2006
NSF Base	6,825	6,642	7,742	7,969	7,956	8,400	8,234	8,331
Air Force Ops Funding	535	432	400	435	439	450	450	450
NASA Ops Funding	32	32	32	32	32	32	32	
NSF REU/RET	40	40	80	80	80	111	117	118
NSF SOLIS Construction	1,400	1,400						
NSF ATST	-	-	1,100	1,700	2,400	4,186	2,413	2,000
NSF AO MRI (NJIT)		1,000	400	400				
Revenues	172	182	182	207	207	207	207	208
Non-NSF Soft Monies	443	400	361	331	939	1,458	709	759
Total	9,447	10,128	10,297	11,154	12,053	14,844	12,162	11,866

6.1 Spending Breakdown by Location & Facility

Although we have broken down costs by location and facility as requested for this review, it should be remembered that the program is operated as a whole, whereby programs and facilities at both sites are used collaboratively to give a global view of the Sun and to address the science questions discussed throughout this document.

6.1.1 Sacramento Peak

Table 6-2 presents the distribution of funding at Sacramento Peak based on FY 2006 start salaries (these were determined in April 2005) as normally presented to the NSF. Although the allocation of funds among individual facilities and programs varies from year to year depending on maintenance needs and the distribution between instrument and telescope improvement projects, we have attempted to divide the costs shown in Table 6-2 among science support, individual telescope operations, instrumentation programs and in-house science, and instrument support going to the ATST.

Table 6-3 shows this allocation among operation of individual facilities, science, and instrument programs. Current instrument programs include MCAO, DLSP, SPINOR and an upgrade of IBIS to a polarimeter. While these instruments are being developed for use at the DST, they are all also aimed at defining instruments for the ATST. Thus we view the instrument effort as something that NSO would continue even without the present facilities. However, having ready access to the DST (or the McMP in the case of Tucson) makes these programs highly efficient.

Table 6-2. Costs Attributed to Sacramento Peak at the Beginning of FY 2006

	Payroll	*Non-Payroll*	*Total*
Scientific Staff	349,626		349,626
Scientific Support	200,904	148,412	349,316
Telescope Operations	177,902	26,423	204,325
Instr & Telescope Support	486,215	48,497	534,712
Facilities Support	286,052	350,755	636,807
Administrative Support	224,293	24,681	248,974
ATST In-house Contribution	431,000	80,000	511,000
NOAO Support		150,000	150,000
Visitor Center	24,637	32,000	56,637
Total Spending	**2,180,629**	**860,768**	**3,041,397**
USAF Support			(450,000)
Misc. Revenues			(157,720)
Total NSF Expenditures			**2,433,677**
NSF Base Funding			**2,248,000**

If one excludes the NOAO support, which is primarily composed of partial FTEs in budgeting, payroll, and human resources, NSF spends just under $2.3M at Sacramento Peak. These NOAO support funds along with the USAF funding and revenues would not be recoverable through closure of the Peak.

Table 6-3. Allocation of Sacramento Peak Costs to Facilities and Programs

	OPERATIONS								
	SCIENCE	General	DST	ESF	HT	ISOON	Instrument Program	ATST Support	Total
Payroll	506,220	65,391	696,408	66,595	12,487	4,162	429,192	400,175	2,180,630
Non-Payroll	205,360		210,269	18,691	3,504	1,168	176,655	95,122	710,769
NOAO Support	39,000		51,300	4,560	855	285	37,800	16,200	150,000
TOTAL	750,580	65,391	957,976	89,846	16,846	5,615	643,647	511,497	3,041,399

In Table 6.3, most of the cost of the ESF and all of the ISOON costs are covered from the USAF support ($450K). The remaining USAF funding is distributed among the various support functions that support observatory operations and provide support to the resident USAF scientists. General operations include maintaining communications, computers and networks.

Funding that would be recovered by closure of a telescope facility or all of Sacramento Peak depends on what part of the programs are retained and transferred to a new location. The revenues and Air Force funding would certainly be lost. The NOAO support consists of partial FTEs in Tucson and would not be recovered. Thus complete closure and dismissal of the entire staff would save about $2.28M year. Assuming that all the science and technical staff supporting instrumentation and the ATST are retained along with sufficient support at their new site requires $1.9M, this reduces the net savings per year to $377K. In theory, the $1.4M currently going into science and instruments outside of ATST could be reprogrammed. This may make sense after MREFC and partner funding are secured and ATST is near commissioning. Then we do not risk losing both the NSO science and technical staff and the user base that will exploit the ATST.

Closure costs for Sacramento Peak have been estimated, but they depend on several assumptions. If staff is retained, there will be a one-time relocation cost that would include moving and securing office and laboratory space. The current estimate for this is about $250K for moving and relocation. Our estimates for demolishing

all the structures on Sac Peak are between $1.5M and $2.0M. The degree to which the land must be restored would have to be negotiated with the US Forest Service and is a potential cost driver.

6.1.2 Tucson/Kitt Peak

Table 6-4 shows the distribution of funding at Tucson including SOLIS but excluding GONG, which is discussed separately in the next section. For the purposes of this table, of Table 6-5 below and Table 6-7 in the GONG discussion, we have transferred the salaries of the NSO Tucson staff that devote most of the science to helioseismology to the GONG budget. A substantial fraction of the cost of operating the McMath-Pierce telescope is included in the NOAO budget (~$400K). This includes technical support for maintenance (~1.5 FTEs) and some fraction of the overall cost of keeping Kitt Peak open. These costs are not considered recoverable to NSO unless all of Kitt Peak were shut down. Again, even though costs vary from year to year depending on maintenance needs and the distribution between instrument and telescope improvement projects, we have attempted to divide costs among science support, telescope support and instrumentation in Table 6-5.

Table 6-4. Costs at Tucson Attributed to Tucson at the Beginning of FY 2006

	Payroll	*Non-Payroll*	*Total*
Scientific Staff	381,196		381,196
Scientific Support	187,584	52,958	240,542
Telescope Operations	142,629	71,115	213,744
Instrument Development	393,891	46,538	440,429
ATST In-House Contribution	150,000	40,000	190,000
SOLIS	319,464	199,769	519,233
VSO	87,750	105,701	193,451
NOAO Support		450,000	450,000
Astrobiology	110,794		110,794
Total Spending	**1,773,308**	**966,081**	**2,739,389**
NASA SOLIS support	-199,074	-32,000	(231,074)
NASA Astrobiology			(110,794)
NASA VSO Proposal			(193,451)
Total NSF Expenditures			**2,204,070**
NSF Base Funding			**1,586,778**

Table 6-5 shows the allocation among facilities, science and instrument programs. Current instrument programs include the development of a large format IR camera, development of the SOLIS Full-Disk Patrol, and making the IR-AO system user friendly. The IR camera and its uses at the McMP support the ATST effort and will also be available for use at the DST and other telescopes.

Table 6-5. Allocation of Tucson Spending to Facilities and Programs

	OPERATIONS							
	SCIENCE	McMP	SOLIS	VSO	ATST Support	Instrument Program	Astro-biology	Total
Payroll	$ 190,060	$ 178,460	$ 339,650	$ 287,325	$ 154,441	$ 457,346	$ 110,794	$ 1,718,077
Non-Payroll	$ 42,658	$ 68,193	$ 170,235	$ 105,701	$ 40,000	$ 144,525		$ 571,312
NOAO Support	$ 49,004	$ 76,350	$ 118,880	$ 20,638	$ 26,675	$ 158,452		$ 450,000
TOTAL	$ 281,722	$ 323,004	$ 628,765	$ 413,664	$ 221,116	$ 760,323	$ 110,794	$ 2,739,389

Table 6.5 contains soft money from NASA for the VSO, Astrobiology, and SOLIS. The first two are almost completely funded by NASA while NASA contributes $199,074 to the operation of SOLIS. Estimating the

savings from a complete shutdown of the Tucson operations and removal of assets from Kitt Peak is somewhat difficult and intertwined with GONG and KPNO operations. As mentioned above, the cost of operating the McMath-Pierce telescope shown in Table 6.5 does not contain mountain support from NOAO. The value of this support is estimated at about $400K and is embedded in the KPNO budget. If we remove the soft-money support for SOLIS, the VSO and Astrobiology ($485K) from the Tucson budget, NSO saves about $2.25M/year with complete closure and dismissal of the entire staff. If only the McMP is closed, $323K is saved, assuming the technical and science staff that support the facility are reprogrammed into ATST and SOLIS efforts.

Closure of facilities on Kitt Peak would require dismantling the McMP and the SOLIS Tower (the old KPVT). These costs are estimated at about $750K. Assuming SOLIS is to be retained and relocated to a new site (e.g., with the ATST), the relocation cost is estimated at about $500K.

6.1.3 GONG

GONG is headquartered in Tucson and operates six telescopes located at sites around the world. GONG funding pays for the operations of the sites, collection, processing, archiving, and distribution of the data for scientific analysis. Table 6-6 gives the breakdown of GONG funding. As mentioned in the previous section, the GONG scientific staff salary line item shown here contains the Tucson scientists that primarily do helioseismology as well as those scientists hired primarily on soft money to support GONG.

Table 6-6. Cost of GONG, Excluding NOAO Prorated Support

	Payroll	*Non-Payroll*	*Total*
Scientific Staff	895,160		895,160
Scientific Support	155,385	45,000	200,385
Telescope Operations	454,998	653,300	1,108,298
DMAC Operations	473,173	214,992	688,165
Administrative Support	159,976	15,900	175,876
NOAO Support		320,000	320,000
Total Spending	**2,138,691**	**929,192**	**3,387,883**
NASA SEC GI			(250,000)
NATO			(52,207)
Total NSF Expenditures			**3,085,676**

In addition to their own science, the GONG scientific staff supports the analysis and distribution of data and the development of new algorithms and applications, while the DMAC support includes data processing, archiving, and distribution. Since GONG telescopes must operate as a unit to obtain unbroken time sequences, we have not broken the costs down further as we have in the other two sections. Closing GONG and dismissing the entire staff would save about $2.7M/year, after losing the soft-money grants and removing the NOAO support. These savings would not be realized immediately because of closure costs.

Estimating GONG closure costs is complicated by agreements with the various host countries and observatories. GONG entered into a Memorandum of Understanding (MOU) with each of its site host organizations. These MOUs include termination clauses, with well-defined time periods (six months to one year, depending on the site), which control the start times for removing the on-site equipment. In addition, the termination clauses include returning the site to its original condition. All of the equipment, materials, and

goods, including accessories, spare parts, and instruments provided at the sites by GONG remain the property of AURA/NSO, thus, all high-value items will be returned to Tucson, incurring freight charges.

If a decision were made to shutdown the network, it would take about six months to put into place a complete plan to dismantle the site stations and cleanup the locations. Once the third station in the network is turned off, the network would be considered shut down and data collection at the remaining sites would stop. It is estimated that it would take a minimum of one month per site to dismantle the station and return the site to its original condition (a minimum of six months to dismantle the network). We estimate the cost of closure to be approximately $2.9M.

Following the removal of the network stations, the program would begin ramping down program resources. Part of the science staff (4 FTEs) would be retained to complete the analysis of the final data, 3 FTEs would remain to complete the data reduction, processing, and archiving, and a minimal administrative staff would be needed to close-out the program. This would cost approximately $1.1M per year, reducing the savings from $2.7M to $1.6M for the first few years following closure.

6.2 NSO Relocation and ATST Operational Costs

We do not have solid numbers for these costs at this point. When the ATST comes on line, the NSO plan calls for consolidation of its staff to a single headquarters location and establishing a remote operations center for the ATST. The SOLIS unit on Kitt Peak would be moved to the ATST site or to another site providing stable seeing conditions. (One possibility is BBSO, which currently hosts one of the GONG sites, and even though they do not achieve the extremely good conditions that make Haleakala the choice for the ATST, they do have almost no ground turbulence coupled with very good average seeing throughout the day. SOLIS could be located there without a high tower.)

The cost of establishing a new NSO headquarters varies significantly, depending on the need to construct (a) new building(s) or to lease (an) existing building(s). Of course consolidation to an existing site would be less expensive, but neither of the current NSO sites could accommodate the staff from the other site without obtaining more office and laboratory space. One of the goals of relocating NSO and consolidating the staff is to establish a strong relationship with a university that would form synergistic programs with NSO and promote the growth of the solar community by giving better access to students. What the university might provide in the way of infrastructure and its cost may vary widely depending on location. NSO has talked with several universities that have expressed interest in hosting NSO.

Rough estimates of one-time costs for relocation of NSO would include $15-20M for a building(s) and $1-2M for moving the staff and equipment. These are in addition to the cost given above for closure of existing facilities. As part of its planning for ATST, NSO will formulate a plan for relocations and make realistic estimates of these costs.

A preliminary estimate of the total number of positions that will be required to support the ATST is ~ 50-55. We anticipate that 40-45 of these positions will be located at the ATST site and the remainder at NSO Headquarters. In addition, the ATST will receive support from the NSO Director's office, and will share services with other NSO programs, such as the NSO Digital Library and Virtual Solar Observatory, SOLIS and GONG, and Headquarters instrument laboratory.

Table 6-7. FY 2004 Estimated Annual Cost for ATST Operations ($K)

Total Payroll	**5,435**
Non Payroll	**4,516**
Instrument & Facility Development (e.g., MCAO)	**3,000- 4,000**
TOTAL	**12,951 – 13,951**

Typically, operations require 5-10 % of the capital cost. For the ATST, this would be between $8.5M and $17M in FY 2004 dollars. A bottom-up estimate, based on our knowledge of current operations at the Dunn Solar Telescope and the McMath-Pierce Solar Telescope Facility, must be increased to account for the higher level of technological complexity to be used in ATST. Comparisons with new nighttime facilities that use similar technologies imply approximately $10M. This assumes a dedicated staff for ATST operations of approximately 50 people. In addition, we estimate a need for ongoing development of new instrumentation every few years at $2M per year. We anticipate incorporation of major telescope upgrades during the lifetime (e.g., adaptive primary and/or secondary, MCAO) and perhaps a few major maintenance items not covered in routine maintenance. Facilities upgrades, such as implementation of MCAO, add another $1M to $2M to the operations phase, each year, for the first 5-10 years for a total of $13-14M per year in today's dollars (see Table 6-7). The current NSO operations budget is $8.4M, which includes the science program, GONG operations, and SOLIS operations at a minimum level, and operation of the existing telescopes. Given that about $6.2M of the current operations would shift from existing telescopes (Table 1, Executive Summary), an additional $7M to $8M will be needed to sustain ATST operations along with the remainder of the NSO programs, giving the need for an overall NSO budget of $17M to $18M, depending on the level of new instrument development.

7 Conclusions

NSO has a robust program that supports a wide variety of users from PI experiments to those who use the synoptic data in their scientific research, to the space weather community. It has a logical roadmap fully supporting the goals of the solar community as expressed through the Astronomy and Solar and Space Sciences Decadal Surveys and the Parker Report on ground-based facilities, at the same time providing ongoing support to the solar community.

With GONG++ implemented and the first SOLIS station well on its way, it is important that the Senior Review properly address the role and timing of the ATST to the growth of solar astronomy, and, accordingly, provide for a timely entry into the MREFC process.

APPENDIX A

Science Themes

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

Interior Structure and Dynamics

Through the Global Oscillation Network Group (GONG) program, NSO provides a fundamental data set and contributes substantial staff research to the study of the structure and evolution of the solar interior over extended periods of time. Combined with data from the SOHO/SOI experiment, these helioseismology experiments are revolutionizing our understanding of the Sun. These data enable solar researchers to investigate the structure of the deep solar interior, which maintains its role as a fundamental physics laboratory (as confirmed with the recent awarding of the Nobel prize in physics), to study the nature of the microphysics underlying the theory of stellar structure (e.g., the equation of state, opacities, diffusion of species, and the revolutionary new heavy element abundances), probe the structure of the upper and lower boundaries of the solar convection zone where the solar dynamos are thought to operate, delineate the properties of subsurface rotation and flows and their evolution with the solar cycle, and investigate the physics of the p-mode oscillations themselves.

Through operating the GONG instruments, now upgraded to higher spatial resolution, over the 22-year Hale Cycle of magnetic activity, NSO makes a substantial contribution to the data set that the solar community requires in order to advance our understanding of solar (and stellar) structure and dynamics. These studies will help distinguish among competing dynamo models, contribute to the prediction of the solar activity cycle, and yield insights on the nature of the operative dynamo mechanism(s) in stars.

Origin of the Solar Activity Cycle and the Dynamo

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

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

New observations using infrared spectral lines at the McMP will be made with a variety of infrared detectors, including the new NSO Array Camera (NAC). From polarization measurements using the well-known He I

1083 nm and Fe I g=3 1565 nm spectral lines, to sunspot studies with the 2231 nm Ti I line, to the most sensitive magnetic measurements possible with the 12000 nm Mg I emission line, the high flux and all-reflecting optics of the McMP still provide a unique facility to conduct highly sensitive IR magnetic measurements. Unique spectral measurements of the coronal emission line at 3934 nm will also be made at the McMP with the NAC, taking advantage of the darker sky background at longer infrared wavelengths.

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

Transient Eruptions: Flares and Coronal Mass Ejections (CMEs)

NSO synoptic observing facilities currently provide some information on flares and CMEs, but crucial measurements are unavailable, such as the evolution of the vector magnetic field. SOLIS will provide these as well as a large variety of data suited to address the topic of transient activity. It is this transient activity that is especially relevant to the determination of space weather and its potential hazards to space activity. In addition to the SOLIS data, the NSO provides, through the GONG facility, continuous one-minute-cadence longitudinal magnetic flux measurements with a nominal resolution of 5 arcseconds. These data have proven to be of great value in defining magnetic field changes associated with flares.

Although small-scale processes trigger CMEs, they result in a major large-scale restructuring of the solar corona, causing propagating chromospheric disturbances and coronal/chromospheric waves, and even triggering flare outbursts in distant active regions. A unique combination of full-disk observations (SOLIS, ISOON) will enable a comprehensive study of the complex phenomena associated with the CME eruptions. The results, in turn, will be of particular relevance to the space weather community since Earth-directed CMEs are now recognized as the major drivers of the physical conditions in the near-Earth space environment.

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

Origin of Variability in Solar Irradiance

The KPVT, and now SOLIS, provides the basic magnetic field maps that are successfully used in modeling solar irradiance variations. The RISE/PSPT network, developed at NSO and now operated by HAO and California State University at Northridge, provides highly accurate intensity images of the Sun to identify the regions with increased or decreased solar irradiance. The use of PSPT data with SOLIS magnetograms and new high-resolution observations of magnetic fine structure with the ATST may shed light on how magnetic fields interact to provide the energy driving these irradiance variations.

Heating of the Outer Atmosphere and the Origin of Solar Wind

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

The McMath-Pierce telescope enables observations of the cool component of the chromosphere by studying carbon monoxide in the thermal infrared. Such combined measurements in the optical and thermal IR are necessary to diagnose the structure of the chromosphere and the associated heating mechanisms. The DST is currently being used to measure signatures of magnetic reconnection, which may play an important role in

heating the atmosphere. The ATST will have a major impact in understanding chromospheric and coronal structure and heating. Among the salient investigations that will be conducted is the detection of MHD waves in the photosphere through the measurement of temporal variations of the Stokes parameters in individual flux tubes.

Many coronal structures (e.g., coronal bright points, loop-like structures, transequatorial loops) may be formed as a result of magnetic reconnection. Although these structures are typically observed in the EUV or X-ray from space-borne instruments, the observation of the vector magnetic fields in the photosphere and chromosphere are essential for understanding and modeling the process of magnetic reconnection. SOLIS (and, to a lesser extent, GONG) will play a unique role in providing such data.

Surface and Atmosphere Structure and Dynamics

Using the newly developed adaptive optics system at the DST and image reconstruction techniques, NSO staff and visiting scientists have obtained the highest resolution time sequences of solar magnetic, intensity, and velocity fields ever made (~0.14"). They have discovered a wealth of features inside magnetic pores, intergranular lanes, and sunspots that suggest there is unresolved fine structure below the resolution of existing solar telescopes. Images from the 1-meter Swedish Solar Telescope have verified the presence of this fine structure. Establishing accurate physical parameters for small-scale flux is crucial for testing the results of numerical simulations and addressing flux formation and dynamics. NSO scientists have made observations of oscillatory magneto-convection, sub-arcsecond convective motions inside magnetic pores. In addition, NSO scientists have utilized the McMath-Pierce to discover the occurrence of rapidly moving magnetic elements in sunspot penumbrae. DST observations were used to uncover a dynamic of plasma flows associated with canceling magnetic features. A combination of magnetic and coronal data suggested the existence of very specific changes in magnetic field twist at early emergence of active regions. The continuation of the studies using a combination of ground-based and space-borne instruments is a necessary step in bringing further understanding of the evolution of magnetic flux in solar atmosphere.

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

With the ATST, individual flux tubes will be resolved and the joint variations of plasma, magnetic field, and temperature within and around the flux tube will be accurately measured, allowing direct comparison with theory. Moreover, the ATST will also provide accurate measurements of coronal magnetic fields off the limb in the infrared. New techniques for measuring coronal fields have been developed by Lin, Penn, Tomczyk, & Casini, and using the ESF (Lin and Casini, 2000, ApJ 542, 528; Lin, Penn, & Tomczyk 2001, ApJ 541, L83), and at the McMath-Pierce telescope Judge et al. (2002; ApJ, 576, 157) have conducted preliminary IR observations of this kind. Lopez, Casini, Lites and Tomczyk have used the DST to do full Stokes polarimetry in H-alpha prominences and spicules (Casini et al. 2003, ApJ 598, L67, Lopez & Casini, 2005, ApJ 621, L145 & A&A 436, L325). The ATST will extend this fundamental and uniquely powerful investigation of coronal magnetic properties to both higher sensitivities and resolutions. In addition, the ATST will complement the full-disk coronal capabilities that are expected to be available with FASR—the Frequency Agile Solar Radio telescope—a recommendation of the Decadal Survey.

The Solar-Stellar Connection

The stars offer a range in physical parameter space—rotation rate, mass, convection zone depth, metallicity, and so forth—that is unavailable with the Sun alone. Thus, stellar studies enable the investigation of the broad astrophysical applicability of models developed purely in a solar context. The relatively large aperture of the McMath-Pierce telescope, combined with its availability for utilization at night, led NSO to establish an innovative program in the study of the stellar counterparts of solar activity using high-resolution spectroscopy. Among the unique results of this program was the first ever measurements of a portion of the magnetic flux cycle in a solar-type star that exhibited a solar-like cycle in its Ca II H and K variations. Budgetary pressures

forced the elimination of the productive NSO stellar synoptic program at the McMath-Pierce in the late 1990s. The SOLIS integrated sunlight spectrometer is continuing Sun-as-a-star studies through daily observations in a variety of key spectral diagnostics such as the chromospheric Ca II H and K features. These spectra will be compared to analogous spectra obtained for solar-type stars in order to gain further insights on the nature and origin of spectral variability in the Sun and stars.

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

An active nighttime program of solar system investigations, supported primarily by NASA grants, continues at the McMath-Pierce complex. In addition, preliminary discussions have begun (with Prof. Jian Ge, University of Florida) concerning the establishment of a long-term program of Doppler spectroscopic observations of extrasolar planetary systems. This project would utilize a significant fraction of the available nights at the McMath-Pierce telescope. These kinds of long-term investigations serve as prototypes of the programs that could be initiated at the 4-m ATST on behalf of the community. Finally, NSO scientists are actively participating in a NASA-supported (NAI) program in astrobiology, in collaboration with the NOAO and the University of Arizona at its Life and Planets Center (LaPLACE). NSO participation involves the characterization of brightness variations in solar-type stars spanning an evolutionary range of ages.

Appendix B

Dunn Solar Telescope

The 76-cm *Dunn Solar Telescope*, located on Sacramento Peak at an altitude of 2804 m, is the U.S. premier facility for high-resolution solar physics. It is an evacuated tower telescope with a 76 cm entrance window. The evacuated light path eliminates internal telescope seeing. The image enhancement program over the past few years has included active control of the temperature of the entrance window to minimize image distortion and high-speed correlation trackers to remove image motion and jitter. The DST has two high order adaptive optics (AO) systems feeding several optical benches. These systems provide diffraction-limited seeing under moderate to poor conditions making possible stunning time sequences of not only images, but of spectral sequences leading to vector magnetic field and Doppler measurements.

Observations with the DST have revealed the fundamental nature of convective overshoot in the solar atmosphere, led to the realization that solar oscillations are global in nature, and provided the first detection of the locations where the p-modes are excited. Using AO developed by the NSO with the DST in conjunction with the Advanced Stokes Polarimeter, developed by the High Altitude Observatory (HAO), detailed, quantitative measurements of the vector magnetic field associated with sub-arcsecond magnetic flux tubes have been accomplished. Much of our knowledge about sunspots and the evolution of solar active regions is being challenged by the new high-resolution observations. Detailed measurements of sunspot penumbra have revealed the mechanisms leading to the Evershed flow. High-resolution observations of surface flows have revealed twisting motions and magnetic helicity changes prior to activity events, which may provide a basis for solar activity prediction. Other highlights include the first measurements of prominence magnetic fields, maps of sub-arcsecond convective motions inside magnetic pores, oscillatory magnetoconvection, measurement of weak fields inside granules and observations of magnetic reconnection in the chromosphere.

NSO users and staff are vigorously pursue the opportunity presented by high-resolution, diffraction-limited imaging at the DST. This work continues to help refine ATST science objectives and requirements and ensures the growth of the expertise needed to fully exploit ATST capabilities. With the advent of AO, the DST has seen an increase in proposal pressure and the over subscription rate has nearly doubled. Major science themes from Section 3 that this work will address include:

- *Transient eruptions*. Flux tube evolution and interactions that trigger activity.
- *Origins of solar variability and atmospheric heating*. Role of small-scale flux tubes, convection, and waves.
- *Surface and atmospheric structure*. Fields and flows in magnetic structures such as sunspots, pores, filaments, and prominences.

Recent Science Results with the DST

Observational Evidence for Magnetic Flux Submergence

It is widely believed that the magnetic field on the Sun is generated by a dynamo operating at the base of the convection zone, although recent studies suggest that there may be a second dynamo operating at or near the visible solar surface, the photosphere. In 1984, Eugene Parker concluded that only a small fraction of magnetic flux threading the solar surface can escape. He also pointed out an inconsistency between the upper limit of magnetic flux stored at the base of the convection zone and the rate of flux emergence in a long-lived complex of activity. To resolve this "dynamo dilemma," Parker suggested that magnetic flux retracts below the surface and is recycled several times. So far, however, this flux submergence has proven to be illusive.

Magnetic flux concentrations in the photosphere often disappear via flux cancellation when opposite poles collide with each other and vanish. The reconnection forms two loop-like structures: concave-up and concave-down. The magnetic tension would try to "shorten" newly formed "loops," and thus, at the place of maximum curvature (apex/valley), one loop would show rising motions, and the other would show descending motions. The observer would see only one loop crossing the photosphere whenever the reconnection took place below or above the photosphere.

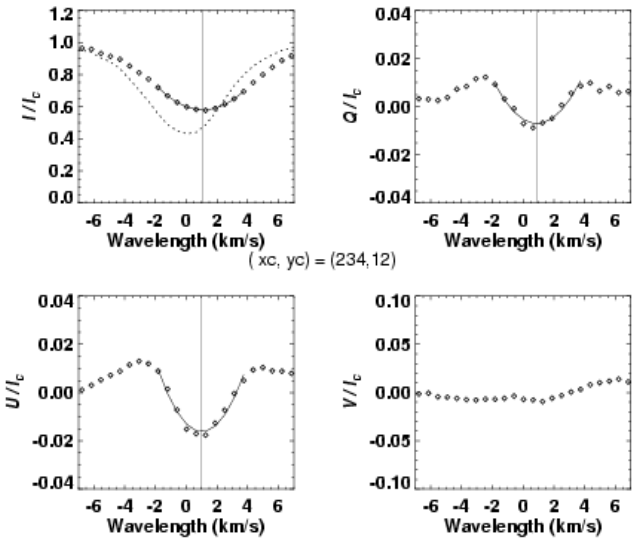


Figure B-1. *Stokes profiles at the flux cancellation site shown in Figure B-2. The wavelengths for all profiles are expressed in units of velocity relative to the nearby quiet Sun. Negative velocity corresponds to blueshift, or upward (with respect to image plane) motions. The dotted curve in the top left panel shows the Stokes I profile from the quiet Sun area. The vertical solid line represents the center of the Stokes profile.*

Using high-resolution vector magnetograms of active region NOAA 10043, observed on 26 July 2002 with the Advanced Stokes Polarimeter and low-order adaptive optics system at the NSO Dunn Solar Telescope, Alexei Pevtsov (NSO), in collaboration with Jongchul Chae (Seoul National University and Big Bear Solar Observatory) and Yong-Jae Moon (Korea Astronomy Observatory and Big Bear Solar Observatory) studied the magnetic field topology and line-of-sight velocities at two flux cancellation sites. The observations showed that near the cancellation site, the longitudinal magnetic field vanishes, but the transverse field reaches its maximum. This implies that the magnetic field is mostly horizontal there, as at the top of a loop connecting two canceling bipoles. However, the velocity map shows significant downflows where the magnetic field is horizontal, suggesting that the magnetic field is moving downwards. Detailed analysis of Stokes profiles at the flux cancellation site support the above description of plasma motions and the magnetic field topology. These rare observations provide the first observational evidence for submergence of magnetic flux on the Sun. Further studies of magnetic flux submergence would provide important clues for understanding the origin and evolution of magnetic flux on the surface of our nearest star.

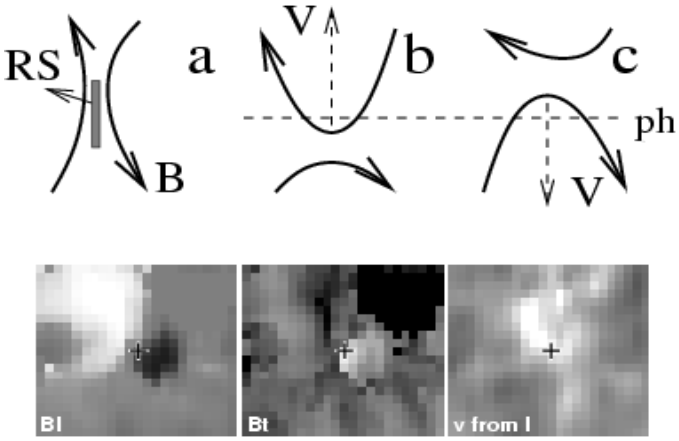


Figure B-2. *Upper panel: Schematic representation of the magnetic topology at a flux cancellation (reconnection) site (RS) prior to reconnection (a) and after the reconnection below (b) and above (c) the photosphere (ph, horizontal dashed line). Solid lines with arrows represent the magnetic field B, and vertical dashed arrows show the direction of motion of newly formed loops. Lower panel: Observations of a flux cancellation site; longitudinal field B_l (white/black corresponds to positive/negative polarity), transverse field B_t, and Doppler velocity V (white halftone corresponds to downward motions). The flux cancellation site is marked by a "+".*

Plasma Flows and Fine-Scale Structure in the Solar Atmosphere with Adaptive Optics

Theoretical models of magnetoconvection are now being challenged to explain plasma-field interactions at fine-scale in the solar atmosphere. Plasma flows associated with small flux concentrations (Rimmele 2004, ApJ, 604, 906) were obtained with the DST using high-order AO. The bright points in Figure B-3 mark the location of magnetic flux concentrations. Strong narrow down-flows are located at the edge of most flux concentrations. This is the first direct confirmation that strong downflows at the edge of flux tubes are driven by radiative losses into the evacuated magnetic structure. MHD simulations predict such downflow jets.

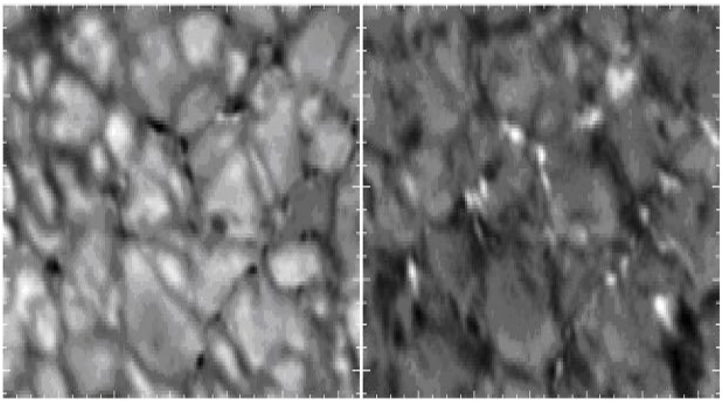


Figure B-3. *Velocity obtained from the Fe I 5434 spectral line (Left) and intensities in the line wing (Right) show strong downflows (dark features) are associated with bright intensity features where magnetic field penetrates the solar surface. The images cover a FOV 8.6 x 12.6"and tick marks show 0.5" intervals.*

Internetwork Fields

The weak, small-scale fields of the quiet Sun "internetwork" regions have been the subject of considerable scientific scrutiny recently. New observations (Lites and Socas-Navarro 2004, ApJ, 613, 600) have attained both higher sensitivity and higher angular resolution, revealing a wealth of small-scale structure, and demonstrating that the net "unsigned" flux of the Sun rivals, or even exceeds, that of the 11-year-period solar active region fields, as well as that from the intense flux concentrations at the boundaries of the quiet solar supergranular network pattern. Theorists have also examined the internetwork fields and speculate that a local, small-scale dynamo may be acting to produce those fields. The reality of this dynamo process, and the influence that the small-scale mixed-polarity internetwork fields have upon heating and dynamics of the solar atmosphere, are issues that are of considerable prominence in solar physics today.

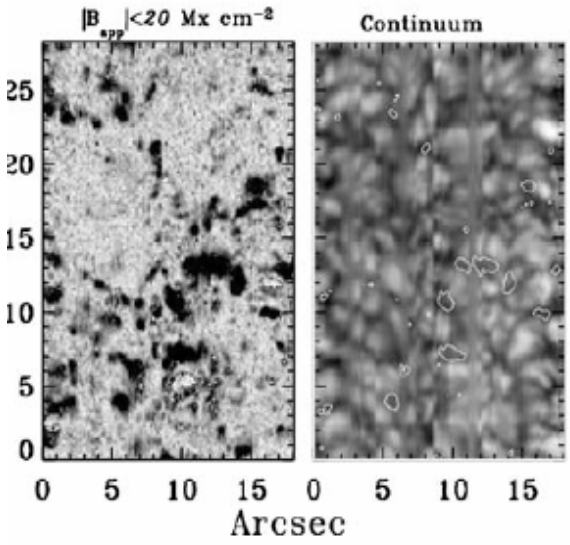


Figure B-4. *Observations of a small patch of quiet Sun from the DLSP on 16 September 2003 reveal the very weak. fields of the "internetwork" regions. Left: $|B_{app}|$, the unsigned apparent flux density, scaled so that maximum strength (dark) corresponds to 20 Mx cm^{-2}. Right: Continuum intensity from the spectral map used to generate the image on the left, with contours of 32 Mx cm^{-2} superimposed. Other studies, based upon newer but unproven observational techniques, would have all the dark intergranular lanes occupied by strong, mixed-polarity elements (i.e., such contours would cover most of the dark lanes in this map). Variable seeing causes the vertical stripes.*

The new Diffraction-Limited Spectro-Polarimeter (DLSP) at the NSO Dunn Solar Telescope (DST) is ideally suited to explore this topic. In combination with adaptive optics systems now in place at the DST, much higher angular resolution of the internetwork fields may be achieved, while maintaining very high polarimetric sensitivity. High spatial resolution is necessary to better resolve the tangled small-scale field, and high polarimetric sensitivity is necessary to detect the intrinsically weak and small-scale magnetic elements. The DLSP is based on the same spectropolarimetric technique as its predecessor, the Advanced Stokes

Polarimeter (ASP), which provides spectrally resolved, simultaneous line profiles in all four Stokes polarization parameters. Among extant techniques, spectropolarimetry yields the most complete and unambiguous inferences of magnetic fields in the solar atmosphere.

These measurements represent the highest spatial resolution precision spectropolarimetry of the quiet Sun yet obtained. The results are illustrated in the figure, where the inferred apparent magnetic flux density |(Bapp)| is shown at high sensitivity on the left panel for a small patch of quiet Sun. The right panel shows the corresponding continuum intensity ("granulation") with contours of |Bapp| < 32 Mx cm_{-2}. These results demonstrate that it is far from the case that most intergranular lanes are occupied by strong flux elements. In fact, the net unsigned flux of these DLSP measurements is not much different from older ASP measurements at half the spatial resolution. Note also the extensive regions devoid of significant flux at this polarimetric sensitivity (which is some factor of 10 better than that of recent observations suggesting otherwise).

These DLSP observations suggest that the complexity and the net unsigned flux of quiet internetwork regions in fact do not increase rapidly at smaller scales. These early results must be verified by the much more capable final version of the DLSP. Such observations are now scheduled, and will examine the properties of the quiet Sun internetwork fields in various regions of quiet Sun large-scale structure.

Diffraction-Limited Stokes Polarimetry of Sunspots and Flares

The Diffraction-Limited Spectro-Polarimeter (DLSP) was used to obtain ultrahigh-resolution Stokes profiles of a sunspot at the Dunn Solar Telescope (DST) on 24 October 2003. The observed Stokes profiles were processed to produce polarization maps of the sunspot. Figure B-5 shows the continuum intensity and polarization map of the observed sunspot. A total of 660 steps were used to scan the field of view and it took about 50 minutes of observing time to produce this high-resolution map. Structure close to the diffraction limit of the DST is visible in these maps, showing that the goal of diffraction-limited polarimetry has been achieved.

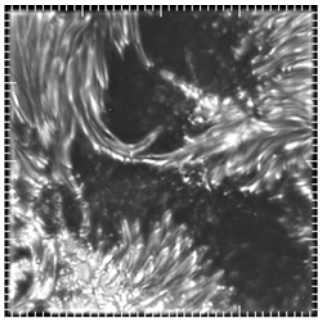


Figure B-5

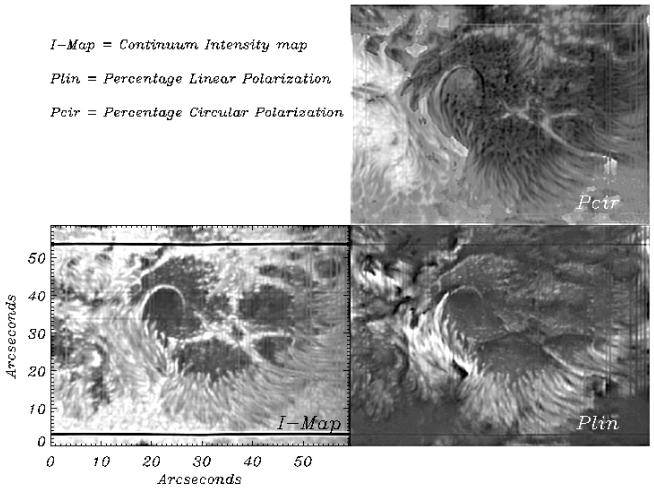


Figure B-6

On 23–25 October 2003, the DLSP recorded several scans of active regions. During much of the observing time, the high-order AO delivered excellent and consistent image quality, and we were able to scan a sunspot with the DLSP's highest spatial resolution mode (0.09-arcsec step size). The Universal Birefringent Filter (UBF) recorded high-resolution Hα filtergrams and spectral scans of a photospheric line (Fe I 543.4 nanometers). G-band images were recorded to provide contextual information, and flare activity was observed in two different active regions. Movies of Hα filtergrams, Dopplergrams, and G-band images are currently being produced. A stunning first Hα flare movie has been posted on the NSO Web page (*www.nso.edu*) showing, to our knowledge for the first time, flare structure at scales of 0.2 arcsec (see Figure B-6). DLSP vector magnetic field maps were recorded before and after the flare.

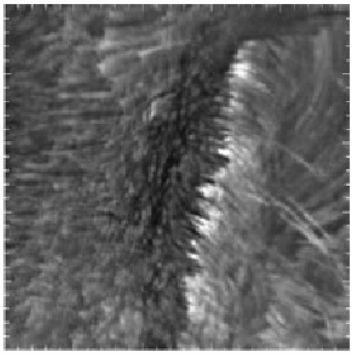


Figure B-7

An Hα image of a flare is shown in Figure B-7. The small sunspot observed close to the limb on October 24 was part of the big active region that produced the X17.2 flare on October 28. The time sequence shows a super-

penumbral loop system eruption. It appears that the footpoints of the loops, as well as some loop tops, become bright during the flare. The data indicate that the flare was triggered by new flux emerging in the lower right corner of the image. This particular image is from near the end of the flare. Tick marks are 1 arcsec. Structure on spatial scales of 0.2 arcsec is visible in this image.

Prominence Magnetic Fields

Using pattern recognition techniques combined with full Stokes polarimetry in He D3 line at 5876 Å obtained from the Advanced Stokes Polarimeter at the DST, A. Lopez and R. Casini (ApJ 598, L67-L70) measured the vector magnetic field associated with a prominence. They present the first magnetic maps of a prominence, derived from inversion of spectropolarimetric data in He I D3 using the principal component analysis of all four Stokes profiles. This prominence, along with several others, was observed in 2002 May using the Dunn Solar Telescope of the National Solar Observatory/Sacramento Peak Observatory, equipped with the High Altitude Observatory Advanced Stokes Polarimeter. The use of an unocculted instrument allowed them to map the prominence magnetic fields down to the chromospheric limb. Their analysis indicates that the average magnetic field in prominences is mostly horizontal and varies between 10 and 20 G, thus confirming previous findings. However, their maps show that fields significantly stronger than average, even as large as 60 or 70 G, can often be found in clearly organized plasma structures of the prominence.

Future Research Plans with the DST

Below is a sampling of the many problems that can be attacked with diffraction limited spectroscopy and polarimetry using the DST and adaptive optics. While we expect to make progress on many of these outstanding problems, we expect to open even more questions that must await the advent of the ATST to answer.

Sunspot Polarimetry

What is the nature of magnetic and velocity fields in sunspot umbra, penumbra and super-penumbra? Using AO with the DLSP and SPINOR it should be possible to probe the substructure of the umbra and understand the changes in convection that occur in the presence of strong magnetic fields.

G-band and continuum images show that umbral dots (or umbral grains) have considerable structure. The AO system coupled with the DLSP and/or ASP/SPINOR high-resolution Stokes profile data of the photospheric and chromospheric levels can be used to search for spectral signatures of umbral dots. Using these instruments to derive vector magnetic field and LOS velocity data, there are plans to investigate structural characteristics of umbral dots and light bridges, and dynamics of these structures.

The dark fibrils in photospheric penumbra are coincident with dark Hα fibrils in the inner-super-penumbra of sunspots. The photospheric penumbra displays the Evershed outflow while the chromospheric outer super-penumbra displays an inflow. The nature of flows along the chromospheric inner penumbra are not well understood. Simultaneous, high-resolution spectropolarimetric observations of photospheric penumbra and chromospheric super-penumbra have been elusive, but now the combination of AO with advanced Stokes polarimetry should make such observations possible.

Filament Eruptions

What causes some filaments to quickly become unstable and erupt, often leading to coronal mass ejections? High-speed spectral images using IBIS and Stokes polarimetry with SPINOR and the DLSP will be used to measure the interaction between flows and the vector magnetic field to understand the stability of filaments and what triggers their eruptions. The full vector field is needed to accurately model overlying loops in the corona. To understand the consequences of flow-magnetic field interaction seen in the photosphere and chromosphere at higher atmospheric layers, these data will be combined with data from TRACE, SOHO, and eventually Solar-B and SDO. Data from SOLIS and ISOON will provide a global picture of how the filaments are interacting with other magnetic regions and will provide detection of 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.

Spicules

With the Diffraction-Limited Spectro Polarimeter and SPINOR, it should be possible to make detailed vector magnetograms of spicules. In a preliminary attempt (A&A, 436, 325, 2005), A. Lopez Ariste and R. Casini made observations of spicules in the He I D3 line with full-Stokes spectropolarimetry, using the Advanced Stokes Polarimeter at the Dunn Solar Telescope . The line profiles appear to be significantly broadened by non-thermal processes, which they interpreted using the hypothesis of a distribution of velocities inside the spicule. The possibility of inferring the magnetic field in those conditions was tested on synthetic data, and the results were generalized to the interpretation of the observed data. They concluded that the magnetic field is aligned with the visible structure of the spicule, with strengths above 30 G in some cases (for heights between 3000 and 5000 km above the photosphere). Because the ASP is not optimized for diffraction-limited imaging, spicule substructure and the possible mechanisms for acceleration were not tested. Recent models indicating that spicules are the channeling of *p*-mode waves along magnetic flux tubes are inferred from time sequences of images.

There is still much work to do to understand the physics of this interaction. For example, the twist and helicity in spicules may provide evidence of global magnetic helicity. Using high-resolution Hα imaging and Hα spectroscopy at the DST with the UBF, the DLSP a nd SPINOR it will be possible to investigate the vector magnetic fields associated with the magnetic network at the base of spicules. By doing this in the northern and southern hemispheres, it will be possible to ascertain whether or not there are hemispheric preferences of spicule twists.

Chromospheric Fields

Observing and understanding chromospheric fields are extremely important to understanding the link between photospheric fields, which are relatively easy to measure, and coronal fields, which are difficult to measure, but are where much of solar activity is manifested. Accurate measurements of coronal fields will require the ATST. Now coronal fields are usually inferred from loop observations and/or from models based on photospheric foot points. 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 Hα, Ca II 8542 Å, and Mg I 5172 Å, are intricately tied to an assumption of a model atmosphere coupled with non-LTE (NLTE) radiative transfer. NLTE radiative transfer methods have been developed at NSO and elsewhere to simulate chromospheric lines, under varied magnetic field strength conditions. Using Stokes polarimetry measurements of photospheric and chromospheric spectral lines at the DST, these, along with principal component analysis (PCA), will be applied to chromospheric Stokes spectra in order to derive chromospheric magnetic fields. These will be combined with photospheric field measurements to understand the 3-D magnetic structure of active regions.

Magnetoconvection

Models of magnetoconvection predict how the field should behave near the solar surface, the generation of waves along field lines, and the eventual submergence or annihilation of fields due to reconnection processes. While much of the physics lies below the resolution of the DST and must await the ATST to resolve, there are aspects of the interaction at the 0.2” level that the DST can be used to explore. This will help refine modeling efforts and compel modelers to begin thinking about the <0.1” level where much of the physics is thought to occur and that will be tested with the ATST.

The photosphere is a crucial region where energy is readily transformed from convective motion into thermal and magnetic energy, and electromagnetic radiation. The energy stored in magnetic fields is eventually dissipated at higher layers of the solar atmosphere, sometimes in the form of violent flares and coronal mass ejections (CMEs) that ultimately affect the Earth and drive space weather. Using the DST with AO,

narrowband polarimetric imaging and spectroscopy, the interaction of the flow with magnetic fields will be investigated using high cadence time sequences. Several campaigns with SOHO, TRACE and RHESSI are planned to link these measurements with upper atmospheric conditions.

The morphology, thermal structure and dynamics of small-scale flux concentrations drive much of the physics of the lower solar atmosphere. In the G-band these characteristics are readily observable, in intensity. However, for magnetic field measurements, we have had to rely on co-spatial and co-temporal measurements in other spectral lines, complicating interpretation. H. Uitenbroek, with REU student E. Miller-Ricci and A. Arsensio Ramos and J. Trujillo Bueno of the Spanish Institute of Astrophysics in the Canaries (2004; Ap. J. 604, 960), have made detailed radiative transfer calculations to predict the circular polarization characteristics of the CH lines in the G-band spectrum. With their demonstration of the feasibility of Stokes V polarimetry in the G-band, it is is now possible to make observations of magnetic structures in these regions to directly compare with models for flux tube behavior. The combination of the DST with AO and IBIS and SPINOR will lead to breakthrough observations in this area.

Instruments at the DST

Below we describe the primary instrumentation available at the DST. These are the instruments that will form the heart of DST-user support as we prepare for the ATST era. In addition, the DST has available a number of blocking filters with various band-passes, several Fabry-Perot filters, and high-speed correlation trackers.

Adaptive Optics (AO) – Multi-Conjugate AO (MCAO)

The DST now provides two identical AO systems, well matched to the seeing conditions at the DST and feeding two different instrument ports that can accommodate a variety of facility-class instrumentation, such as the Diffraction-Limited Spectro-Polarimeter (DLSP) and the new Spectropolarimeter for Infrared and Optical Regions (SPINOR), as well as experimental setups and visitor instruments such as the Italian Interferometric BI-dimensional Spectrometer (IBIS). NSO deployed the Big Bear Solar Observatory (BBSO) AO system in December 2003. The NSO AO team integrated the AO system into the BBSO optical setup and closed the servo loop at BBSO.

Another important aspect of this project is the development of AO data-reduction techniques and tools. The interpretation of AO data for an extended object like the Sun is challenging. The AO point spread function (PSF), and temporal and spatial variations thereof, must be understood in order to be able to interpret high-resolution imaging and spectroscopic data of solar fine structure. In collaboration with the Center for Adaptive Optics (CfAO) and researchers at the Herzberg Institute in Canada, the PSF estimation tools were developed by a graduate student during FY 2004. The student is now applying the computed PSFs to reconstruct an excellent time sequence of UBF filtergrams. This work will be the basis of his PhD thesis at NJIT.

The AO project is now focused on the development of multi-conjugate adaptive optics (MCAO). The Sun is an ideal object for the development of MCAO since solar structure provides the "multiple guide stars" needed to determine the wavefront information in different parts of the field of view. An MCAO proof-of-concept experiment was successfully performed at the DST using the two existing deformable mirrors placed at conjugates of two different altitudes in the atmosphere. The control loop was closed on three "guide stars." Initial evaluation of imaging data recorded during the observing run clearly shows an extended correct field of view compared to the conventional AO case. Several MCAO observing runs are planned for FY 2005 in order to perform a more detailed performance evaluation of the system and to optimize the system as needed.

The project will continue to work closely with other MCAO efforts at such institutions as the Kiepenheuer Institute, the National Optical Astronomy Observatory (NOAO), the Center for Adaptive Optics, and the Gemini Observatory.

Horizontal Spectrograph (HSG)

The Horizontal Echelle Spectrograph at the DST is an extremely flexible system. Several gratings with different ruling can provide spectral resolution up to 250,000. It can accommodate several cameras that

simultaneously observe different spectral regions. It has adjustable slit width, adjustable tilt and adjustable rotation capability. The entrance slit is contained in a reflective slit jaw that can be viewed with various imaging cameras for exact location of the spectral measurements on the Sun in different wavelength bands. Stepping of the slit on the Sun is controlled by the DST Instrument Control Computer (ICC), allowing complex raster scanning of active regions or other features. When used in the ASP mode, it is fed by rapidly rotating polarizers that chop between polarization states and that can be synchronized with the data cameras to permit near simultaneous accumulation of the four Stokes vectors.

Diffraction-Limited Specto-Polarimeter (DLSP)

The diffraction-limited spectro-polarimeter is a collaborative project between the High Altitude Observatory and NSO. The DLSP permits different image scales, from high-resolution (at the diffraction limit of the Dunn Solar Telescope) to lower resolution (0.25 arcsec/pixel) with a larger field-of-view. The DLSP is a fixed, facility-class instrument located on Port 2 and integrated with the high-order AO system and new CCD context imagers. A new modulation and demodulation package is included in order to make the instrument stand-alone. The DLSP achieves a spatial resolution equal to the diffraction limit of the DST. Context imagers include a 2K × 2K G-band camera capable of frame selection, a 2K × 2K CaK imager and a 1K × 1K slit-jaw imaging camera. Online Stokes inversion will be implemented into the DLSP data pipeline.

The DLSP was successfully operated during several engineering runs in 2004 and is now fully integrated with the high-order adaptive optics. Integration of the DLSP with the context imagers is underway while the instrument and its software are being fine-tuned. The DLSP will be fully commissioned for operations in August 2005. After commissioning, the DLSP will be made available for a "solar queue observing mode." This mode will make more efficient use of the optimal seeing conditions at the DST. The solar queue-observing mode will be defined within the observatory in close consultation with users and the ATST project and community. We plan to start implementation of this mode during FY 2006. In addition to more efficient DST operations and higher scientific productivity, we expect the experience gained at the DST to be very valuable in developing efficient operational modes for the ATST.

The Advanced Stokes Polarimeter (ASP) & the Spectro-Polarimeter for Infrared and Optical Regions (SPINOR)

SPINOR is also a joint HAO/NSO program to upgrade the existing advanced stokes polarimeter (ASP) at the Dunn Solar Telescope. The ASP has been the premier solar research spectro-polarimeter for the last decade. Its ability to explore new spectral lines and to observe in multiple lines simultaneously is still unique. However, the ASP wavelength range is restricted to the visible, limiting its ability to sample new solar diagnostics, and its hardware is becoming outdated and difficult to maintain. HAO has received National Center for Atmospheric Research (NCAR) funding to help develop SPINOR. SPINOR extends the wavelength of the ASP from 750 nm to 1600 nm with new cameras and polarization optics, provides improved signal-to-noise and field of view, and replaces obsolete computer equipment. Software control of SPINOR will be brought into the DST control system as opposed to the stand-alone ASP and will therefore be phased with the DST control system upgrade. SPINOR will augment capabilities for research spectropolarimetry at the DST and extend the lifetime of state-of-the-art research spectropolarimetry at the DST for another decade. A first test run with many elements of SPINOR was made in May 2005. Commissioning is currently planned for 2006.

Interferometric BI-dimensional Spectrometer (IBIS)

The Interferometric BI-dimensional Spectrometer (IBIS) is now available to the community as a user instrument at the Dunn Solar Telescope.. IBIS is a dual Fabry-Perot instrument that produces high spatial-resolution images with a spectral resolution of 25–40 milliangstroms. The instrument is fed by the recently upgraded high-order adaptive optics system on port 4. The observing staff at the DST have been through several training sessions and have produced a document describing the operational procedures.

Following its installation in June 2003, IBIS has been used successfully in a series of observing runs to look at granular dynamics, flares, and chromospheric structures. The instrument now features a white-light channel

that produces a diffraction-limited continuum image simultaneously with each spectral image. This is used to align and de-stretch the separate spectral images at each wavelength in the line profile. The instrument also has been used in conjunction with G-band and Ca II K filters as well as the UBF setup on the adjacent optical bench. Because of its high throughput, exposure times of 20–100 milliseconds are possible at the full detector resolution of 0.085 arcsec per pixel. This makes possible both short exposure times to freeze the atmospheric seeing and studies of fainter features such as prominences. The spectral sampling for each spectral line can be chosen based on the needs of a particular program.

IBIS can presently observe in one of five spectral channels: 1) 5896 angstroms – Na D1; 2) 6302 angstroms – Fe I; 3) 7090 angstroms – Fe I; 4) 7224 angstroms – Fe II; 5) 8542 angstroms – Ca II. In a recent collaboration with the High Altitude Observatory, IBIS was paired with a liquid crystal variable retarder to do di□raction-limited spectropolarimetry. Observations were made in the Fe I 6301-angstrom and 6302-angstrom iron lines, as well as in the chromospheric calcium and sodium lines. Further engineering will be needed to optimize the polarimetric performance and make this mode available tothe community as well.

Infrared Polarimeter

This is a collaborative project between the NSO and the University of Hawaii Institute for Astronomy (IfA) to provide a facility-class instrument for infrared spectropolarimetry at the Dunn Solar Telescope. H. Lin (IfA) is the principal investigator of this NSF/MRI-funded project. This instrument will be able to take advantage of the diffraction-limited resolution provided by the AO system for a large fraction of the observing time at infrared wavelengths. Many of the solar magnetic phenomena occur at spatial scales close to or beyond the diffraction-limited resolution of the telescope. NSO has made tremendous progress in adaptive optics instrumentation to provide the highest quality images possible on its existing telescopes in the past few years, and as of now, both Ports 2 and 4 at the DST are equipped with high-order AO systems. The IR polarimeter will reside on Port 2. A dichroic beamsplitter will be used to direct infrared light to the instrument. The detector is a 1K × 1K IR camera synced to a liquid crystal modulator. The project is currently in its conceptual design phase. Currently, most of the effort is located at the IfA. The NSO will contribute mechanical design work and manufacturing, and will assist with electronic and software design.

Universal Birefringent Filter (UBF)

The Universal Birefringent Filter is a Lyot-type filter with rotating crystal elements using quarter waveplates and linear polarizers to tune. The filter is a very flexible instrument to use. The UBF can be used as a primary or secondary instrument on the Port 4 optical bench or a secondary limited range tunable filter on the Port 2 additional science bench. The following information relates to the UBF in its standard configuration.

The UBF can be used in one of two bandwidths: 0.5 or 0.25 Å. The specified tunable range of the UBF is from 4000 to 7000 Å. It can be operated in different modes: Intensity Mode: direct imaging with wavelength scanning (direct filtergrams); Magnetic Field Mode: imaging of opposite circular polarizations (Zeeman Splitting); Velocity Mode: imaging of red and blue shifted transmission profiles (Doppler Effect).

Appendix C

McMath-Pierce Solar Telescope

Much of the infrared spectrum is still barely explored, especially in flares, sunspots, and the corona. The McMath-Pierce telescope will be used to pursue IR studies to develop techniques and science questions that will continue to refine the ATST IR capabilities. The implementation of the new high-quality IR camera (NAC, which saw first light in July 2005), and the upgrade of the drive systems in the near future, will ensure that the McMath-Pierce Solar Telescope will continue to contribute to solar physics research in a very valuable and unique way for many years to come, certainly until the planned Advanced Technology Solar Telescope becomes operational.

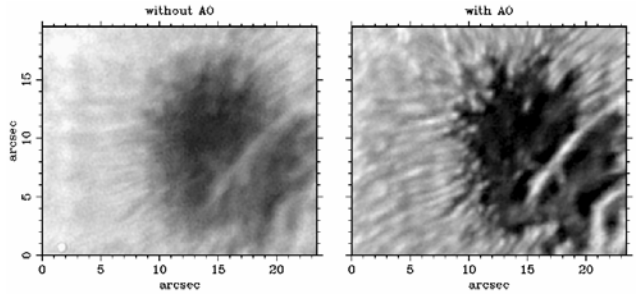


Figure C-1. *16-ms exposure-time images of a sunspot at 990 nm without (left) and with (right) adaptive optics. Both images were filtered with an unsharp mask to compress the large intensity range, and both are displayed at identical contrast. The image to the left was among the sharpest images recorded without adaptive optics.*

Recent Advances in Solar Research

Infrared polarimetry and infrared imaging developed at NSO have been combined with the McMath-Pierce Solar Telescope to reveal a ubiquitous presence of weak fields associated with turbulent convection at the solar surface that could play an important role in solar magnetic flux loss and heating of the outer solar atmosphere. Other observations with these systems have measured chromospheric magnetic fields and may provide the opportunity to directly observe coronal magnetic fields.

Scientific progress at the McMath-Pierce of the kind described above has exploited the unique features of the telescope. In particular, the new work in solar physics that we discuss in the following requires the uniquely large light gathering capability of the telescope, or uses the infrared capability of the all-reflecting optics, or utilizes both features. As these features of the McMath-Pierce are likely to remain unique until ATST is brought on-line, the telescope will continue to produce vigorous new work.

Hanle Effect and Related Novel Magnetic-Field Diagnostics

While the paper that introduced the Hanle effect for the diagnostics of turbulent magnetic fields (Stenflo 1982, Solar Phys. 80, 209-226) was largely based on observations obtained at Sacramento Peak, the introduction of the differential Hanle effect with combinations of spectral lines was done in 1998, based on McMath-Pierce observations with ZIMPOL in 1996. The focus by the Swiss team led by Jan Stenflo during their observing runs in recent years has been on the variety of complex effects that magnetic fields have on the Second Solar Spectrum, for instance in combination with optical pumping and hyperfine structure. Their results are still in the process of being prepared for journal publication (glimpses have been shown in conference proceedings). The initial work is described in the following: Stenflo, J.O., Keller, C.U., Gandorfer, A.: "Differential Hanle Effect and the Spatial Variation of Turbulent Magnetic Fields on the Sun." A&A, 329, 319-328, 1998, and Stenflo, J.O., Gandorfer, A., Wenzler, T., Keller, C.U.: "Influence of magnetic fields on the coherence effects in the Na I D1 and D2 lines." A&A, 367, 1033-1048, 2001.

The Second Solar Spectrum

The "Second Solar Spectrum" refers to the linearly polarized spectrum near the solar limb that is due to coherent scattering processes. The initial survey was performed at the McMath using the vertical spectrograph in the near UV and the Fourier Transform Spectrometer (FTS) in the visible above 420 nm with. The survey

results were published by Stenflo et al. (1983; A&AS 52, 161-180 & 54, 505-514). The combination of the ZIMPOL (Zürich Imaging Polarimeter) and the high photon flux available at the McMath-Pierce provided the polarimetric sensitivity needed for a systematic exploration of the new world of polarization physics in the "Second Solar Spectrum." The light-gathering power of the McMath-Pierce is crucial for the ZIMPOL instrument since its polarimetric noise is exclusively limited by the photon statistics, and effects that are too small to be seen with other instruments are being explored

Solar Magnetic Field Measurements in the Far Infrared

An instrument team from NASA/Goddard Space Flight Center, led by Donald E. Jennings, has been developing 12-micron polarimetry. The high Zeeman sensitivity attained at these long wavelengths enables high precision magnetic field studies utilizing spectral line diagnostics arising in the upper photosphere/low chromosphere of the solar atmosphere. Their efforts are described in a recent series of papers in *The Astrophysical Journal* entitled "Solar Magnetic Field Studies Using the 12-Micron Emission Lines." The most recent work in this series involves observations of a delta region solar flare (Jennings, et al. 2002, ApJ, 568, 1043). In an effort led by T. Moran, the NASA/GSFC group developed, for the first time, solar magnetograms from statistical moments at 12 microns. This work has been submitted for publication.

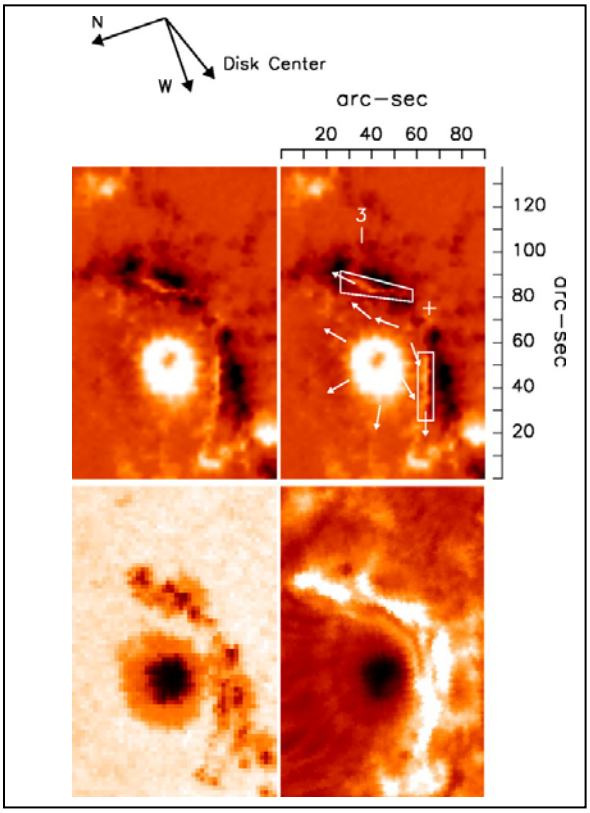


Figure C2. *ApJ 2002 v568 p1043 Jennings et al.*

The McMath-Pierce continues to be the only facility that can be used for this work because of its high photon flux and spatial resolution in the far IR, and the spacious and flexible laboratory environment for experimental work with visitor and other non-standard instrumentation. The experience in this particular effort has shown that the addition of adaptive optics at the McMath-Pierce improves imaging at 12 microns. Thus, the McMath-Pierce AO system is used regularly for this pioneering work. The experience gained in this program will be applied toward the design and construction of a polarimeter and thermal-IR spectrometer for the ATST.

Penumbral Moving Magnetic Features

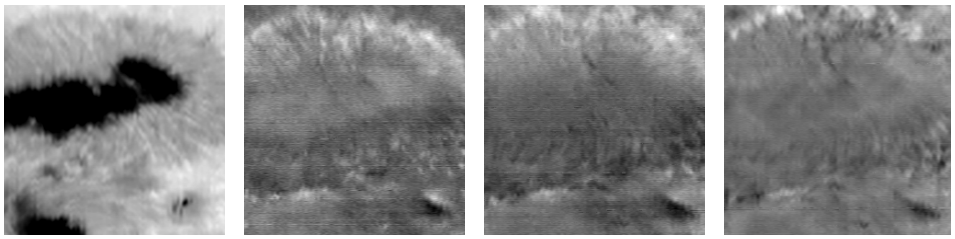
The sensitive magnetic spectral line of Fe I at 1564.8 nm has been used to measure the vector magnetic field in sunspots with the McMath-Pierce and the NSO/CSUN IR camera. Time sequence observations of two sunspots have shown that the well-known photospheric moving magnetic features (MMFs) can be traced back to moving magnetic features inside the sunspot penumbra. This is the first time that magnetic field observations have shown features systematically moving inside sunspot penumbrae, and such observations will yield important insights on the decay of sunspot magnetic fields, as well as the dynamics of the penumbral plasma. Penn and collaborators have recently submitted the results of this work for publication.

Molecular Spectroscopy of Evershed Outflow in Sunspots

A molecular line from CN at 1564.6 nm (near the well-known Fe I g=3 1564.8 nm line) has been used to provide a new window on the Evershed flow in sunspot penumbra. Not only does this spectral region probe a deep level in the photosphere (near the opacity minimum), but the molecular lines are sensitive probes of the plasma conditions in the cool plasma only, as there is little or no contribution function from plasma at photospheric temperatures to the line formation. Observations at the McMath-Pierce using the NSO/CSUN IR

camera of sunspots at various positions on the disk clearly showed large Doppler shifts of 6 km/sec in the line position, with some line absorption shifted even further suggesting flow speeds of up to 9 km/sec—speeds much faster than seen in previous Doppler studies using atomic spectral lines. These fast molecular Doppler speeds unite the Evershed flow speeds determined by tracking continuum features in the penumbral fibrils and the observations of atomic line asymmetry features in high spatial resolution penumbral spectra. Results are presented in Penn et al. (2003, ApJ 590, L119).

In a parallel investigation of the Evershed flow in sunspot penumbrae, images of penumbrae of sunspots near to the solar limb have been imaged at the wavelengths of CO lines of various strengths. Dopplergrams from these lines, originating from different depths in the solar atmosphere over the penumbrae, have been shown to map the outflow of CO at different depths. This flow appears to change from a radial direction for weak lines originating deep in the atmosphere to a spiral flow following the magnetic field direction for stronger lines originating higher in the atmosphere. The high-speed flow is correlated with darker fibrils within the penumbrae (Clark T.A., Plymate, C, Bergman, M.W., Keller, C.U. 2004, "Evershed flow of CO at Different Heights in Sunspot Penumbra," BAAS 36, 712).



1 **2** **3** **4**

Figure C3 -
1. *AR0507 continuum image, 4.7 microns, 46 (vertical) × 45 arcseconds (horizontal).*
2. *Weak ^{13}CO line Dopplergram.*
3. *Medium-Strength CO Dopplergram.*
4. *Strong CO line Dopplergram.*

CO Layer Heights

One of the enduring problems in the understanding of the upper solar atmosphere is the presence of significant amounts of the molecular gas, CO, existing in a hostile thermal environment where almost every observational indication points to gas temperatures of over 4000K. In distinct contrast, extreme-limb observations of CO lines in the IR solar spectrum show consistent equivalent temperatures at least 800K below the ambient gas temperature.

The continuing research program has concentrated upon determining the precise depth of CO emission within this inhomogeneous atmosphere. Key measurements have been eclipse observations of the occultation by the Moon of the CO layer, starting with low spectral resolution observations from aircraft and Mauna Kea, and culminating in an important high-spectral resolution measurement in 1994 using the IR camera on the main spectrograph the McMath-Pierce telescope. Follow-up observations have continued on limb distribution of CO, as Adaptive Optics systems have improved the attainable spatial resolution of this telescope, particularly for selected spectral-spatial frames. This work has improved our knowledge of the source depth of this enigmatic layer by at least an order of magnitude over the past decade. The present work is focused upon determining the correct cause of this cold emitting layer; whether expansion of gases forced high into the atmosphere leads to abnormal cooling in a dynamic process or whether the CO is a semi-permanent constituent of cooler cells within hotter magnetic supergranular network, unheated by wave energy concentrated within this network (Clark, T.A., Lindsey, C.A., Rabin, D.M. Livingston, W., 2005, "Eclipse Observations of CO Emission Distribution above the Solar Limb" to be submitted to ApJ.). In future work, the new IR camera and adaptive optics system will be used to examine limb regions in detail, particularly the structure of the limb for lines of different strengths.

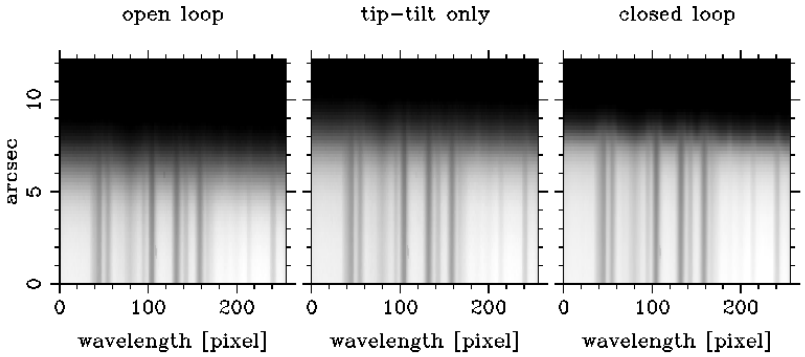


Figure C-4. *Averages of thirty 300-ms exposure spectra of the solar limb in the CO fundamental band at 4.8 microns observed during poor seeing conditions. The spectrum on the left was recorded with the AO system off, the center spectrum was recorded with tip-tilt correction only, and the spectrum on the right was recorded with full AO correction. Note the off-limb emission of the CO lines. The diffraction limit at this wavelength is 0.8 arcsec. All three spectra are displayed at identical contrast settings.*

Molecular Layers over Sunspot Umbrae

Weak absorption lines from molecular species H_2O, SiO, HCl and OH as well as CO lines with a wide range of absorption strengths in the IR solar spectrum have been used to image layers over umbrae. The different temperatures required to dissociate each of these molecules means that the temperature structure of these cold magnetically controlled regions. The correlation between IR continuum intensity and absorption line depth seems to demonstrate saturation effects, where the majority of atoms of certain species are locked up in these molecules. These observations indicate that the atmospheres above umbrae must be colder than previously thought. Recent observations of the OH molecule has been published by Penn et al. 2003, Sol. Phys., 213, 55-67.

Further observations of molecular layers, particularly with the higher spatial resolution now possible with the adaptive optics system, will be used to examine the correlation between the observed structure of umbral dots and colder regions and the strengths of molecular absorptions under these magnetically-controlled conditions in large sunspots.

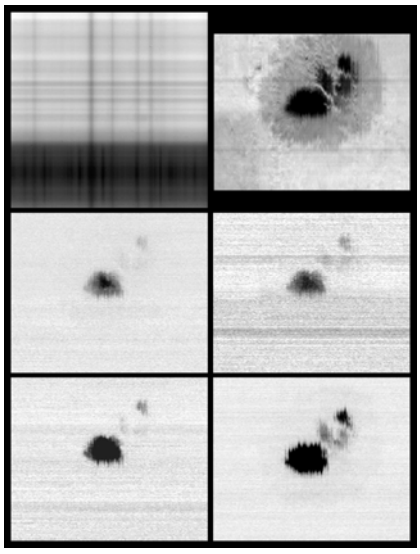


Figure C-5.1 *This single spectral frame shows the region around 2428 cm^{-1} over the active region AR8971 on April 27, 2000.*
Figure C-5.2. *The IR continuum near the wavelength of Brackett α.*

Figure C-5.3. *Excess absorption from H_2O over inner umbral regions.*
Figure C-5.4. *Excess absorption from HCl over the umbral regions.*

Figure C-5.5. *Excess absorption from SiO over the umbral regions.*
Figure C-5.6. *Absorption from OH over penumbral and umbral regions.*

Future Research Plans at the McMath-Pierce

The research summarized above by staff and visitors alike is active and ongoing. In the following we indicate some of the near-term projects that solar physicists are now in the process of pursuing at the NSO McMath-Pierce Solar Telescope.

The Solar Chromospheric Magnetic Field

Studies of the magnetic field in the solar chromosphere have been initiated using the near infrared 854.2 nm Ca I lines. It is widely acknowledged though that the 1083 nm He I spectral line is one of the best probes of the dynamics in the high solar chromosphere. Initial observations of the Stokes polarization of this line have been done at the McMath-Pierce since other facilities cannot provide enough photon flux to study this weak spectral line. Future observations are planned at the McMath-Pierce of filaments (during the Solar Minimum) and of active region magnetic fields using this powerful spectral diagnostic.

Investigation of IR Metal Lines for Use in Future Solar Magnetometers

Several strong absorption lines from metals in the IR spectrum of the Sun seem to hold significant promise for use for mapping magnetic fields at the source depths of these lines in the mid-level photosphere. Furthermore, the Zeeman sensitivity of these lines is higher than all other equivalent lines at present used for magnetic field measurements except the 12-micron Mg I lines.

The present investigation is exploring these lines, particularly the following relevant features of the lines:

(a) Zeeman sensitivity.
(b) Line temperature sensitivity, particularly line presence in umbral spectra.
(c) Contamination of spectral region surrounding the line, where Zeeman components would appear, by Earth's atmospheric absorption lines.
(d) Contamination of these spectral regions by molecular lines in umbral regions.

Several lines appear to be suitable for this purpose, including two adjacent lines with different Zeeman sensitivities, which can be measured simultaneously in spectral-spatial frames using the Main spectrograph on the McMath-Pierce telescope. Some useful lines for exploring sunspot umbra, e.g., Ti at 2231nm, have been studied (Penn et al. 2003, Sol. Phys., 215, p87) and other lines near 4000nm will be investigated in the future.

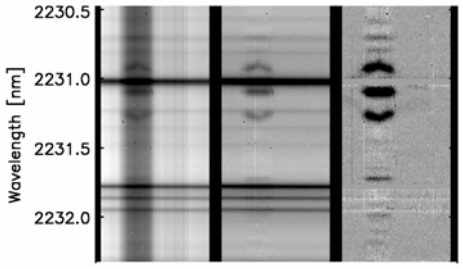


Figure C-6. *Time-processed spectra*.

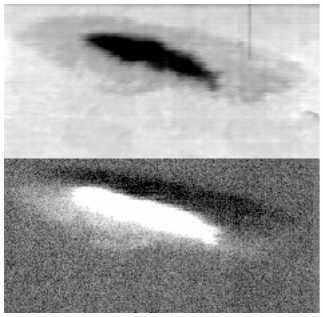


Figure C-7. *Ti-temperature map (top) and Stokes V map (bottom)*

Study of Ellermann Bombs at Brackett-α and Pfund-β Wavelengths

Studies of Ellermann bomb features around sunspot penumbrae at the IR wavelengths of Brackett-α and Pfund-β are being carried out to explore the dependence of these features at the atmospheric source depths of these HI lines compared to visible-light H- observations. Exploratory observations of these transient events around Emerging Flux Regions show promise and high spatial resolution measurements with the Adaptive Optics system and the new IR camera will permit examination of the detailed relationship between observations of these events at these wavelengths.

Observations of Prominences at Hydrogen Brackett-α, Pfund-β and HI n = 11-4 Wavelengths

Prominences can be clearly imaged at the specific wavelengths of hydrogen light from higher transitions at IR wavelengths. These studies should help to define the thermal state of gases within these magnetically-

controlled plasma structures.

Height Dependence of Emission from Metal lines in the IR

This work on the quiet sun is an extension of work in the far IR in which high-level Rydberg transitions of hydrogen, magnesium and silicon have been measured in emission above the solar continuum. The new IR camera, when allied with the adaptive optics system, will produce significantly improved spatial resolution of the solar limb and better profiles of emission to be compared to model calculations of expected emission.
An allied series of observations is planned of equivalent high-n Rydberg emission lines of Hi, Mg I and S II from the 8-7 transition, in the 20 μm window, using the FTS associated with the McMath-Pierce telescope. These measurements will be compared to the unique far IR measurements made from balloon altitudes many years ago of the series of lines from the n = 10 to n = 16 energy levels and the n = 20-19 and 22-21 lines measured more recently in the sub-mm wavelength range from the J C Maxwell Telescope on Mauna Kea. Analysis of these lines is providing a filling factor for the hot regions of the solar chromosphere that produce these emission lines. A paper is in preparation on this subject (Clark, T.A. and Boreiko, R.T. "Analysis of Solar Far IR Recombination Lines from High n Rydberg Transitions in H and Heavier Elements", to be submitted to ApJ).

The Second Solar Spectrum

The "Second Solar Spectrum" discussed above still remains a largely unexplored territory with much diagnostic potential. Hence, the team of investigator utilizing the ZIMPOL instrument have stated that they intend to return to the McMath-Pierce on a regular basis in the years to come. In addition to its relatively large aperture among currently operating solar telescopes, the McMath-Pierce offers a spacious experimental environment. This feature of the McMath-Pierce is indispensable for the accommodation of bulky optical and electronic visitor instrumentation.

Instrumentation at the McMath-Pierce

NSO Array Camera (NAC)

The NSO Array Camera (NAC) is currently running at the McMath/Pierce telescope and obtained first light in July 2005 (see Figure C-8). The system can collect intensity spectra from the Main Spectrograph, and work is currently underway to implement a polarimeter system based on liquid crystal variable retarders so that polarization spectra can be obtained from 1000 nm to 2300 nm. The array has a low-read noise and practically no dark current during the typical solar exposure time. The 1K × 1K images from the camera can be read and stored to disk at a rate of just over 10 frames per second. The NAC, which will use a 1K × 1K InSb array to measure the solar spectrum from 1000 nm to 4660 nm, is the replacement for the NIM system and the NSO/CSUN IR camera system.

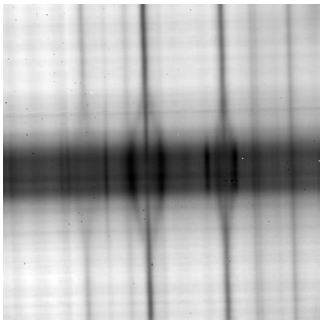


Figure C-8. *July, 2005. First sample spectra, taken with the NAC, of He I 1083 nm limb emission and the Zeeman splitting of the Fe I 1565 nm in a small sunspot.*

The NAC is one of only two 1K × 1K IR cameras observing the Sun from 1000 to 4660 nm (currently the University of Hawaii has another similar device, and there are less than a handful of 1K arrays in the world that observe the Sun from 1000 to 2300 nm), so the NAC has enormous potential to collect unique and scientifically valuable solar observations. When coupled with the McMath/Pierce telescope (which provides the largest IR flux of any solar telescope), the NAC will produce new science results that will not be replicated at any other observatory.

The NAC instrument will target several exciting science question using spectroscopy and polarimetry at infrared wavelengths. First, filament dynamics and magnetic field measurements using the He 1083 nm absorption line will be observed. The polarization of the He 1083 nm spectral line will provide critical tests of

several magnetic models of filaments, and will be used to constrain modeling efforts currently underway at several institutes. The NAC instrument with its large format will be well-suited to study active region magnetic fields using the polarization of the Fe I 1565 nm spectral line. This line provides the most sensitive probe of the magnetic field in the quiet Sun and in parts of sunspots. Current tests using this line have been made with smaller cameras at the McMath-Pierce, and the instrumental contribution to the observed polarization is well-understood. The NAC instrument should make regular maps of the vector magnetic field of solar active regions for years to come. The plasma in the solar atmosphere will be studied in several ways with the NAC camera; the cold plasma of the chromosphere will be investigated using CO absorption lines at 4600 nm, and the hot plasma of the corona will be studied with emission lines from Fe XIII at 1075 nm and Si IX at 3934 nm. Finally, exploratory work at infrared wavelengths will be done using Ti I lines near 2200 nm, and using molecular lines throughout the wavelength range, in order to study sunspots and even to understand the basic physics of molecular line formation itself.

The NAC and the ATST

The NAC system is also planned to be a bridge to the ATST near-infrared instrumentation. The NAC dewar is flexible with plenty of internal space available, and can accommodate upgrades for use with the ATST first-light instrumentation. Tests are planned with the NAC to make polarimetry observations beyond 2200 nm and the instrumentation developed during those tests will be directly applied to the ATST. Certainly the scientific discoveries, which will come from the NAC observing runs during the next few years, will drive near-infrared science programs at the ATST.

The established solar user community, which has produced science with the NIM instrument (see below), will be the community served by the NAC; and with its low-read noise and dark current, the NAC has the ability to make night-time observations at the McMath/Pierce in the IR.

The Integral Field Unit

The Advanced Image Slicer (AIS) Integral Field Unit (IFU) will be the first instrument of its kind for a solar telescope. Its development and construction is a joint project of the New Jersey Institute of Technology and the NSO, and supported by an NSF grant to NJIT (PI: Deqing Ren). The AIS IFU will enable simultaneous sampling of the AO-corrected field at the McMath-Pierce for 3-dimensional spectroscopy and polarimetry. The AIS IFU will take full advantage of the AO-corrected image, makiing the most efficient use of the telescope for spectroscopy and polarimetry at high spatial and high temporal resolution with high throughput. To address questions that cannot be studied at visible wavelengths, the image slicer IFU is optimized for the infrared (1.0 –5.0 μm), although it can still work in the visible (0.36-1.0 μm) for multi-band wavelength diagnostics.

The IFU will be tested and used as a facility instrument at the McMath-Pierce Solar Telescope on Kitt Peak. The future 4-m aperture ATST will also require IFUs for its suite of instruments. Thus, this effort is the first step in developing IFUs for the ATST. The IFU instrument development is supporting one postdoctoral and one graduate student pursuing advanced instrumentation-based research programs. The AIS IFU will be completed in 2006.

NSO/CSUN IR Camera

The NSO/CSUN IR camera is a 256 × 256 HgCdTe array built by Rockwell and interfaced with a polarization analysis package assembled from liquid crystal variable retarders from Meadowlark Optics. The instrument has been used at the McMath/Pierce during the past 4 years, and has measured solar magnetic fields from 1083 nm (He I line) to 2231 nm (Ti I line in sunspot umbrae).

Currently, we plan to move the NSO/CSUN IR camera to CSUN's San Fernando Observatory in the summer of 2005. The schedule for moving the NSO/CSUN camera to CSUN will be coordinated with the development at Kitt Peak of the polarimeter for the new NSO Array Camera (NAC).

NSO IR Magnetograph (NIM)

The NIM instrument is based on a 256 × 256 InSb array (from Amber Engineering) cooled with solid nitrogen to obtain solar spectra from 1000 nm to 4660 nm. The NIM is used in conjunction with the IR grating of the Vertical Spectrograph.

The NIM had been the workhorse IR camera at the McMath-Pierce, particularly for 1-5 micron spectral imaging and polarimetry. However, the high-background and high-noise level of the NIM instrument currently limit its scientific capability, and it is planned to be retired in the late-2005 to early-2006 time frame following the implementation of the NAC.

IR Adaptive Optics (IRAO)

The IRAO is an extremely low-cost ($25K) adaptive optics system for the McMath-Pierce that utilizes off-the-shelf, commercially available components to minimize hardware costs & software development. The all-reflecting optical design is optimized for the IR ($\lambda > 1\mu$). Designed to optically couple to the Vertical Spectrograph, the IRAO is capable of providing diffraction-limited images in the IR (>2.3 μm) during moderate to good seeing. This AO system has been successfully used with both the McMath-Pierce Main and 0.9 m West Auxiliary telescopes.

Universal Tracker (UT)

The Universal Tracker provides fast image motion correction (image stabilizer) with an update rate of 955 Hz. Originally built as test bed for IRAO tip-tilt mirror, the UT uses the Piezo controlled tip-tilt mirror, wavefront sensor camera and PC from the IRAO. The UT has been in visitor use since 2003. It is used with the Vertical Spectrograph, Celeste (the Goddard 12μ Cryogenic Spectrometer), and the Stellar Spectrograph. The Universal Tracker is usable with all three McMath-Pierce telescopes: the 1.5-m Main and the 0.9-m East and West Auxiliaries. Using an Image Intensifier, the Universal Tracker has been used to lock onto stellar sources as dim as 7th magnitude.

Spectrographs

Vertical Spectrograph: A high-resolution, 13.7-m focal length with two available output ports, the Vertical Spectrograph is accessible by both the McMath-Pierce Main and East Auxiliary telescopes. It includes two diffraction gratings in a computer controlled rotatable turret: The visible light grating provides resolutions ($\lambda/\Delta\lambda$) ranging from 8.9×10^5 to 1.6×10^6 at key diagnostics extending from the Ca II K line at 393.4 nm to Hα at 656.3 nm. The IR grating yields resolving powers in the near-to-mid-infrared of 6.3×10^4 (4.7 microns) to 2.4×10^5 (1.5 microns) . The Vertical Spectrograph is also used to collect photoelectric spectra using a computerized fast scanning technique (PHOTO). The current, primary use of PHOTO is for a long-term study (PI: Dr. W. C. Livingston, NSO) of the variability of solar lines in integrated light. The SOLIS-ISS data is now being compared with simultaneous observation taken for this program with PHOTO. The SOLIS ISS will replace PHOTO in this study. Once that occurs, PHOTO will no longer be supported.

Stellar Spectrograph: Originally developed for spectroscopy of solar-type stars, now primarily used for planetary spectral imaging. The instrument houses two diffraction gratings in a rotating turret that yield spectra characterized by $R \sim 10^4 - 10^5$ at visible wavelengths. Image slicers are used in conjunction with the Stellar Spectrograph to enhance throughput for point sources and to provide a 2-D spectral imaging capability for extended sources, such as solar system objects. The spectrograph is accessible by both the McMath-Pierce Main and East Auxiliary telescopes.

Fourier Transform Spectrometer (FTS)

The Fourier Transform Spectrometer is a unique national resource in wide demand by atmospheric physicists and chemists, as well as astronomers. The FTS is a highly stable, Michelson interferometer that is able to simultaneously achieve high spectral resolution, excellent signal-to-noise ratio and wide bandpass. The FTS is thus able to produce high-quality measurements of line positions, strengths and widths. The McMath-Pierce

FTS is a multi-disciplinary facility that is utilized for research programs in solar physics, laboratory spectroscopy, astrophysics and atmospheric sciences. The McMath-Pierce facility has been designated as an official complementary site for the Network for the Detection of Stratospheric Change (NDSC). The Earth atmospheric measurements that are made at this facility are included in the NDSC archive.

In **solar physics,** the FTS is the source of benchmark spectrum atlases of the Sun. The spectral coverage of the solar atlas is 357 nm to 22000 nm in the photosphere, and complementary sunspot umbral atlases that range from 435 nm to 21000 nm. A byproduct of the compilation of the umbral observations was the discovery of water on the Sun in exceptionally cool spots. The FTS is applied in studies of solar magnetism because of its ability to acquire a broad range of spectral lines simultaneously and because of its extremely high spectral resolution that enables the direct detection of Zeeman splitting without polarization optics. Studies of the cool component of the solar chromosphere using the CO fundamental (4.7 μm) and first overtone bands (2.2 μm) are performed with the FTS.

Visiting Instruments

- Celeste — High-resolution liquid helium cooled grating spectrometer built by NASA Goddard Space Flight Center (PI: Donald E. Jennings)
- Athena — 12-μm Fabry-Perot Spectrometer (PIs: D. Jennings & D. Deming)
- ZIMPOL & ZIMPOL II — Fast polarization modulator plus masked CCDs for ultra-precise polarimetry (PIs: C. Keller and J. Stenflo)
- Tunable Heterodyne Infrared Spectrometer (THIS) — A Heterodyne Infrared Spectrometer designed for SOFIA (PI: G. Sonnabend)
- Spatial Heterodyne Spectrometers (SHS) — A compact Fourier transform spectrometer developed at the University of Wisconsin (PI: J. Morgenthaler, U. Washington)

Interdisciplinary Science Programs at the McMath-Pierce

Solar System Astrophysics

At the time of this writing, a team led by J. Morgenthaler (University of Washington) is setting up their visitor instrument at the McMath-Pierce to perform spatial heterodyne spectroscopy (SHS) of comet Tempel 1 in support of Deep Impact on 2005 July 4. This team has been using the McMath-Pierce for observations of diffuse solar system objects, such as the Io plasma torus and comets, utilizing a Fabry-Perot and SHS techniques.

The team of A. E. Potter (NSO) and R. M. Killen (U. of Maryland) utilize the McMath-Pierce and stellar spectrograph to map the sodium and potassium atmospheres of Mercury, and to measure the thermal emission spectrum of Mercury. Potter and Killen also utilize the AO system at the McMath-Pierce for daytime Mercury observations and for nighttime Europa and Io observations. Highly productive synoptic studies of the Io torus are conducted at the McMath-Pierce. In fact, the McMath-Pierce Stellar Spectrograph remains the only facility to have detected [O I] 630 nm emission from Io while Io is in sunlight. HST/STIS, Keck, and Galileo could/can only do it when Io was in eclipse. This difference in capability is critical because of temporal variability of Io (volcanic, orbital phase angle, etc.) and the temporal and spatial variability of the plasma torus as it encounters a wide range of magnetospheric conditions.

G. Sonnabend (NASA-Goddard Space Flight Center) and collaborators in Germany have developed a Tunable Heterodyne Infrared Spectrometer (THIS), which is an ultra-high resolution receiver for the mid-infrared region. They used this complex visitor instrument at the McMath-Pierce to observe ozone and carbon dioxide emission on Mars with interesting results. Their observing runs are also part of a Ph.D. thesis for Daniel Wirtz. Their observations of Marian non-thermal CO_2 emission near 10 microns with THIS were just published (2005; A&A, 435, 1181).

The FTS plays a crucial role in the detection of **extrasolar planetary systems** by Doppler spectroscopic methods. In particular, this technique utilizes an Iodine absorption cell in the beam as a superimposed wavelength reference on the stellar spectrum. It also serves to measure the variable PSF of the spectrograph. These facets enable the necessary precisions of 3 meters per second (corresponding to about 1/1000 of a pixel) to be achieved for extrasolar planet detection. The calibration of the Iodine absorption cell constructed at Lick Observatory was accomplished with the FTS. The resulting "sacred" McMath-Pierce FTS Iodine atlas ultimately led to the discovery of five out of the first six known extrasolar planets at Lick Observatory. This original Lick Observatory Iodine cell has been requested by the Smithsonian Institution upon its retirement. It is only with the FTS calibration spectrum that it is possible to unlock the information rich Iodine spectrum. Every active astronomical Iodine absorption cell has been calibrated at the FTS. In this sense, about two-thirds of the known extrasolar planets have a direct lineage to the McMath-Pierce FTS.

In brief summary, key elements in the success of these programs include, as in the case of the solar programs, the ability to carry out instrument development and complex instrument set-ups in a spacious and stable lab environment; the availability of multiple meter-class telescopes; flexible scheduling; and, the accommodation of graduate and undergraduate students.

Educational Outreach

As recent examples of our efforts in educational outreach, the NSO has been heavily involved in student and teacher training and education. The NSO has made significant contributions to the TLRBSE program over the past four years and is actively engaged in preparations for this year's cohort of TLRBSE teachers. During the past 3 years the TLRBSE teachers have observed on the McMath-Pierce, where a Zeeman-split IR spectral line study has been conducted each year. NSO staff members have assisted with developing research questions, with gathering data used in an on-line preparatory course, as advisors during the DL course, with teaching the teachers how to observe during the summer institute, with answering their questions on content, data reduction, analysis and interpretation of the data and recently with development of data reduction and analysis software by Frank Hill. In particular the new software is designed to make measurements of the quiet Sun, in preparation for solar minimum. Claude Plymate and Frank Hill have also been an integral part of subsequent teacher/'student observing runs during the year. The TLRBSE staff and the NSO staff have begun to talk about future plans to incorporate data from the new NAC array as well as SOLIS.

In a joint program with the University of Arizona's newly established *Life and PLAnets Center (LAPLACE)* and the NOAO, the NSO is participating in a program of research and educational outreach funded by a five-year award from the NASA Astrobiology Institute (NAI).

In the area of educational outreach in astrobiology, the joint program organizes exchanges of students and staff with other NAI member institutions. Members of the NSO staff participated in the *LAPLACE-University of Washington Exchange* on March 19-21, which involved a visit to Kitt Peak by 14 graduate students from the UW astrobiology program along with members of *LAPLACE* of the University of Arizona. The graduate students represented a broad range of disciplines in the life and physical sciences, and engineering. During their 3 days on the mountain, the students participated in demonstration observing exercises in order to gain an understanding of how astronomical data relevant to goals in astrobiology are obtained, reduced and analyzed. At the McMath-Pierce solar telescope, the grad students obtained infrared spectra of sunspots and measured umbral field strengths based on the observed Zeeman splitting of a magnetically sensitive Fe I line at 1.56 microns. In addition, they saw Ca II H and K spectra acquired for active regions in the vicinity of the spot, similar to the kind of spectra obtained at the nighttime telescopes for active solar-type stars. Frank Hill and Mark Giampapa interspersed the solar observations with PowerPoint presentations on solar-terrestrial interactions, solar-stellar activity, and helioseismology. As one student remarked, "I really learned a great deal about the Sun." Exchanges of this kind will be held annually during either the winter or spring breaks, and feature hands-on demonstration observing programs at the NSO McMath-Pierce Solar Telescope on Kitt Peak.

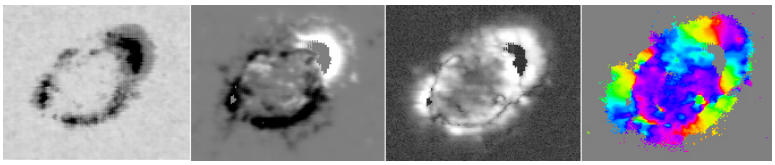
Appendix D

SOLIS

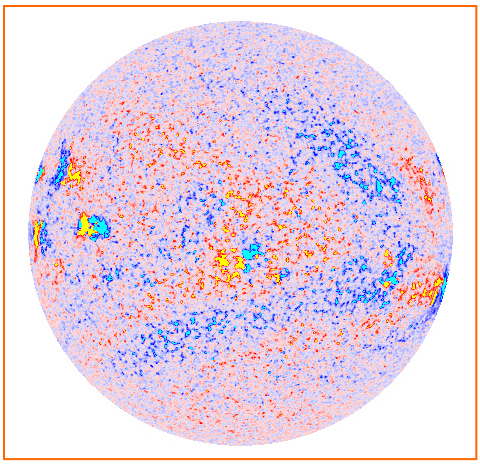
Overview

The Synoptic Optical Long-term Investigations of the Sun (SOLIS) facility was proposed and developed in response to a need to make optical measurements of solar processes whose scientific study requires sustained observations over periods of years. SOLIS replaces obsolete NSO equipment that made synoptic observations for three decades and it provides new observational capabilities. SOLIS complements space-based instrumentation and is intended to operate for 25 years.

Description and Current Status



Above panels: *Full-disk photospheric vector magnetic field in 24 minutes (3 per day).*



Right: *Deep photo-spheric magneto-gram (1 per day).*

SOLIS consists of three instruments on one equatorial mounting. The primary instrument is the Vector Spectro-magnetograph (VSM). It is a low-polarization, 50-cm aperture telescope joined with a grating spectrograph and polarization modulator that produces full-disk magnetic field measurements in the solar photosphere and chro-mosphere. This instrument has been operating regularly since August 2003 and has replaced the Kitt Peak Vacuum Telescope facility built in 1973. An Integrated Sunlight Spectrometer (ISS) provides synoptic observations of the line profiles of selected solar spectrum lines and is in the process of assuming the continuation of similar observations made since 1975 at Sacramento Peak and Kitt Peak. After a satisfactory period of overlap, these programs—K-line monitoring done at the Sacramento Peak Evans facility and a many-line program done at the McMath-Pierce telescope on Kitt Peak—can be stopped. The final instrument is a Full-Disk Patrol (FDP) that will record full-disk intensity images of the Sun using filtered portions of spectrum lines of importance to the study of solar activity. Similar observations are available from other sources, so this instrument is the last to be finished. It is intended that the FDP will replace some routine monitoring done at the Hilltop Dome facility at Sacramento Peak. The prototype ISOON instrument operating at Sacramento Peak is a very capable filter imager and the possibility of combining ISOON and SOLIS data sets is being explored.

A growing number of data products are available at the SOLIS Web site. These now include full-disk images of the line-of-sight components of the magnetic fields in the solar photosphere and chromosphere, images made using the 1083 nm He I line and derived products from these data such as synoptic maps, coronal hole maps and global magnetic indices. The quality of the data is far superior to similar data produced with the old synoptic facility. While full-disk vector magnetograms have been taken routinely since September 2003, reduction of these data has proven to be difficult. Additional resources to help accomplish this have been obtained from NASA through a Living With a Star Targeted Research and Technology grant awarded in February 2005. Release of vector magnetograms should begin before the end of 2005.

SOLIS is in transition from a construction project to an operational program. Personnel and budget shortages, and some equipment failures, have extended this transition over a longer time period than had been planned. Barring unforeseen events, the transition should be completed by the end of FY 2006.

Science Impact

SOLIS is not yet in full operation and NSO staff members have been busy completing it rather than using it for science projects. However, the superior quality of the new observations has already revealed several new findings about the Sun and solar activity. For example, active regions are found to be frequently surrounded by weak and diffuse, but extensive and predominantly horizontal magnetic fields in the photosphere and especially the chromosphere. Such areas have magnetic, radiative, dynamic and structural properties that are distinct from other parts of the solar atmosphere and have not been studied from that perspective. Another example is seen in high time cadence observations of the vector magnetic field of network elements near the disk center. Observed, as expected, is a strong and more or less steady radial component but also a horizontal component that changes rapidly in minutes, presumably in response to buffeting of the magnetic elements by granulation and/or *p*-mode oscillations. A third example comes from observations of the He I 1083 nm chromosphere. This spectrum line is unique in ground-based observations in responding to the intensity of radiation from the overlying corona. SOLIS observations of this line show, near the limit of resolution, that plages are frequently composed of a myriad of tiny loop-like structures. This is a puzzling observation given the absence of small-scale bipolar magnetic features in plages.

The three-decade life of the SOLIS VSM predecessor, the Kitt Peak Vacuum telescope, produced many 'firsts' and discoveries, and a bibliography of more than 1000 refereed papers and theses. There is every reason to expect SOLIS to continue this record when it becomes fully operational. The newly available full-disk vector magnetograms promise to be a particularly rich source of important new findings. Users of early SOLIS data are beginning to publish papers that utilize SOLIS data. One use is to extrapolate the surface magnetic field upward into the corona and heliosphere. A user reports that by using SOLIS data the correlation between extrapolations and observed streamers in the solar corona is as 'perfect as one could ever hope to expect.'

In the future, SOLIS will be the primary source of data for many research projects. For example, investigations of the characteristics of the solar vector magnetic field outside of active regions. But more frequently, as was the case with its predecessor, SOLIS' unique data will be used with that from other sources for more comprehensive studies of the Sun. This is especially likely as new solar space missions are launched, e.g. Stereo 2/2006, Solar-B 8/2006, SDO 4/2008, and others in planning. SOLIS will also provide the full-disk context observations required for many ATST research projects. Such pairings between wide and narrow field instruments are common in nighttime astrophysics.

Improvements

Years ago, it was possible to design and build an instrument with the expectation that spare parts would be available for a long time. That is no longer possible. Product lifetime cycles are now so short that one has to plan for frequent upgrades and replacements of (especially) electronic and computer components and supporting software.

A serious delay in the construction of the SOLIS VSM occurred when a vendor defaulted in supplying critical CCD cameras. Interim cameras were installed that are slower, noisier and have larger pixels than originally planned. This prevents the VSM from achieving its design performance. New cameras have recently become available with characteristics very similar to the original design. It is not possible to do a simple replacement because the data output of the new cameras is incompatible with the existing data acquisition system. A major effort will be required to replace both the cameras and the data acquisition system. Funding to accomplish this will be sought either from NSO's base instrumentation budget or as part of a SOLIS network proposal.

When SOLIS was designed, a capability was included to make measurements of the line-of-sight component of the chromospheric magnetic field. This has been quite successful. A vector field capability was not included because interpretation of the measurements of linear polarization of chromospheric spectrum lines in terms of transverse magnetic field was beyond the state of the art. This has changed and there is now great community interest in obtaining chromospheric vector magnetic field measurements. To do this requires building a new polarization modulator package. This is a relatively small project that can probably be accomplished during FY 2006 using SOLIS operations funding.

As explained below, the most recent decadal survey recommends that SOLIS be expanded into a three-site network to provide nearly continuous vector magnetograms. Personnel shortages and a requirement to identify willing foreign partners have delayed preparation of a proposal to NSF to accomplish this recommended expansion. Preliminary work has been done and some contacts have been made with potential foreign partners. The basic concept is to replicate the mounting system and construct two new VSM instruments but not the ISS or FDP instruments. This will leave considerable space for partners to mount their own instruments.

Relationship to Decadal and Other National Survey Goals

SOLIS is, in part, a response to a community plea for full vector magnetic field measurements expressed in "Working Papers, Astronomy and Astrophysics Panel Reports" (page IX-13, National Academy Press, 1991). In 1995, this call was extended to full solar disk measurements in "The National Space Weather Program: The Implementation Plan" (pages A-27, A-28, FCM-P31-1997, 1997). SOLIS was also conceived to improve the quality and efficiency of NSO synoptic observations and to reduce costs by using modern technology to replace obsolete equipment.

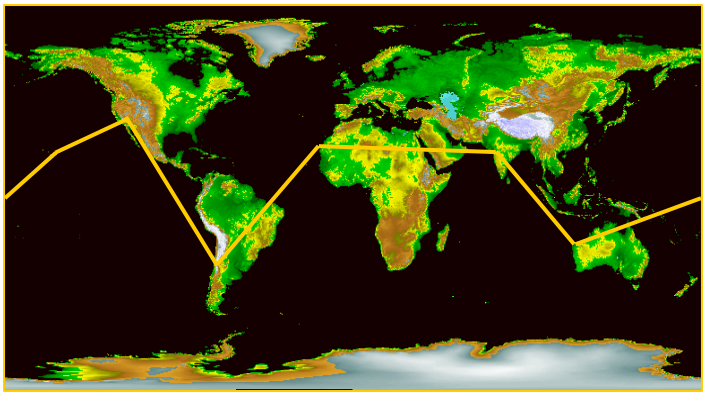
The proposal to build SOLIS was submitted to NSF in 1996 and was descoped at the request of NSF in 1997. In 1997, the NSF requested the Space Studies Board of the National Research Council to form a Task Group on Ground-based Solar Research to evaluate the entire national ground-based solar program. Recommendation 1 of that report was to complete fabrication of SOLIS, to operate it at an appropriate site and to provide funding for US scientists for SOLIS data analysis ("Ground-based Solar Research: An Assessment and Strategy for the Future," National Academy Press, 1998). Design and construction of SOLIS started in 1998 when funding from the Astronomy and Atmospheric Sciences Divisions became available under the Major Research Instrumentation program at NSF

.

In 2000, the Solar Panel of the decadal survey "Astronomy and Astrophysics in the New Millennium" (National Academy Press, 2001) assigned its primary recommendation for a small-size, ground-based facility to an expansion of SOLIS to a three-site network to enable nearly continuous full-disk vector magnetic field observations. This recommendation is included in the main report under small initiatives.

Appendix E
GONG

The new, improved Global Oscillation Network Group program (GONG++) explores the rapidly evolving sub-surface dynamics of the solar plasma and magnetic field, to understand the origins of stellar magnetism and "space weather."



Building on the success of the original GONG study of the global structure of the solar interior and responding to the recent development of techniques to study local structures using resonant modes as well as as well as local area helioseismology, GONG++ has embarked on epochal studies of *i)* the structure and dynamics of local concentrations of magnetic field in the upper convection zone with its strong shear and surface dynamo, *ii)* changing meridional and torsional flows which provide flux transport to drive the dynamo, *iii)* changing structure of the deep convection zone and the region of strong shear to the radiative core ("tachocline") which is thought to be the source of the deep-seated dynamo giving rise to the 22-year solar magnetic cycle, and *iv)* dynamics of the surface magnetic field and coronal response to support a growing community.

Background, GONG to GONG++

GONG was conceived of, and implemented as, a three-year long measurement of the frequencies of the resonant global modes of the Sun in order to study the global structure of the solar interior. Three years [1000 days] was chosen as it was viewed as roughly ten excitation times of the longest-lived modes then known, sufficient to determine a precise spectral line profile for the measurement of the resonant mode frequencies.

It was subsequently discovered that the resonant mode frequencies varied with the solar magnetic activity cycle, and that these variations reflected real structural changes of the solar interior, which are related to the origin of solar magnetic fields. The GONG Scientific Advisory Committee (SAC) and the AURA Solar Observatory Council (SOC) recommended that GONG be continued for a full solar cycle and that it replace the original 256^2 detector system with a 1024^2 one to obtain the maximum science achievable from the ground. It was also decided that, in order to remove the periodic, hourly interruptions to obtain a magnetogram, the instrument would obtain them continuously (once per minute, at the same cadence as the velocity images).

In addition to global, resonant-mode seismology of the Sun as a whole, running-wave seismology with spatial resolution of a few degrees and temporal resolution of a day or less became possible, enabling the study of significant time-varying structures. This discovery gave rise to a new requirement from the SOC and SAC to study these structures for a full solar cycle of 22 years. **This entirely new program of continuous local helioseismology and magnetogram science, known as GONG++, began routine operations in 2003.** The GONG++ instrument, data, and analysis system continues to support the original global helioseismology science program, which now represents only a small fraction of the total effort.

The Future

GONG++ has undertaken the long-term study of the rapidly-varying solar interior in order to understand i) the astro-physical phenomena in the solar and stellar contexts, ii) the role of interior structures and flows in the creation of solar and stellar surface magnetic activity, and iii) how these structures and flows give rise to "space weather." In addition, GONG++ has undertaken, as a fundamental part of its mission, obtaining, processing, and disseminating

continuous, high cadence, high sensitivity, well-calibrated line of sight magnetic flux measurements to support the large community of researchers focusing on the magnetic structure of the solar atmosphere and the heliosphere.

In order to achieve these objectives, GONG++ is completing the re-engineering of the instruments, which were designed for a three-year lifetime, to run continuously, and to support the requirements of the all-new magnetogram science with new polarization modulator electronics and post-processing. The worldwide development of the internet is making possible the near-real-time acquisition of the data from the GONG++ stations, which has already enabled provision of images of the farside of the Sun for predictive purposes and which soon will make all of the scientific products available with little or no delay. GONG++ continues to work closely with the SOHO helioseismology experiments, and with the forthcoming SDO/HMI investigation.

Appendix F

The Advanced Technology Solar Telescope

1 OVERVIEW

The Sun sustains life on Earth and impacts human endeavors in space through variations in its radiative, magnetic and particle output as caused by magnetic activity. The solar atmosphere is controlled by magnetic fields. The Advanced Technology Solar Telescope (ATST) is the first major instrument designed by the astronomical community in all of its aspects as a tool for magnetic remote sensing. Its collecting area, spatial resolution, wavelength performance and integral focal plane instrumentation are all targeted for understanding how magnetic fields affect the physical properties of the Sun. It will be the largest leap in ground-based solar capabilities since Galileo's telescope.

We propose to build the Advanced Technology Solar Telescope, a four-meter off-axis reflecting telescope, which will have the spatial, temporal, spectral resolution and dynamic range that is needed to see and measure the basic magnetic structures (magnetic fibrils) at the solar surface and into the outer atmosphere. Currently much of the magnetic field is invisible. We therefore will depend on the ATST for quantifying, understanding, and predicting the consequences of such magnetism on solar-terrestrial and astrophysical plasmas. An essay by one of the preeminent experts on astrophysical magnetism (Eugene N. Parker, Appendix 1) aptly describes the broader implications this understanding has for science and technology

Figure 1.1. TRACE image of coronal loops (courtesy of A. Title). From this and similar images, it is clear that magnetic fields permeate and dominate the structure of the solar atmosphere. The ATST will measure the magnetic fields associated with these loops.

The ATST partnership (Table 1.1) of universities, industry, and national centers, with the strong support of the entire solar research community, is prepared to move into full-scale development, construction, and scientific exploitation of the ATST. The National Solar Observatory (NSO) has provided the nation's premier observational capabilities in solar physics for the last several decades and, working with the community, has provided the focus for this grass roots program for the next generation. The scientific specification and design of ATST is already providing opportunities to train the next generation of solar astronomers and to strengthen solar programs at universities. Other members of the ATST partnership are providing expertise in instrument development, polarimetry, modeling and theory, as well as advice and oversight to the project. The ATST program includes strong international participation. In Europe, a consortium has formed to seek both national and European Union (EU) support for the ATST.

Table 1.1. The ATST Collaborators

Air Force Research Laboratory	National Solar Observatory*
California Institute of Technology	New Jersey Institute of Technology*
California State University, Northridge	Princeton University
Colorado Research Associates	Southwest Research Institute
Harvard-Smithsonian Center for Astrophysics	Stanford University
High Altitude Observatory*	University of California, Los Angeles
Lockheed Martin	University of California, San Diego
Michigan State University	University of Chicago*
Montana State University	University of Colorado
NASA Goddard Space Flight Center	University of Hawaii*
NASA Marshall Space Flight Center	University of Rochester

*Denotes PI and Co-PI institutions

The NSF-funded ATST Design and Development (D&D) effort commenced in late 2001 and has produced a design with sufficient detail to allow a thorough assessment of ATST's feasibility and construction. The cost of construction and commissioning of the ATST is $161M. This includes three

major instruments, a fully integrated adaptive optic system, support facilities, contingency, and inflation. Scientific operations are scheduled to begin in 2012.

The National Research Council's Astronomy and Astrophysics Survey Committee (AASC) decadal survey, *Astronomy and Astrophysics in the New Millennium* (McKee & Taylor, 2001), assigned high priority to the need for a large-aperture solar telescope capable of resolving fundamental physical processes and magnetic fields throughout the solar atmosphere: "The first scientific goal for advancing the current understanding of solar magnetism is to measure the structure and dynamics of the magnetic field at the solar surface down to its fundamental length scale – ATST is designed to achieve this angular resolution." The NSF/NASA Solar and Space Physics Decadal Survey (Lanzerotti, 2003) also recognizes the high priority of the ATST and its synergism with space missions as essential for solving the questions surrounding solar magnetism and solar activity.

In short, solar physics is at an impasse. Substantial improvements in computational capabilities now enable physical theory and numerical modeling to address the most fundamental scales and processes in the highly magnetized and turbulent solar atmosphere. There is no other telescope, existing or planned, which can observe solar magnetic features with the required resolution to test and distinguish between these models. The community of solar theoreticians, observers, and instrumentalists are unanimous in pressing for the observing capability that will be provided by the ATST design and that should be available for the next maximum in solar activity in 2012. This proposal requests funds to construct the ATST.

2 SCIENCE DRIVERS

"ATST will observe solar plasma processes and magnetic fields with unprecedented resolution in space and time. It will provide critical information needed to solve the mysteries associated with the generation, structure, and dynamics of the surface magnetic fields, which govern the solar wind, solar flares, and short-term solar variability." *Astronomy and Astrophysics in the New Millennium* (McKee & Taylor, 2001)

The ATST addresses the basic questions: What is the nature of solar magnetism; how does that magnetism control our star; and how can we model and predict its changing outputs that affect the Earth? Models of magnetoconvection predict that the Sun's magnetic fields coalesce and dissipate at spatial scales of a few tens of kilometers, well beyond the reach of current telescopes in space or on the ground. One such model is shown in Figure 2.1. These elementary magnetic building blocks, or magnetic fibrils, are strongly linked to the Sun's properties as a variable magnetic star. The unambiguous measurement of magnetic fibril characteristics and the buffeting of these fibrils by turbulence, the coalescence of fields into strong concentrations such as pores and sunspots, their role in

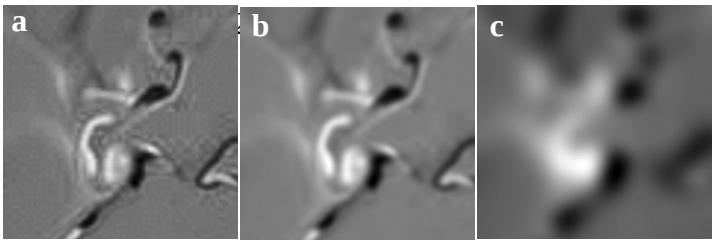


Figure 2.1. (a) A frame taken from a 3-D simulation (10-km grid) of solar magnetoconvection near the solar surface (courtesy of Fausto Cattaneo). Each box is 800 km on a side (1.1 arcsec) and shows a snapshot of the magnetic field as it would appear looking down on the simulation. (b) The same fields seen through a diffraction-limited 4-m telescope, and (c) through a diffraction-limited 1-m telescope (the best currently available). The model predicts rapidly evolving, highly mixed, bipolar fields that are twisted by strong turbulent downflows. The 4-m ATST is required to measure both the spatial and temporal characteristic of the magnetic field associated with this small-scale dynamo process that is crucial to solar magnetism and to distinguish between competing models (see Part II, Section 2.1).

transporting and dissipating energy, the resulting solar activity, and the validation or rejection of models for these processes are major goals of the ATST.

The photosphere is a crucial region where energy is readily transformed from convective motion into thermal and magnetic energy, and electromagnetic radiation. The energy stored in magnetic fields is eventually dissipated at higher layers of the solar atmosphere, sometimes in the form of violent flares and coronal mass ejections (CMEs) that ultimately affect the Earth and drive space weather. The photosphere, the chromosphere, transition region, and the corona are connected through the magnetic field and therefore have to be treated as one system, rather than as individual layers. The ATST is a crucial tool to understand this complex, interconnected physical system.

ATST observations will answer many long-standing questions that are essential to the physics of solar activity and variability:

- What role does the ubiquitous small-scale solar magnetic flux play in the generation of solar magnetism leading to cyclic variation of magnetic activity?
- How do strong field concentrations (pores and sunspots) form, and how do they modify the turbulent convection?
- How does the magnetic field carry energy into the solar atmosphere, making the Sun a variable X-ray star?
- How do magnetic fields drive solar irradiance changes (especially those that impact the terrestrial climate)?
- How is magnetic energy stored and then released catastrophically?
- What is the role of magnetic helicity (twist) and chirality (handedness) in the solar dynamo and in solar activity?

Table 2.1. The ATST Gives Needed Spatial Resolution on the Sun

Wavelength	Angular Resolution (arcsec)	Linear Resolution (km)	Current Limit (km)
320 nm	0.02	14	60
500 nm	0.03	23	100
1,600 nm	0.1	75	200
4,800 nm	0.3	225	600
12,000 nm	0.75	560	1500

To answer these questions, we must investigate the energy transport and conversion processes in magnetized plasma to establish:

- How mass motions and magnetic field interact in the Sun.
- How the magnetic field emerges through the solar surface and how it disappears.
- How magnetic reconnection/annihilation works.
- How micro-scale instabilities lead to large-scale effects.

The "Faint" Sun – Photons and Cadence

ATST's large collecting area is determined by a combination of spatial resolution and photon flux requirements. Although the Sun appears very bright to the eye, high-resolution spectral observations are frequently photon starved, even in the bright photosphere. A 15-km^2 photospheric feature observed in a blue 0.005 nm (50 milliangstrom) spectral passband yields fewer than 10^6 photons/m^2/sec before polarization and unavoidable losses are taken into account, but evolves on a 2-to-5-second time scale. Other features in the chromosphere and corona are orders of magnitude fainter. ATST's 12-m^2 collecting area is both necessary and sufficient to collect polarimetric data faster than the evolution of interesting features in each of these atmospheric layers (see Table 2.2).

The ATST is necessary to accumulate sufficient photons to accurately measure magnetic fields over a time scale in which the dynamic scene does not evolve significantly.

Achieving the ATST scientific goals (Part II of this proposal) will answer the fundamental questions raised above. Part II contains details of the critical problems in solar physics in which small-scale

magnetic fields and dynamical processes play a dominant or major contributing role, and where only a very well instrumented, large-aperture telescope will provide breakthrough science. The observational requirements that will achieve these science goals were developed in the ATST Science Requirements Document (SRD) (*http://atst.nso.edu*) by the ATST Science Working Group with substantial inputs from the solar community. Table 2.2 summarizes these key goals and their translation into requirements. This flow down from the SRD to requirements and compliance criteria for the telescope are discussed in detail in Part III of this proposal.

Table 2.2. Science Goals Leading to Observation Requirements and Technical Specifications

Science Goals	Observational Requirements	Telescope Requirements	Telescope and Site Parameters	Instruments
• Small-scale dynamo • Origin of weak field and importance for solar cycle • Magnetoconvection • Flux emergence and dissipation • Formation, destruction, internal structure of flux tubes/sheets • Structure of sunspots • Generation of MHD and acoustic oscillations • Chromospheric and coronal heating • Triggering of activity	• Observe fundamental astrophysical processes over scales at which they occur • Measure B and plasma parameters with sufficient spatial and temporal resolution and sufficient accuracy to test theoretical models • Observe: visible and near-infrared spectrum	• Spatial resolution: – 0.03" at 500 nm – 0.1" at 1600 nm • Large photon collecting area • Accurate polarimetry (better than 10^{-4}) • Low scattered light	• Aperture: 4 m • Seeing control: – Adaptive optics – Thermal control • Low and stable instrumental polarization < 1% • Excellent seeing site	• Visible/NIR spectrographs and polarimeters • Visible/NIR narrow-band filters • Visible/NIR detectors • UV polarimeter
• Structure and dynamics of upper atmosphere: – Shock wave heating – COmosphere – Spicules – MHD-wave and topological heating – Prominence formation and eruption – Flares – CMEs • 3D-structure of magnetic field: – Chromospheric and coronal magnetic fields	• Measure B and plasma parameters in upper atmospheric layers • Observe: – CO lines at 4800 nm (transition zone from $\beta > 1$ to $\beta < 1$, T diagnostics) – Mg I at 12000 nm (magnetic field, upper photosphere) – He I 1083 nm (Magnetic field, chromosphere) – Coronal lines at 1074.7 nm and 3900 nm, (magnetic field, corona)	• High resolution • IR access (>12000 nm) • Large photon flux • Accurate polarimetry • Low scattered light < 10^{-5} at 1.1 solar radii • Coronagraphic capabilities in IR	• Aperture: 4 m or larger • Open-air design • Dust control • Adaptive optics • Unobscured light path • Low sky brightness	• NIR/thermal IR detectors • NIR/thermal IR spectrograph and polarimeter
• Active region evolution • Understand process of activity build-up and triggering • Dynamo processes	• Measure B and plasma parameters at different layers in atmosphere and over entire active region • Long time series	• Large FOV • High resolution over large FOV	• AO & site with large isoplanatic patch or MCAO	• All of the above
• Explore the unknown • New discoveries	• e.g., Explore IR spectrum >12000 nm • Flare spectra in IR	• Flexibility, adaptability	• Multi-observing stations • Ability to implement new ideas	• All of the above • User furnished

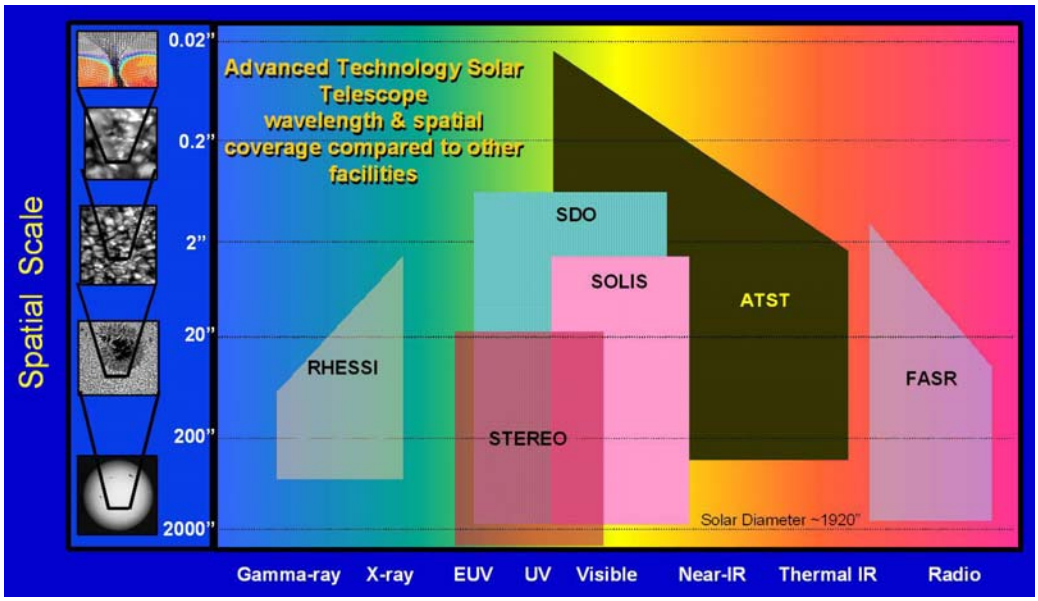
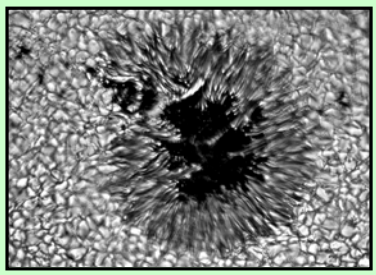


Figure 2.2. Spatial and Spectral coverage of ATST compared to other major new facilities. The Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI), the Solar Dynamics Observatory (SDO), and the Solar Terrestrial Relations Observatory (STEREO) are NASA missions. The Solar Optical Long-term Investigation of the Sun (SOLIS) and the Frequency Agile Solar Radio (FASR) array are NSF supported programs.

Magnetic fields control the static and dynamic structure of the solar corona, and ATST, for the first time, will allow us to measure this "dark energy," which has been largely invisible with all current ground and space experiments. With careful attention to scattered light performance and by optimizing the facility for infrared capabilities, we will finally be able to see the coronal magnetic fields, which are responsible for so much of the Sun's variability.

The left-hand sequence of images in Figure 2.2 shows a progression (bottom to top) from large-scale phenomena of the entire Sun, through sunspots, convection, and indications of bundles of magnetic field, to the actual interaction of matter with the magnetic field. This smallest scale, the real building block of all of the large aggregates, is a model rather than an observation. ATST will provide this missing observational scale as well as open new windows in the infrared for measuring chromospheric and coronal fields and improving the accuracy of field strength measurements. Using observations over a full range of spatial, temporal, and wavelength scales will enable a comprehensive approach to understanding solar magnetism and activity.



Sunspot: When Magnetic Flux Dominates

The magnetic field obviously controls coronal structure (Figure 1.1). However, even in deeper layers where the plasma density is much higher, the fields can become sufficiently concentrated to form pores and sunspots (Part II, Section 2.1.5). In these cases the field has profound effects on the turbulent flow and thermodynamic properties. The strong fields of sunspots and their motions form the basis of active regions and subsequent solar activity (Part II, Section 2.2). Only with the ATST will we be able to collect precision polarimetric data with a temporal cadence necessary to capture the evolution of sunspot fine structure and finally understand its physical origin. (Image from the NSO Dunn Solar Telescope courtesy of Thomas Rimmele.)

We need to observe the weak field in the photosphere, which requires high polarimetric sensitivity and high spatial resolution (<0.1 arcsec). We must observe the vector magnetic fields at high spatial and temporal resolution to determine their twist and its source, the types of waves being generated and dissipated, and how reconnection takes place. We need to understand the structure of the small-scale field and how much flux is hidden within the resolution element. The position and geometry of the field in the outer atmosphere is inferred from brightness images showing loops, or from extrapolations of photospheric field. We must observe the chromospheric and coronal vector magnetic fields associated with these loops. These observations drive spatial resolution, polarimetric sensitivity, access to the IR, coronagraphic capabilities, and temporal cadence.

Summary of Key Drivers of Telescope Design

Image Quality (0.03 arcsec at 500 nm)
- Diffraction limited optical spectroscopy and polarimetry
- Near IR spectral polarimetry
- Near IR coronal magnetometry

Polarization (10^{-4} of Intensity)
- Optical and IR polarimetry

Scattered Light (<1% at 10 arcsec)
- Near IR coronal magnetometry
- Dark objects (e.g., magnetic pores, and sunspots) against bright background

3 TECHNICAL PROGRAM

To satisfy the scientific requirements, the ATST will be an all reflecting, four-meter, diffraction-limited, visible and infrared telescope housed in a co-rotating ventilated and cooled dome. It will deliver a 3×3 arcminute field of view to three observing stations. It is an open system, providing broad spectral coverage from the near ultraviolet to the thermal infrared. ATST will have the lowest scattered light performance of any large-aperture telescope ever constructed. Its coronagraphic properties, especially at infrared wavelengths, allow it to observe the solar corona far from the solar disk.

Development of a four-meter solar telescope presents several challenges not faced by conventional astronomical telescopes. The enormous flux of energy from the Sun makes thermal control a paramount consideration, both to remove the heat without degrading telescope performance and to control mirror seeing. To achieve diffraction-limited performance, a powerful adaptive optics system is required that uses solar structure as the wavefront sensing target. Low scattered light is essential for observing the faint outer atmosphere, as well as for accurately measuring physical properties of small structures in, for example, sunspots. This leads to a requirement for efficient contamination control of the primary and secondary mirrors. The ATST D&D work has produced thermal and scattered light control and enclosure designs that will solve these problems.

ATST Meets All Science Requirements	
Aperture	4 m
FOV	3 arcmin minimum, [5 arcmin goal]
Resolution	Diffraction-limited with adaptive optics
Wavelength Coverage	300 nm - 28 μm
Polarization Accuracy	Better than 10^{-4} of intensity
Polarization Sensitivity	Limited by photon statistics down to 10^{-5} I_c
Coronagraphic	Prime focus occulting
Instruments	Photometric imaging, spectropolarimeters and tunable filters
Operational Modes	Flexibility to combine multiple post-focus instruments simultaneously

To achieve the science goals, ATST must be located at an excellent site. A careful site-testing program has identified three sites offering excellent seeing, coronal sky clarity, and sustained periods of clear weather that meet ATST science requirements. More detailed testing will identify a site that best enables ATST to realize its full performance.

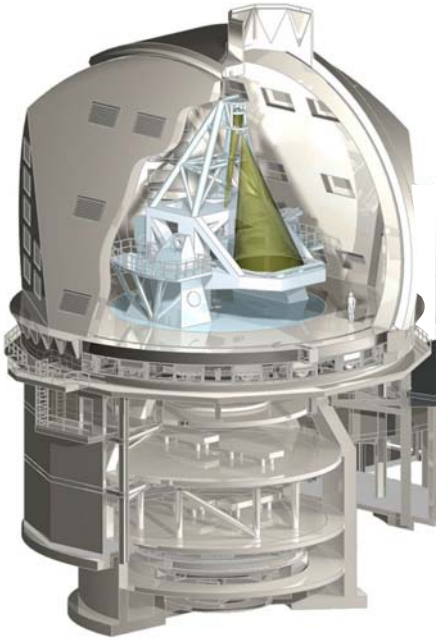


Figure 3.1. A cut-away image showing the essential design features of the ATST. Part III of the proposal discusses these in detail.

NSF funding of the ATST D&D effort along with investments by the ATST partnerships (Table 3.1) have produced and verified technologies that will ensure ATST success. Some of these technologies are now being incorporated into existing telescopes, including scalable, high-order adaptive optics systems that can use features (even the fairly low contrast solar granulation) on the solar surface to detect wavefront errors and correct the images for atmospheric seeing. Adaptive optics technologies are key to the success of the ATST. NSO has successfully demonstrated the operation of high-order adaptive optics systems on the Dunn Solar Telescope and Big Bear Solar Telescope through a joint New Jersey Institute of Technology/NSO program funded under the NSF Major Research Instrumentation program. Some of these techniques have uses outside of solar physics, including vision science and satellite imaging, in addition to other faint, low-contrast imaging applications. The Sun naturally lends itself to multi-conjugate adaptive optics (MCAO), and efforts in this area are aimed at producing a MCAO system for the ATST that will also have broad applications in astronomy as well as in other fields. MCAO is planned as a future upgrade and is not part of this proposal. The successful implementation of low scatter, off-axis optics for coronagraphic observations over the past several years is another critical technology, as are high-speed camera systems for high-resolution spectro-polarimetry in the visible and infrared portions of the solar spectrum, and spectrometers and tunable filters capable of diffraction-limited spectroscopic and spectropolarimetric imaging.

Table 3.1. Activities Conducted at Partnering Institutions.

ATST Collaborator Activities	
High Altitude Observatory	• Visible spectropolarimeter
U of Hawaii	• Near IR spectropolarimeter • Occulting disk • Sky brightness monitors • Site survey support
NJIT	• Near IR tunable filter • Site survey support
U of Chicago	• Site survey engineer, theory
UCSD	• Stray light study
AFRL**	• Thermal engineer
Lockheed Martin	• Wide band optical filter system
NASA Goddard**	• Thermal IR camera
NASA Marshall**	• Visible tunable filter (w/ NSO)
ETH, Switzerland*	• UV polarimeter
Other Partners	• Committees, workshops and advice, theory

**Partner contributed effort
* International contributed effort

As a telescope system, ATST's focal plane instrumentation is fundamental to its scientific performance and mission. ATST requires its spectropolarimetric imaging instrumentation to achieve exceptional magnetic remote sensing capabilities. Thus, visible and near-infrared spectropolarimeters, as well as visible tunable filters, are essential instruments and must be developed during the construction phase.

Additional instruments, such as an IR tunable filter, IR fiber spectrographs, and UV spectropolarimeters, will be developed as part of the ongoing ATST instrument program after commissioning and during operations.

4 MANAGEMENT

The ATST project has assembled an experienced and talented team of engineers and scientists that includes individuals responsible for the design and construction of two of today's large (~8 m) optical/infrared telescopes. The Principal Investigator has many years of significant project and institute leadership, including management of the Air Force Solar Research Branch, management of the Solar Mass Ejection Imager project flown on the Coriolis spacecraft, and the current directorship of the National Solar Observatory. The Project Manager successfully managed the twin Gemini 8-meter Telescopes project and has led the ATST project team during the D&D phase. The Project Scientist developed the first high-order solar adaptive optics systems and is highly experienced with instrumentation and solar telescopes. He has led the science team and chaired the ATST Science Working Group during the D&D phase. The project is following a design-to-life-cycle cost philosophy. A complete work breakdown structure (WBS) for the construction phase (with responsible person, description, cost estimates and schedules tied to each item) has been prepared as part of this proposal. In addition to required tracking systems such as Earned Value accounting, the project will track and manage multiple critical and near-critical-path tasks through use of the integrated central team, i.e., key WBS responsible engineers who have generated the detailed plans from the bottom up.

A careful flow down from science requirements to telescope and design specifications, with special attention to error budgets, risk mitigation, and cost has marked the design phase and will continue throughout the construction phase. Where possible, the project has adopted existing, proven designs to reduce development costs and risks.

Cost estimates reflect a complete bottom-up costing and include comparisons with similar work, reflect

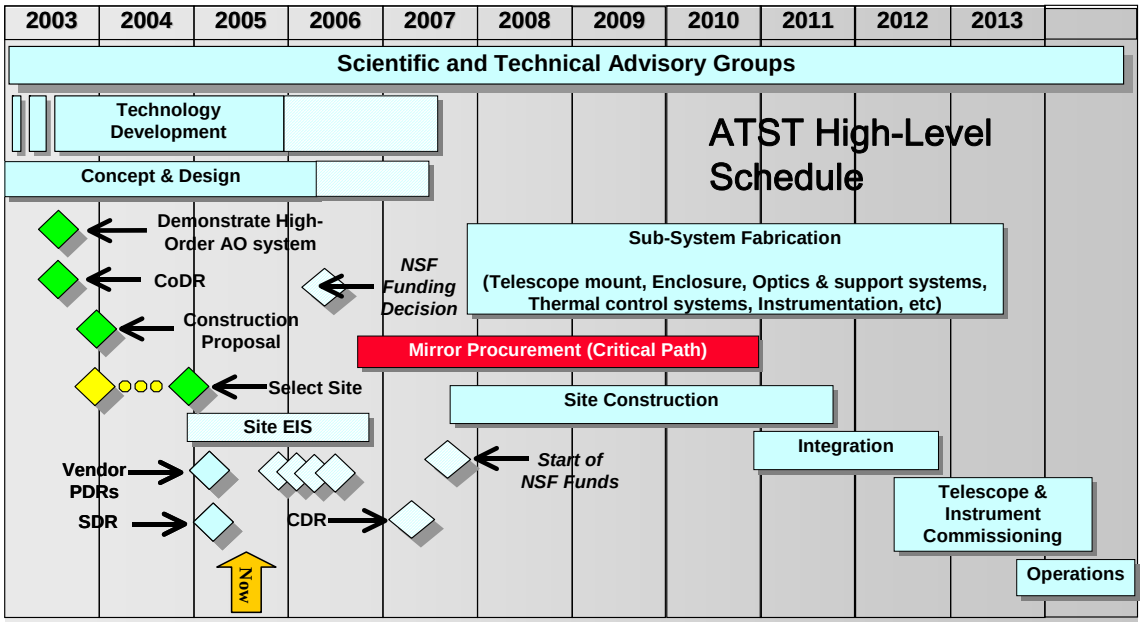


Figure 4.1. High-Level ATST Schedule.

estimates from manufacturers and partners, inflation to the time period of each item of work to be performed, and a line-by-line contingency estimate based on assessed risk and uncertainty. The

remaining D&D phase will help reduce the uncertainty that is reflected in the current $29M (20%) contingency contained in our $171M request. This request includes construction, integration, and commissioning of ATST and its support facilities. Integral to the proposal is a suite of configurable facility-class scientific instruments that will allow significant scientific return for this preeminent facility in the early years of operations. The cost estimates are based on the high-level ATST schedule shown in Figure 4.1.

To understand the full costs, we also present preliminary operational needs in terms of staff, non-payroll costs, and future developments that must be considered for the early operational years. The future developments include facility development projects, such as MCAO, and an on-going instrumentation development plan to further increase the scientific capability and enhance the scientific return. The operational planning will allow for future technology and scientific evolution.

The ATST is an international project. Germany, Spain, Italy, and Switzerland have invested resources to help develop the ATST design, including participating on the ATST Science Working Group, funding parts of the site survey operations, and developing instrumentation designs. A consortium of European nations has formed to develop a European Union (EU) Framework 6 proposal for additional contributions to the final stages of the design effort and to propose to both the EU and their respective governments for participation in ATST construction. The USAF and NASA have also contributed personnel to work on design activities. We will negotiate cost sharing with groups that have expressed their intent to share in building the ATST. The Air Force Office of Scientific Research is working with the Air Force Research Laboratory to develop a request for military construction funds to participate in the ATST construction phase. ETH in Switzerland is committed to developing a UV polarimeter for the ATST using Swiss funds.

5 BROADER IMPACTS

The Sun is an ideal object for teaching physical and mathematical concepts at all levels, because of its proximity to Earth, the wide range of observable phenomena it exhibits, and the impact of these phenomena on the Earth. The scientific and technical challenges of the ATST provide many opportunities for training the next generation of solar physicists and instrumentalists and for educational and public outreach (EPO). The ATST EPO program will focus on national needs in Science, Technology, Engineering and Math (STEM) education as well as public appreciation and understanding of the Sun, astrophysics, and the scientific process. Although the Major Research Equipment (MRE) program does not fund educational outreach, we will seek other support from NSF to take advantage of the opportunity offered by the ATST.

The ATST project, the close collaboration among the national laboratories and the universities involved in its development, and the exciting science it will enable, provide the opportunity to educate and bring students and postdoctoral candidates into solar research. Several students have already participated in instrument development, the site survey, and theoretical work aimed at quantifying ATST requirements. Anticipation of the ATST is helping to develop university faculty positions. NSO and AURA have created fellowship positions for post-docs and graduate students to participate in the ATST.

The ATST EPO program will leverage existing programs within the partnering groups and creates new opportunities for student and public involvement. As part of the program, we will develop:

- Hands-on activities for schools and at partners' public displays and visitor centers.
- Web-based solar observatories that can be used by students and the public at large, tailored to various grades and ages.

- Educational modules based on solar observing for teachers through programs such as the Teacher Leaders in Research Based Science Education (TLRBSE).
- Solar research classroom activities in collaboration with Project ASTRO.
- Solar programs in collaboration with the Lodestar Planetarium in Albuquerque that will be made available to other planetariums.
- We will include Research Experience for Undergraduate (REU) students and Research Experience for Teachers (RET) participants in ATST development and outreach programs and in ATST research projects.

The involvement of universities with large minority populations, the current location of NSO in regions with substantial Hispanic and Native American populations, and the geographic range of the partnering institutions all permit us to address both ethnic and geographic diversity issues. The project is strongly committed to the recruitment of under represented groups in astronomy and engineering. We will work closely with women and minority organizations in the American Physical Society, American Astronomical Society, and American Geophysical Union to recruit qualified women and minority candidates.

In response to the AASC's decadal survey recommendation (McKee and Taylor, 2001) to accompany major projects with a "Theory Challenge Program," we are also requesting that the NSF establish, under separate funding, such a program for investigating solar magnetism (see Part V, Section 2). The community-wide *Solar Magnetism Initiative* presented in the AASC solar panel report could serve as the primary vehicle for such a program.

6 SUMMARY

ATST will open and explore new regimes of physics that are accessible in no other way, than by high-resolution observations of the solar atmosphere. Table 5.1 summarizes major ATST science goals. Synergies with other space- and ground-based observing assets and with modeling are import for developing a total understanding of the Sun's magnetic field. These synergies are emphasized throughout the science discussions in Part II.

Table 5.1. Summary: What Science ATST Will Enable

Clearly resolve fundamental magnetic structure and processes.

Provide high photon flux for accurate, precise measurements of physical parameters throughout the solar atmosphere.

- Measure magnetic field strength and direction, temperature, and velocity on the short time scales of the dynamic solar atmosphere.
- Obtain high signal-to-noise spectro-polarimetry of magnetic field on its elemental scale.
- Measure coronal and chromospheric magnetic fields.

Observationally test models of:

- Magnetoconvection.
- Flux emergence, transport and annihilation.
- Flux tube formation and evolution.
- Sunspot magnetic fields and flows.
- Atmospheric heating.
- Solar activity.
- Solar wind acceleration.
- Generation of UV and X-ray flux.

The following sections of the proposal are organized to allow the reader to focus on scientific, technical, management, and outreach. Part II presents scientific questions the ATST will answer and gives detailed paths to achieve those answers. It begins with a broad overview of the need. It is loosely organized from surface to corona, but because the atmospheric layers are closely linked by magnetic field, these linkages are emphasized in each section. Part III describes the design and how it meets the science goals. We discuss the major design challenges of building a large-aperture telescope to point at the Sun and the trade and technical studies used to solve them. Part IV presents the detailed management and implementation plan as well as the transition to operations. Finally, Part V discusses ATST impacts on educating the next generation of solar physicists, educational and outreach opportunities for all ages, and a Theory Challenge program that will continue to engage the theoretical and modeling community in the ATST effort.

Appendix G

NSO STAFFING and NSO STUDENT & TEACHER PROGRAMS

NSO Scientific Staff

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

Sunspot-Based Scientific Staff

NSO Staff

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

Grant-Supported Staff

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

Air Force Research Laboratory Staff at Sunspot

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

Thesis Students

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

Tucson-Based Scientific Staff

NSO Staff

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

Grant-Supported Scientific Staff

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

Emeritus Staff in Tucson

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

NSO Educational Outreach

Undergraduate Student-, Graduate-Student-, & Teacher- Program Participants **(1999 – 2005)**

2005

NSO Program	Participant Name	Advisor	Institute	What they are doing now...
REU	Andrea Allen	M. Penn	Florida Institute of Technology	
REU	Paul Anzel	F. Hill	Rice University	
REU	Christopher Beaumont	M. Giampapa	Calvin College	
REU	Yu Chen	H. Uitenbroek	Skidmore College	
REU	Rachel Hock	Balasubramaniam	Osford University/Wellesley	
REU	Patrick Maloney	S. Keil	Carleton College	
REU	Doug Mason	R. Komm	University of Southern California	
REU	Kyle Momenee	N. Dalrymple	Milwaukee School of Engineering	
RET	Mark Calhoun	C. Henney	Sabino High School, Tucson, AZ	
RET	Vera Dillard	H. Uitenbroek	Bernalillo Middle School, Bernalillo, NM	
RET	Jim Renshaw	B. Livingston	St. Pius High School, Albuquerque, NM	
RET	Michael Sinclair	J. Mozer	Kalamazoo Math and Science Center, MI	
Grad SRA	Lokesh Bharti	T. Rimmele	Mohanlal Sukhadia University, India	
Grad SRA	Nina Karachik	A. Pevtsov	Tashkent State Pedagogical University	
Grad SRA	Amel Zaatri	R. Komm	U.S.T.H.B, Algeria	
SRA	Fredrich Woeger	T. Rimmele	Germany.	
Grad SRA/HAO	Justin Edmonson	S. Tomczyk (HAO)	University of Michigan	
Grad/PhD Candidate	Jose Marino	T. Rimmele	New Jersey Institute of Technology	
Grad/AF Scholar	Cheryl-Annette Kincaid	J. Mozer	North Texas State University	
Grad/AF Scholar	Walter Allen	N. Dalrymple	Howard University	
Grad/PhD Candidate	Hyun Kyong An	T. Rimmele	University of Alabama/Huntsville	
Grad/PhD Candidate	Brian Harker-Lundberg	Balasubramaniam	Utah State University	

2004

NSO Program	Participant Name	Advisor	Institute	What they are doing now...
REU	Heidi Gerhardt	K.Sankarasubramanim	Towson University	2005 Physics Undergrad, Univ of Maryland
REU	Joel Lamb	A. Pevtsov	University of Iowa	2005 Physics Undergrad, Univ of Iowa
REU	Michelle McMillan	H. Uitenbroek	Northern Arizona University	2005 Physics Undergrad, Northern Arizona Univ/ 2005 REU Los Alamos National Laboratory

2004 (cont.)

REU	Frances Edelman	F. Hill	Yale University	
REU	Statia Luszcz	M. Penn	Cornell University	
REU	Stuart Robbins	C. Henney	Case Western Reserve University	
RET	Michael Sinclair	J. Mozer	Kalamazoo Math and Science Center, MI	2005 RET NSO, 2005 NASA NEAT Teacher, 2005 Excellence in Education Award - Kalamazoo County, Kalamazoo Math & Science Ctr Leadership Award Winner.
RET	Creighton Wilson	A. Pevtsov	Lovelady High School, Lovelady, TX	2005 RET Univ of Alabama - Birmingham
RET	Mark Calhoun	B. Livingston	Sabino High School, Tucson, AZ	2005 RET National Solar Observatory
RET	Matt Dawson	R. Hubbard	Brockton High School, Brockton, MA	
Grad SRA	Maria Kazachenko	A. Pevtsov	St. Petersburg St. University	2005 MS Thesis Student/St. Petersburg State University, Russia
Grad SRA	Andrew Medlin	Balasubramaniam	New Mexico Institute of Mining & Technology	Employed 2005 NASA Goddard Space Flight Center
Grad SRA	Leah Simon	T. Rimmele	Macalester College	2005 2nd Year Grad Student, Univ of Florida, Gainesville, FL
Undergrad SRA	Anna Malenshenko	J. Leibacher	St. Petersburg State Univ, Russia	
Grad/AF Scholar	Cheryl-Annette Kincaid	J. Mozer	North Texas State Universtity	2005 AF Space Scholar, 2nd Year Grad Student, North Texas Univ
Grad/PhD Candidate	Brian Harker-Lundberg	. Balasubramaniam	Utah State University	2005 PhD candidate Utah State University

2003

NSO Program	Participant Name	Advisor	Institute	What they are doing now...
REU	Victoria Astley	R. Komm	Florida Institute of Technology	Fall 2005, 2nd-year grad student, Physics, Rice Univ
REU	Charles Baldner	Balasubramaniam & H. Uitenbroek	Macalester College	
REU	Thomas Haxton	K. Sankarsubramaniam	University of Chicago	
REU	Sarah Jaeggli	M. Penn	University of Arizona	Fall 2005, 1st-year grad student, Institute for Astronomy, Univ of Hawaii
REU	Mark Janoff	H. Jones	Swarthmore College	
REU	Jesse Miner	G. Moretto	State University of New York - Stony Brook	
REU	Steven Olmschenk	Balasubramaniam & A. Pevtsov	University of Chicago	
REU	Francisco Virgili	N. Dalrymple	Michigan State University	2005 2nd Year Grad Student, University of Nevada - Las Vegas
RET	Matt Dawson	F. Hill	Brockton High School, Brockton, MA	
RET	Travis Stagg	C. Henney		
RET	Linda Stefaniak	Balasubramaniam & D. Neidig	Allentown High School, Allentown, NJ	2005 Spitzer Space Telescope Observing Program for Teachers and Students Participant
Grad SRA	Laura Allaire	Balasubramaniam	University of Rochester	Employed by Ball Aerospace - Boulder, CO 2004

2003 (cont.)

Grad SRA	Ludovico Cesario	A. Cacciani	University La Sapienza/Italy	2004 Working as a software specialist in Italy
Grad SRA	Sebastien Deroche	T. Rimmele & B. Jones	Ecole Nationale Superieure de Physique de Grenoble/FRANCE	2005 Working as an engineer for Daimler Chrysler - France
Undergrad SRA	Anna Malenshenko	J. Leibacher	St. Petersburg State University, Russia	Fall 2005, 1st-year grad student, solar physics, Montana State Univ
Grad/AF Scholar	Cheryl Annette Kincaid	J. Mozer	North Texas State University	2004 AF Space Scholar, 1st Year Grad Student, Northern Texas University
Grad/PhD Candidate	Jose Marino	T. Rimmele	New Jersey Institute of Technology	
Grad/PhD Candidate	Capt. David Byers	Balasubramaniam	Utah State University	2005 Maj. U.S. Air Force Office of Scientific Research, PhD granted from Utah State University 2004.

2002

NSO Program	Participant Name	Advisor	Institute	What they are doing now...
REU	Joy Chavez	J. Leibacher	University of Houston	
REU	Marjorie Frankel	H. Uitenbroek	Wellesley College	
REU	Adam Kraus	M. Giampapa	University of Kansas	2nd-year grad student, Physics & Astronomy, Caltech, Pasadena
REU	Mary "Molly" Melton	H. Uitenbroek	Texas A & M College Station	
REU	William Plick	M. Penn	Connecticut College	
REU	Erika Roesler	Balasubramaniam	Northern Arizona University	
REU	Carol Thornton	H. Jones	Virginia Polytechnic Institute	
REU	Adria Updike	A. Pevtsov	Smith College	
RET	Ben Briggs	M. Penn	Cross Middle School, Tucson, AZ	
RET	Demetria Fenzi-Richardson	H. Uitenbroek	Sarracino Middle School, Socorro, NM	2005 Continues teaching in Socorro, NM
RET	William "Joey" Rogers	A. Pevtsov & K.S. Balasubramaniam	Cloudcroft Middle School, Cloudcroft, NM	2005 Continues teaching in Cloudcroft, NM
RET	Nate Van Wey	J. Mozer	Perry High School, Massillon, Ohio	
Grad SRA	Michael Eydenburg	Balasubramaniam	New Mexico Inst of Mining &Tech	2005 PhD Candidate/Math - New Mexico State University
Grad SRA	Vasily Maleev	A. Pevtsov	St. Petersburg State University, Russia	
Grad SRA	Anna Malanushenko	C. Lindsey	St. Petersburg State University, Russia	
Grad SRA	Emilie Rousset	T. Rimmele & K. Richards	Ecole Nat Superieure de Physique de Grenoble/FRANCE	2004 MS Internship - Thales, France - Thales Avionics - Flight Management Systems working on AirBus
Grad/PhD Candidate	Capt. David Byers	Balasubramaniam	Utah State University - Logan	2005 Maj. US AFOSR, PhD granted from Utah State Univ, 2004.
Grad/PhD Candidate	Jose Marino	T. Rimmele	New Jersey Institute of Technology	
Grad/AF Scholar	Michelle Rooney	J. Mozer	Colorado State University	2005 Grad student - Eastern Medicine - Univ New Mexico; Begin nursing program, fall of 2005.

2001

NSO Program	Participant Name	Advisor	Institute	What they are doing now...
REU	Daniel Brickman	M. Sigwarth	Rice University	
REU	Kristen Brock	A. Pevtsov	Bates College	
REU	Eliza Miller-Ricci	H. Uitenbroek	Middlebury College	
REU	Tiffany Titus	Balasubramaniam	Illinois Inst of Tech	
REU	Stephen (Mark) Ammons	C. Keller	Duke University	
REU	Kara Dunn	H. Jones	New Mexico State University	
REU	Daniel Isquith	W. Livingston	Yale University	
REU	Danielle Kalitan	C. Keller & A. Potter	University of Central Florida	
RET	Thomas Seddon	H. Uitenbroek	Alamogordo High School, NM	Retired from teaching in 2004; Started Alamogordo Charter School
RET	William Joseph (Joey) Rogers	Balasubramaniam & A. Pevtsov	Cloudcroft Middle School, Cloudcroft, NM	Continues teaching in Cloudcroft, NM
Grad SRA	Eugenia Christopoulou	Balasubramaniam	University of Patras / GREECE	
Grad SRA	Patricia Jibben	Balasubramaniam	Montana State University	
Grad SRA	Arnaud Premat	T. Rimmele	Ecole Nationale Superieure de Physique de Grenoble	
Grad SRA	Miruna Popescu	H. Jones & C. Lindsey	Romanian Academy	Rec'd PhD, ( )

2000

NSO Program	Participant Name	Advisor	Institute	What they are doing now...
REU	Lynn Carlson	R. Radick	Michigan St. Univ	
REU	Michael Eydenberg	Balasubramanian	New Mexico Institute of Mining & Technology	2005 PhD Candidate/Math - New Mexico State University
REU	Erica Raffauf	S. Keil	Indiana University	
REU	Rebecca Pifer	C. Keller	Univ of Wisconsin	
REU	James Roberts	M. Giampapa	Virginia Tech	
REU	Kathryn Roscoe	R. Howe	California State Univ, Chico	
REU	Jose Ceja	H. Jones	California State Univ, Northridge	Received Masters Degree from Cal State Northridge, (Yr, Astronomy)
REU	Jessica Erickson	J. Harvey	Univ of Wisconsin, Platteville	
RET	Thomas Seddon	S. Keil	Almogordo HS	Retired from teaching in 2004; Started Alamogordo Charter School
Grad SRA	Robert Gutermuth	M. Sigwarth	Alfred University	
Grad SRA	Kai Langhans	T. Rimmele	Kiepenheuer Institut fur Sonnenphysik	Rec'd PhD from Kiepenhaeur Institut fur Sonnenphysik, 2005 Institute of Solar Physics, Stockholm, Sweden
Grad SRA	Axel Settele	M. Sigwarth	University of Pottsdam/Germany	
Grad SRA	Markus Roth	R. Komm	Albert-Ludwigs University/Germany	Rec'd Astronomy PhD from Albert-Ludwigs University, 2003

1999

NSO Program	Participant Name	Advisor	Institute	What they are doing now...
REU	Scott Catanzariti	S. Keil	Indiana State University	
REU	Michael Gericke	K.S. Balasubramaniam & S. Keil	University of Arkansas/Little Rock	
REU	James Hague	K.S. Balasubramaniam & L. Milano	Alfred University	
REU	Scott Catanzariti	K.S. Balasubramaniam	University of North Carolina/Chapel Hill	
REU	Chad Bender	H. Jones	Univ of Illinois	
REU	Tim Donaghy	J. Harvey & C. Keller	Stanford University	
REU	Heather Eddy	W. Livingston	Cornell University	
REU	Matthew Povich	M. Giampapa	Harvard	
RET	Edward Mondragon	S. Keil	Step Program	
Grad SRA	Sankarasubramanian K.	T. Rimmele & R. Radick	Indian Insitute	Solar Researcher/ATST Fellow, NSO
Grad SRA	Oleg Ladenkov	F. Hill	UBAI/ Uzbekistan	
Grad SRA	Alexander Serebryanskiy	F. Hill	UBAI/ Uzbekistan	Received PhD, (Yr.); 2005 NASA/NATO Fellow, NSO/GONG

Appendix H

COMMUNITY INPUT

Letters of Support from the User Community:

1. NSO Users' Committee (K.D. Leka, Chair)
2. Professor Jan Olof Stenflo, Institute of Astronomy, ETH-Zürich, Switzerland
3. Guido Sonnabend, NASA/Goddard Space Flight Center
4. Donald Jennings, NASA Goddard Space Flight Center
5. James C. LoPresto, Edinboro University, PA
6. Walter Harris / J.P. Morgan, University of Washington, Seattle
7. A.E. Potter (National Solar Observatory) and R.M. Killen (University of Maryland)
8. Paul Butler, Carnegie Institute of Washington
9. Connie Walker, National Optical Astronomy Observatories
10. Vojtech Rusin, Astronomical Institute, Slovakia
11. Dick Altrock, Air Force Research Laboratory
12. Craig DeForest, Southwest Research Institute
13. Gianna Cauzzi, Arcetri Astrophysical Observatory, Florence, Italy
14. Edward J. Seykora, East Carolina University
15. High Altitude Observatory
16. Mandy Hagenaar, Lockheed Martin, Solar and Astrophysics Laboratory
17. Joel Mozer, Air Force Research Laboratory
18. Haosheng Lin, University of Hawaii, Institute for Astronomy
19. Ernest Hildner, National Oceanic and Atmospheric Administration, Space Environment Center

NSO Users' Committee Members:

K. D. Leka, Ch., NorthWest Research Associates, Inc., Colorado Research Associates Division, Boulder
Thomas R. Ayres, University of Colorado, Center for Astrophysics & Space Astronomy
Sarbani Basu, Yale University, Department of Astronomy
Thomas E. Berger, Lockheed Martin, Solar Astrophysics Laboratory, Palo Alto
Carsten Denker, New Jersey Institute of Technology, Physics Department
Donald E. Jennings, NASA Goddard Space Flight Center, Planetary Systems Branch
Joel B. Mozer, US Air Force Research Laboratory, Space Vehicles Directorate
Vic Pizzo, National Oceanic and Atmospheric Administration, Space Environment Center
Douglas M. Rabin, NASA Goddard Space Flight Center, Space Physics Division
Edward J. Seykora, East Carolina University, Department of Physics
Steven Tomczyk, High Altitude Observatory, NCAR

27 July 2005

To: Dr. W. Van Citters, NSF
Cc: Dr. Stephen Keil, NSO

From: NSO User's Committee

Re: NSF Senior Review of Portfolio Facilities

Dear Dr. van Citters,

As the committee that represents the users of the National Solar Observatory, its facilities and its data, we would like to communicate our evaluation of the scientific capabilities of the NSO facilities at this juncture. The committee has as its charge to represent the scientific community which uses data from the NSO facilities, both data provided by NSO from its systematic daily ('synoptic') observations and those data obtained by a Principle Investigator (PI) using an NSO user-dedicated telescope. The members of the committee thus draw upon their own expertise and consult with other members of the solar physics community to formulate such reports. Below we present our evaluation of the NSO facilities in the two subgroups.

SYNOPTIC FACILITIES:

SOLIS:

While full deployment is not yet complete for the **S**ynoptic **O**ptical **L**ong-term **I**nvestigation of the **S**un (SOLIS) facility, daily maps of the line of sight component of the solar magnetic field (replacing the long-running Kitt Peak Spectromagnetograph) have been available for two years and are enjoying wide-spread use. The Kitt Peak magnetograms were one of the most widely used data products of the NSO and the transfer to SOLIS line-of-sight data has been smooth, especially as the latter have proved to be of higher resolution and higher sensitivity (as was advertised). The vector capability is enthusiastically anticipated by the user community, for it will provide the first full-disk synoptic vector magnetic field data available, anywhere. The vector capability is crucial for determining the heliographic components of the magnetic field, *i.e.* the most physical representation of the magnetic field at the photospheric boundary.

The community strongly supports a plan to clone the SOLIS instrument suite for deployment at complementary terrestrial longitudes in order to obtain more complete observations of the evolving Sun. Temporal coverage is crucial for understanding solar active region evolution, especially for those quickly-evolving active regions that are responsible for the majority of space weather effects. As the GONG program has repeatedly demonstrated in concert with the SOHO/MDI mission, the planned upcoming space-based missions which include full-disk vector field data in no way diminish the need for multiple-SOLIS-like capability, and in fact *enhance* the need for such capability. Complementary ground-based and space-based data provide the redundancy required to track data quality, and the multiple data sets force algorithm consistency checks that are especially crucial to obtain consistent, believable, quantitative results. Additionally, the community encourages NSO to invest in bringing SOLIS to full vector capability for chromospheric data, as interest is growing in routine vector magnetic field measurements at this force-free layer of the solar atmosphere. The lower boundary (photosphere and chromosphere) of the solar magnetic field provides our most direct window into the energy source that drives the space weather and its myriad terrestrial impacts. The community finds it imperative to bring this NSO capability to full fruition in order to provide the data with which key questions about understanding and predicting solar storms can be answered.

GONG:

The **G**lobal **O**scillations **N**etwork **G**roup (GONG) program has undergone a recent revitalization including instrumental upgrades to larger detectors, polarizing optics, and more continuous data acquisition. The resulting "GONG++" network provides data for global, far-side, and local helioseismology as well as maps of the surface magnetic field concentration. The data are being fully exploited by both the helioseismic and synoptic community. As an example, the new line-of-sight magnetic field data product from GONG ++ is included in Big Bear Solar Observatory's Active Region Monitor project. The GONG program also continues to provide checks on complementary space-based helioseismic instruments (e.g., the Michelson Doppler Imager aboard SOHO), and near real-time data acquisition. For a physical understanding of the Sun and the drivers of its magnetic activity, the User's committee strongly supports the recommendation of the AURA Solar Observatory Council that GONG continue for a full 22-year solar cycle.

HILLTOP FACILITY [SPO]

The Hilltop facility now occupies a very low priority for maintenance and support by NSO. The instruments are used daily by NCAR/HAO for coronal magnetic and velocity scans for which NCAR also provides an observer. Thus, Hilltop is active in an on-going scientific program while having minimal impact on NSO resources.

USER -DEDICATED FACILITIES:

This category of NSO facility centers on the flagship telescopes which are centers for PI-driven investigations with instruments either provided by the user or by other institutions. Each telescope in this category was designed and constructed to provide a unique capability, complementary to the other NSO facilities. Each telescope in the NSO suite is provided to the entire U.S. and foreign user community to provide equal access to first-rate observing facilities which would otherwise be available, if at all, only through private or overseas observatories.

The NSO is anticipating construction funding for the Advanced Technology Solar Telescope (ATST), and the user community has been heavily involved in the planning stages for this new flagship facility. While the solar observational community has agreed to the closure of the present facilities upon the commissioning of the ATST, the following discussion is provided to secure their continued operation and unique capabilities *at least* until that time.

DUNN SOLAR TELESCOPE [SPO]

With its relatively new high-order adaptive optics system, the Dunn Solar Telescope (DST) has re-emerged as a user instrument of internationally high acclaim for very high resolution optical imaging and polarimetry. The community has been rapidly developing new instrumentation to both take immediate advantage of the science made available by the AO system, and to prototype instrumentation for the ATST. Recently deployed or in development are the Diffraction-Limited Spectropolarimeter (DLSP), the Italian Bi-dimensional Imaging Spectrograph (IBIS), and the Spectro-Polarimeter for InfraRed and Optical Regions (SPINOR), all developed for the high-resolution multi-height spectropolarimetry required to investigate the 3-D structure of solar magnetic fields, from the tiniest magnetic elements in intergranule lanes to large-scale sunspot and active region evolution. Proposals for observing time have increased in number over recent quarters to the point where there is now routine over-subscription.

Recent results include diagnostics of the magnetic forces in the chromosphere, tracking penumbral waves and feature coherence over extended heights, and the confirmation of strong downflows associated with small magnetic elements. These observations present challenges to theories of magnetoconvection and models of the solar magnetic fields, and are at the cutting-edge of solar

science. Ultimately, observations such as these will be key to understanding the mechanisms responsible for the solar activity cycle.

The DST is currently the only facility in the world which offers the combination of advanced AO, advanced spectropolarimetry, and very high resolution imaging. This will remain the case for at least the next 5 to 10 years. We also foresee an increasing demand from users wishing to coordinate the DST's powerful observational capability with the present TRACE, SOHO and RHESSI missions as well as the upcoming Solar-B, SDO and STEREO missions.

THE EVANS CORONAGRAPH FACILITY [SPO]

The Evans facility is the only coronagraph in the U.S. available for user-defined programs, although with the caveat that users must either operate it or pay for that task. Despite its age, the coronagraph and its Coudé focus still hold great promise for coronal spectroscopy, as demonstrated recently by investigations into coronal magnetography. One of the primary reasons for the recent underutilization of the Evans is the lack of available instrumentation. This issue is being addressed by NCAR which is supporting the development of a new coronal spectro-polarimeter capable of simultaneous data acquisition in the visible and near-infrared. When complete in 2006, this new capability will be available for NSO users. Synoptically, the Evans is still used for daily coronal emission scans by the Air Force operations at SPO, a project which helps ensure the operation of this facility, but does negatively impact outside users requiring the higher-quality observing provided by morning conditions. Still, the Evans facility uniquely provides a testbed for instrumentation, especially for the planned ATST coronal science capability, as well as more immediate developmental research such as the near infrared system tested by Big Bear Solar Observatory. Thus, notwithstanding its small user base, the Evans coronagraph is a definitive component of NSO's observational capability, and a necessary component for instrument development as the community looks forward to ATST.

The Evans telescope supports on-going scientific programs that are key to future NSO capabilities, while having minimal mpact on NSO resources. The User's committee supports the continued support of the Evans facility even at its present nominal level, especially given the interest by NCAR and BBSO to invest in science for which the Evans is presently the sole platform.

McMATH-PIERCE SOLAR TELESCOPE [KPNO]

The McMath-Pierce remains the only large solar telescope in the world suitable for infrared studies beyond 2 μm. This facility also has the unique capability to combine infrared and polarimetric work, allowing investigations of the thermal and magnetic structure of the solar atmosphere from the deep photosphere into the upper chromosphere. Observations from the McMath-Pierce have recently addressed fundamental issues concerning the physical structure of the solar atmosphere spanning the "magnetic transition zone" and provided data that conflict with other diagnostics in an uncomfortable way (at least for present theories). The answers to questions concerning the solar oxygen abundance and the rare isotopes of C and O, which can be addressed by IR spectroscopy in the 1-5 μm band, have important implications for areas as diverse as helioseismology and solar-system formation theories. Polarimetry of Mg lines near 12 μm, which afford the most sensitive known Zeeman diagnostic of solar magnetic fields, cannot be performed anywhere else; this is also the case for the potentially important 3.9 μm coronal line of Si, which was discovered at this facility.

The power of the McMath-Pierce at all wavelengths (but especially in the infrared) has been significantly enhanced recently with an adaptive optics system. Just at the time of this report, the new Aladdin infrared camera achieved first light, affording an eagerly anticipated extension of the IR-array capabilities pioneered at the McMath-Pierce. For the highest spectral resolution from the ultraviolet to the far infrared, the Fourier Transform Spectrometer (FTS) is a unique resource. Thus the McMath-

Pierce telescope is poised for a renaissance as well, the result of a decade of painstaking work by the NSO staff and their collaborators.

As the only facility where long-wavelength infrared techniques can be developed in preparation for the ATST, the McMath-Pierce telescope returns a high value for its operating budget. Moreover, it is simply not feasible to duplicate the infrared capabilities of the McMath-Pierce from space observatories due to the large apertures necessary to achieve the spatial resolution required by today's scientific inquiries.

DATA ACCESS FACILITY:

The Virtual Solar Observatory (VSO) is a program to provide a single, consistent front-end to locating, gathering, evaluating and acquiring solar physics data from a variety of sources, including NSO as well as a plethora of other sources both ground- and space-based.

Significant improvements have been made in the interface software, and there is broad community support for this tool which promises to mitigate the need for researchers to query multiple websites separately in order to coordinate complementary data products for comprehensive investigations. The VSO promoters and staff have been visible at every widely-attended professional meeting, providing demonstrations and offering assistance. As multi-wavelength, multi-scale, multi-platform coordinated observations become the norm for solar physics investigations, and as the number of those platforms increases, the community sees the VSO transitioning from a novel convenience to an absolute necessity.

SUMMARY:

The User's Committee for the National Solar Observatory, on behalf of the user community of solar physics research, strongly endorses the evolutionary long-range plan of the NSO. The programs presently in place and those under development – for existing facilities and the future ATST, for synoptic and the PI-driven programs – advance both science and technology, continually looking to future capabilities and scientific frontiers. The NSO facilities help build the community of ground-based solar astronomers needed to exploit the ATST and the SOLIS and GONG networks of complementary synoptic programs. Additionally, the NSO capabilities enable solar physicists to take full advantage of both current and planned solar and heliospheric space missions: we believe existing NSO capabilities do and will continue to play pivotal roles in supporting and ensuring the scientific productivity of these space missions.

Despite level funding for many years, the National Solar Observatory continues to provide important facilities and data to the user community. The strategic plan for NSO calls for continued support for the Evans facility through at least five more years, and for the flagship DST and McMath-Pierce telescopes until the ATST is commissioned. We argue and demonstrate here that the solar community is actively using the present facilities in a variety of ways for both near-term scientific endeavors and more far-sighted planning for the new flagship telescope. We hold that premature closure of any of NSO's major facilities would jeopardize the present and future ground-based solar community and negatively impact the wider space-based and theoretical programs of solar physics.

Respectfully submitted,

The NSO User's committee: K. D. Leka (chair), T. Ayres, S. Basu, T. Berger, C. Denker, D. Jennings, P. Judge, J. Mozer, D. Rabin, E. Seykora, S. Tomczyk

Date: Mon, 27 Jun 2005 13:12:47 -0700
Jan Olof Stenflo wrote:

Dear Mark,

Below is as promised my report on the use and impact of McMath-Pierce.

Best wishes,
Jan

Prof. J.O. Stenflo
Phone: +41-1-632-3804 (direct) Institute of Astronomy
+41-1-632-3813 (secretariat) ETH Zentrum
Fax: +41-1-632-1205 CH-8092 Zurich, Switzerland
E-mail: stenflo@astro.phys.ethz.ch
Institute web page: http://www.astro.phys.ethz.ch

Contribution of McMath-Pierce to the research of Jan Stenflo

My series of observations with the McMath-Pierce facility over the past 34 years has been the foundation for my scientific career and continues to be so. No other telescope facility in the world comes close to have this impact in my case, as well as the case of a number of younger scientists that have been my students and have been brought up by me through observations with the McMath-Pierce. Examples of such former students are Sami Solanki and Christoph Keller. The scientific reputation of my institute in Zurich has been largely built on our regular use of the McMath-Pierce. During the recent decade we have had observing runs with our ZIMPOL systems at the McMath-Pierce on a nearly annual basis, and we expect this to continue.

In the references given below I will limit myself to picking examples from my own list of publications. I will group them according to discovery or topic. I am not mentioning review papers or the many papers in conference proceedings, only selected ones in leading journals.

Discovery of the kG flux tube nature of photospheric magnetic fields

This discovery occured through my first run with the McMath, in September 1971, when I introduced the line-ratio technique. It was published in 1973:

Stenflo, J.O.: Magnetic-field Structure of the Photospheric Network. Solar Phys. 32, 41, 1973.

This was the starting point for a whole industry of flux tube and facular models, both MHD and semi-empirical ones.

McMath FTS as a tool for detailed, quantitative flux tube modelling

The conversion of the McMath FTS to a powerful solar polarimeter was implemented with the help of Jim Brault and Jack Harvey in a series of FTS observing runs I had in 1978-1979. On the one hand these runs provided a first survey of the "Second Solar Spectrum" (see below), on the other hand they were used as dissertation material for a number of my students in Zurich (including Sami Solanki and Christoph Keller) for the systematic building of flux tube models at increasing levels of sophistication. The series of papers on the Zeeman-effect observations and the flux tube physics was started in 1984. Examples:

Stenflo, J.O., Harvey, J.W., Brault, J.W., and Solanki, S.: Diagnostics of Solar Magnetic Fluxtubes using a Fourier Transform Spectrometer. Astron. Astrophys. 131, 333-346, 1984.

Solanki, S.K. and Stenflo, J.O.: Properties of Solar Magnetic Fluxtubes as Revealed by Fe I Lines. Astron. Astrophys. 140, 185-198, 1984.

Stenflo, J.O. and Harvey, J.W.: Dependence of the Properties of Magnetic Fluxtubes on Area Factor or Amount of Flux. Solar Phys. 95, 99-118, 1985.

Solanki, S.K. and Stenflo, J.O.: Models of Magnetic Fluxtubes: Constraints Imposed by Fe I and II Lines. Astron. Astrophys. 148, 123-132, 1985.

Stenflo, J.O., Solanki, S.K., and Harvey, J.W.: Center-to-limb Variation of Stokes Profiles and the Diagnostics of Solar Magnetic Fluxtubes. Astron. Astrophys. 171, 305-316, 1987.

Stenflo, J.O., Solanki, S.K., and Harvey, J.W.: Diagnostics of Solar Magnetic Fluxtubes with the Infrared Line Fe I 15648.54 A. Astron. Astrophys. 173, 167-179, 1987.

Solanki, S.K., Pantellini, F.G.E., and Stenflo, J.O.: Lines in the Wavelength Range 4300-6700 A with Large Stokes V Amplitudes Outside Sunspots. Solar Phys. 107, 57-61, 1986.

Pantellini, F.G.E., Solanki, S.K., and Stenflo, J.O.: Velocity and Temperature in Solar Magnetic Fluxtubes from a Statistical Centre-to-limb Analysis. Astron. Astrophys. 189, 263-276, 1988.

M\"urset, U., Solanki, S.K., and Stenflo, J.O.: Interpretation of Broad-band Circular Polarization Measurements Using Stokes V Spectra. Astron. Astrophys. 204, 279-285, 1988.

Keller, C.U., Solanki, S.K., Steiner, O., and Stenflo, J.O.: Structure of Solar Magnetic Fluxtubes from the Inversion of Stokes Spectra at Disk Center. Astron. Astrophys. 233, 583-597, 1990.

Discovery and exploration of the "Second Solar Spectrum"

The first survey of the "Second Solar Spectrum" (the linearly polarized spectrum near the solar limb that is due to coherent scattering processes) was done in 1978 at McMath, in the UV with the vertical spectrograph, in the visible above 4200 A with the FTS. This survey was published in 1983:

Stenflo, J.O., Twerenbold, D., and Harvey, J.W.: Coherent Scattering in the Solar Spectrum: Survey of Linear Polarization in the Range 3165-4230 A. Astron. Astrophys. Suppl. Ser. 52, 161-180, 1983.

Stenflo, J.O., Twerenbold, D., Harvey, J.W., and Brault, J.: Coherent Scattering in the Solar Spectrum: Survey of Linear Polarization in the Range 4200-9950 A. Astron. Astrophys. Suppl. Ser. 54, 505-514, l983.

With the introduction of the ZIMPOL technology a new window to the Sun and spectroscopy was opened:

Stenflo, J.O., Keller, C.U.: New Window for Spectroscopy. Nature 382, 588, 1996.

Stenflo, J.O., Keller, C.U.: The Second Solar Spectrum. A New Window for diagnostics of the Sun. Astron. Astrophys. 321, 927-934, 1997.

ZIMPOL, in combination with the McMath-Pierce, brought the polarimetric sensitivity needed for a systematic exploration of the new world of polarization physics in the "Second Solar Spectrum". Examples:

Stenflo, J.O., Bianda, M., Keller, C.U., Solanki, S.K.: Center-to-limb Variations of the Second Solar Spectrum. Astron. Astrophys. 322, 985-994, 1997.

Stenflo, J.O.: Quantum Interferences, Hyperfine Structure, and Raman Scattering on the Sun. Astron. Astrophys. 324, 344-356, 1997.

Stenflo, J.O., Keller, C.U., Gandorfer, A.: Anomalous Polarization Effects Due to Coherent Scattering in the Solar Spectrum. Astron. Astrophys. 355, 789-803, 2000.

Stenflo, J.O., Gandorfer, A., Keller, C.U.: Center-to-limb variation of the enigmatic Na I D1 and D2 polarization profiles. Astron. Astrophys. 355, 781-788, 2000.

Hanle effect and related novel magnetic-field diagnostics

While my 1982 paper that introduced the Hanle effect for the diagnostics of turbulent magnetic fields (Solar Phys. 80, 209-226, 1982) was largely based on my Sac Peak observations, the introduction of the differential Hanle effect with combinations of spectral lines was done in 1998, based on McMath-Pierce observations with ZIMPOL in 1996. Our observing runs in recent years have focused on the variery of complex effects that magnetic fields have on the Second Solar Spectrum, for instance in combination with optical pumping and hyperfine structure, but we are still in the process of preparing these results for journal publication (glimpses have been shown in conference proceedings).

Stenflo, J.O., Keller, C.U., Gandorfer, A.: Differential Hanle Effect and the Spatial Variation of Turbulent Magnetic Fields on the Sun. Astron. Astrophys. 329, 319-328, 1998.

Stenflo, J.O., Gandorfer, A., Wenzler, T., Keller, C.U.: Influence of magnetic fields on the coherence effects in the Na I D1 and D2 lines. Astron. Astrophys. 367, 1033-1048, 2001.

Advantages and future use of McMath-Pierce

The two major advantages of McMath-Pierce, which makes it so attractive for us in comparison with other telescope facilities in the world, are (1) its light-gathering power, and (2) its spacious and flexible environment for experimental work with very non-standard instrumentation.

The light-gathering power is very important as we have a polarimeter (ZIMPOL) with which the polarimetric noise is exclusively limited by the photon statistics, and we are exploring effects that are too small to be seen with other instruments.

The spacious experimental environment is indispensible when we bring with us from Switzerland rather bulky optical and electronic instrumentation that needs to be properly interfaced with the telescope with a setup time not exceeding 1-2 days. It is absolutely essential for the vitality of our science that there exists a major facility that offers such an experimental environment. In comparison with other facilities McMath-Pierce is superior in this respect.

For these reasons, and since the Second Solar Spectrum still remains a largely unexplored territory with much diagnostic potential, we expect to keep wanting to come back for observing runs at McMath-Pierce on a rather regular basis in the years to come, as we have done in the past.

Date: Thu, 23 Jun 2005 13:24:43 -0700
From: Guido Sonnabend gsonnabend@lepvax.gsfc.nasa.gov
.

Guido Sonnabend wrote:

Dear Mark,

I am happy to provide information on our research at the McMath-Pierce. Please let me know if you need more information or details.
Best regards,
Guido

Here is our input:

We used the McMath-Pierce facility on two occasions, the west auxiliary in 2002 and the main telescope in 2003. Both times we shipped our own instrument from Germany and installed it in the main observing room. The instrument we develop is the Tuneable Heterodyne Infrared Spectrometer (THIS), an ultra-high-resolution receiver for the mid infrared spectral region.

In November 2002 we observed molecular features in sunspots over a 10 day period. H20 and SiO absorption lines were recorded at ~1080cm-1 with a spectral resolution of 1 MHz. Lineshapes can thus be analyzed in full detail. We found the linewidth to exceed the thermal broadening by far probably due to local turbulence. Follow up observations of the sun as well as late type stars are planned. In a second project we looked for non-LTE emission features from the atmosphere of Venus to determine the sensitivity limits of the new instrument.

In December 2003 we oberved ozone and CO2 emission on Mars at ~1035cm-1. Again we had a 10 day period. The ozone project is part of a collaboration with a group at NASA Goddard Space Flight Center. Unfortunately we observed during an ozone minimum season and the ozone data still awaits further analysis due to a shortage of personnel. The CO2 non-LTE emission however proved to be very interesting. Due to its origin in the mesosphere slight frequency offsets of the emission feature vs. the low atmosphere absorption allows direct measurements of winds in the Mars mesosphere. To our knowledge this method was demonstrated for the first time.

Both observing runs were part of the PhD thesis of my colleague Daniel Wirtz. We also published a paper on the Martian wind experiment

Sonnabend, G.; Wirtz, D.; Vetterle, V.; Schieder, R. "High-resolution observations of Martian non thermal CO_2 emission near 10 μm with a new tuneable heterodyne receiver", Astronomy and Astrophysics, Volume 435, Issue 3, (2005), pp.1181-1184)

and submitted another one on the sunspot work

Sonnabend, G.; Wirtz, D.; Schieder, R.; Bernath, P. "High-Resolution Infrared Measurements of H2O and SiO in Sunspots" submitted to Solar Physics, 6/2005).

Follow up observations to create a wind map for Mars late Northern hemisphere winter are planned for December 2005. A proposal for observing time at the McMath-Pierce main telescope is in preparation. Further observations in sunspots are desirable but not yet scheduled.

Dr. Guido Sonnabend
NASA Goddard Space Flight Center
Code 693
Greenbelt, Md 20771
Phone: +1-(301)-2861544
Email: gsonnabend@lepvax.gsfc.nasa.gov

Date: Wed, 22 Jun 2005 09:28:03 -0400
To: Mark Giampapa <giampapa@noao.edu>
From: **Don Jennings <Donald.E.Jennings@nasa.gov>**
Subject: Re: NSF Senior Review--McMath-Pierce Solar Telescope

Hello Mark,

For the Senior Review our recent publications are listed below. Our future direction is almost exclusively toward developing 12-micron polarimetry. The McMath-Pierce continues to be the only facility that can be used for our work. In the near-term we will continue to improve our present capability at the McMath-Pierce; we recently upgraded to a more sensitive array and we are modifying our optical design to improve throughput. Our trials have demonstrated that adaptive optics improves imaging at 12 microns and we now use the facility AO system regularly. Long-term, we plan to build a polarimeter and thermal-IR spectrometer for the ATST.

Best regards,

Don

Publications from 12-micron polarimetry program:

"Solar Magnetograms from Statistical Moments at 12 Microns," T. Moran, D. Jennings, D. Deming, P. Sada, and G. McCabe, submitted (2005).
"Solar Magnetic Field Studies Using the 12 Micron Emission Lines IV. Observations of a Delta Region Solar Flare," D. E. Jennings, D. Deming, G. McCabe, P. Sada, and T. Moran, Astrophy. J., 568, 1043 (2002).
"Mapping of Vector Magnetic Fields at 12 mm," D. E. Jennings, D. Deming, P. V. Sada, G. H. McCabe, and T. Moran, in Advanced Solar Polarimetry - Theory, Observation and Instrumentation, proceedings of the 20th Sacramento Peak summer Workshop, ed. M. Sigwarth, Astronomical Society of the Pacific Conference Series, vol. 236, p. 273 (2001).
"Solar Magnetic Field Studies using the 12 Micron Emission Lines. III. Simultaneous Measurements at 12 and 1.6 Microns," T. Moran, D. Deming, D. E. Jennings, and G. McCabe, Astrophys. J. 533, 1035 (2000).

Date: Sat, 25 Jun 2005 11:31:18 -0400
From: lopresto <lopresto@edinboro.edu>
To: giampapa@noao.edu

James C. LoPresto
Department of Physics
Edinboro University Observatory
Edinboro University of PA 16444
814-732-2469
lopresto@edinboro.edu

I have used the McMath-Pierce Solar telescope on and off since 1964. The late Keith Pierce and I started a series of projects in 1978. Most of our research involved measuring solar rotation, the solar limb effect and the solar gravitational red shift We co-authored a series of papers over these years. Perhaps the most important contributions we made are in the paper cited here:

Pierce, A. K, and LoPresto, J.C. *SOLAR PHYSICS*, **93**, 155, 1984, "Solar Rotation from a Number of Fraunhofer Lines".
LoPresto, J.C. and Pierce, A.K., *SOLAR PHYSICS*, **102**,21, 1986, "The Center to Limb Shift of a Number of Fraunhofer Lines".
LoPresto, J. C., Krauss, P., A.K. Pierce, *SOLAR PHYSICS*, **149**,41,1994, "Observations of the Limb Effect in Potassium 7699.
LoPresto. J.C., Schrader, C., A.K. Pierce, *Ap.J.* **376**, 757,1991, "Solar Gravitational Red Shift from the Infrared Oxygen Triplet".
Pierce, A.K., LoPresto, J.C. *SOLAR PHYSICS*, **196**,41,2000,Wavelenght Shifts in the Solar Spectrum.

In addition to the above, Dr. James Breckinridge and I pioneered the use the McMath-Pierce telescope as a night time instrument. We obtained a convincing spectrum of the bright star Arcturus back in 1965 using the main spectrograph at very high resolution onto a photographic plate. One of our contributions to nighttime work is cited here:

LoPresto, J.C. *Pulbications of the Astronomical Society of the Pacific*, **83**, 684, 1971,

Plans are being made to carry out a series of observations on the McMath-Pierce Solar Telescope for the purpose of measuring a suspected solar polar vortex. I will carry out these observations over the next several years in cooperation with Claude Plymate.

In addition, Claude Plymate, Mike Simmons (form the Mt. Wilson association) plan to carry out a variety of observations and demonstrations for the purpose of outreaching science to the community in general. Some of these outreach programs will be done in conjunction with the CUREA program at Mt. Wilson.

Wed, 22 Jun 2005 12:55:16
To: Mark Giampapa <giampapa@noao.edu>
Reply-To: jpmorgen@alum.mit.edu
Subject: Re: NSF Senior Review: McMath-Pierce Solar Telescope Facility
From: **jpmorgen@u.washington.edu Jeff Morgenthaler, Ph.D.**

Hi Mark,

We're on it! We have already sent the attached email directly to Tom Ayres (though maybe we should have CCed it to nso@nso.edu). The email includes a letter from my boss, Walter Harris and a slight update of the NSO newsletter article I wrote for the 2005 July issue. We will be out next week for the Deep Impact event, so thanks for the heads up regarding Matt Penn's activity.

Let us know if there is any other way we can be of assistance.

jpm

--
Jeff Morgenthaler, Ph.D.
Research Scientist/Engineer 3
Dept. of Earth and Space Sciences
1100 NE Campus Parkway
Box 351310
Seattle, WA 98195-1310
Phone: 206-543-2272
FAX: 206-543-0489
jpmorgen@u.washington.edu
http://alum.mit.edu/www/jpmorgen

Date: Fri, 27 May 2005 09:12:41 -0700
From: **Walter Harris <wmharris@u.washington.edu>**
To: ayres@casa.colorado.edu
Subject: Continued support for the McMath-Pierce Solar Telescope

Dear Prof. Ayres,

It has been brought to my attention that you are involved in a review of resources for solar astronomy that will include a discussion of the future of the McMath-Pierce (MMP) telescope at Kitt Peak. While I am not a solar observer, I do make extensive use of this facility during the night program. Indeed, the MMP has become a key element of observing and instrument development programs and so I would very much like to add my voice to this discussion.

From our perspective as solar system astronomers and instrument developers, the MMP provides three meter-class telescopes with very accessible Coude feeds and flexible nighttime scheduling in a world-class observatory setting. The fixed focal planes of the telescopes allow rapid progress in our interferometric instrumentation development programs that now concentrate on the technique of spatial heterodyne spectroscopy (SHS -- see attached) for which we have obtained several grants from NASA, including the SEC theme. These 1st generation instruments are large prototypes that cannot be easily

mounted to the mobile focal plane of typical telescopes. In this regard, the MMP is central to the maturation of this technology. As an observing tool, the flexible scheduling of the MMP allows fast response for targets of opportunity such as comets and excellent temporal coverage for our program of synoptic monitoring of Io and the plasma torus.

The combination of these features is unique among telescopes available to nighttime observers and has allowed us to make great progress in our programs over the past several years. This progress, both on the instrument and observing sides, has also served our educational mission.
Many of our students, ranging in program from undergraduate to Ph.D. have been involved with research using data from the MMP. We currently Masters and one Ph.D. student whose thesis work will depend significantly on the data obtained during our upcoming run to monitor the aftermath of the NASA-Deep Impact spacecraft encounter with comet P/Tempel 1 in early July.

It is very likely that we would be unable to continue any of these programs at the same level if the McMath-Pierce were to cease operations. This unique instrument is suited for the type of flexible, developmental program that we operate from the University of Washington and I look forward to continue making use of these facilities for many years to come.

Sincerely,

Walter Harris
Asst. Professor
Dept. of Earth and Space Science
University of Washington
Seattle, WA 98195
206-616-4068

Planetary Research at the McMath-Pierce Solar Telescope

A.E. Potter (NSO) and R.M. Killen (University of Maryland)

We have used the McMath-Pierce solar telescope to map the sodium and potassium atmospheres of Mercury and the Moon, and to measure the thermal emission spectrum of Mercury. Seventeen publications since 1999 have resulted from this work. Recently, we have adapted the tip-tilt portion of the solar adaptive optics system (Keller C.U., Plymate C., Ammons S.M., Low-cost solar adaptive optics in the infrared, SPIE 4853, in press) to operate for daytime Mercury observations and for night-time Europa and Io observations. Our proposals for new Mercury work and new Europa work were funded this year by the NASA Planetary Astronomy Division to continue for three years. We plan to extend the tip-tilt capability to a full adaptive optics system that can be used not only for Mercury but also for observations of other planets and planetary satellites, and we have submitted an instrument proposal (from U. of Md.) to the NASA Planetary Astronomy Division for this purpose.

Refereed publications since 1999 resulting from work at the McMath-Pierce Solar Telescope

Killen, R.M. and W.-H. Ip. 1999. The Surface Bounded Atmospheres of Mercury and the Moon. *Revs. Geophys. and Space Phys.* **37**, 361-406.

Killen, R.M., A.E. Potter, A. Fitzsimmons, and T.H. Morgan. 1999. Sodium D2 Line Profiles: Clues to the temperature structure of Mercury's exosphere. *Planetary and Space Science.* **47**, 1449-1458.

Potter, A.E., R.M. Killen and T.H. Morgan. 1999. Rapid changes in the sodium exosphere of Mercury. *Planetary and Space Science*. **47**, 1441-1448.

Cooper, B., R.M. Killen, A.E. Potter, and T.H. Morgan. Thermal Emission Spectra of Mercury, in *Thermal Emission Spectroscopy and Analysis of Dust, Disks and Regoliths*, April 28-30, 1999, Houston, Texas, 1999.

Potter, A.E., R.M. Killen and T.H. Morgan 2000. Variation of lunar sodium during passage of the moon through the earth's magnetotail. *JGR Planets*, **105**, 15073-15084.

Killen, R.M. and A.E. Potter, P. Reiff, M. Sarantos, B.V. Jackson, P. Hick, and B. Giles. 2001. Evidence for Space Weather at Mercury. *JGR Planets*, **106**, 20,509-20,525.

Cooper, B., A.E. Potter, R.M. Killen and T.H. Morgan, 2001 Mid-Infrared Spectra of Mercury. *JGR Planets*, **106**, 32803-32814.

Cooper, B., J. Salisbury, R.M. Killen, and A.E. Potter, 2002. Mid-Infrared spectral features of rocks and their powders. *JGR Planets*, **107** E4, 10.1029.

Potter, A.E., C.M. Anderson, R.M. Killen and T.H. Morgan, Ratio of sodium to potassium in the Mercury exosphere, *JGR Planets*, **107**, 7, 2002.

Potter, A.E., R.M. Killen, and T.H. Morgan, The Sodium Tail of Mercury, *Meteoritics and Planetary Science*, **37**, 1165-1172 2002.

Lammer, H., P. Wurz, M.R. Patel, R. Killen, C, Kolb, S. Massetti, S. Orsini, and A. Milillo, The variability of Mercury's exosphere by particle and radiation induced surface release processes, *Icarus* **166**, 238, 2003.

Killen, R.M., M. Sarantos and P. Reiff, Space Weather at Mercury, *Adv. Space Res*. **33**#11, 1899-1904, 2004.

Killen, R.M. and M. Sarantos, Source Rates and Ion Recycling Rates for Na and K in Mercury's Atmosphere, *Icarus*, **171**, 1-19, 2004.

Killen, R.M. A.E. Potter, M. Sarantos and P. Reiff, Recycling of Ions in Mercury's Magnetosphere, *Highlights in Astronomy*, **13**, 66-69, 2004.

Leblanc, F. A.E. Potter, R.M. Killen, and R.E. Johnson, Origins of Europa cloud and torus, submitted to Icarus special issue: Jovian magnetosphere environment science, 2004.

Potter, A.E., C. Plymate, C. Keller, R.M. Killen and T.H. Morgan, Mapping sodium distribution on the surface of Mercury, *Adv. Space Res.* , In press, 2005.

Potter, A.E., R.M. Killen, and M. Sarantos, Spatial Distribution of Sodium on Mercury, *Icarus*, submitted, 2005.

From Paul Butler, Carnegie Institution of Washington

re: FTS applications in extrasolar planet discovery.

Date: Sun, 26 Jun 2005 04:54:45 -0400
From: Paul Butler <bluaper@gmail.com>
Reply-To: Paul Butler <bluaper@gmail.com>
To: giampapa@noao.edu
Subject: Re: NSF Senior Review: McMath-Pierce Solar Telescope Facility Mime-Version: 1.0

Dear Mark,

It is my pleasure to acknowledge the critical importance of the NSO FTS to our precision Doppler search for extrasolar planets. I wrote a short article for the NSO a few years ago on the central roll played by the FTS to our research. I have attached this below. I am also attaching my bibliography since with only one exception every paper listed is directly dependent on the FTS.

Below is a brief write up on the importance of the McMath FTS in the search for extrasolar planets by the precision Doppler technique.

Please feel free to edit or modify this as you see fit. Please let me know if there is anything else I can do to help.

Best wishes,
Paul Butler
Carnegie Institution of Washington
Department of Terrestrial Magnetism
http://astron.berkeley.edu/~paul

The McMath Fourier Transform Spectrometer has been crucial to the success of the precision Doppler planet search programs using Iodine absorption cells. It is not a stretch to say that the McMath FTS is directly responsible for two-thirds of all known extrasolar planets.

Jupiter gravitationally induces a ~10 m/s wobble on the Sun. A three sigma detection of a jupiter-analog thus requires Doppler precision of 3 m/s. For modern high resolution echelle spectrometers, such as HIRES on Keck I and UVES on VLT 2, 3 m/s corresponds to one-thousandth of a pixel - 100 Silicon atoms on the CCD substrate. At this level the smallest variation in the spectrometer completely overwhelm the signal of an extrasolar planet.
CCD dewars routinely drift by as much as a pixel over the course of a night as liquid nitrogen boils off. Temperature changes of 1 degree cause steel and concrete to expand and contract by many tenths of a pixel. Variable seeing and imperfect guiding cause the star to drift by more than a tenth of a pixel over the course of a single exposure. Even more insidious, subtle changes in the point-spread-function of a spectrometer will cause systematic errors of 10 to 50 m/s. This is why the precision of astronomical Doppler velocity measurements stalled at 300 m/s from 1920 into the 1980s.

Starting in 1979 the Canadian group of Bruce Campbell and Gordon Walker introduced the concept of observing a star through an absorption cell prior to the starlight entering the spectrometer. The absorption cell lines serve as the metric against which to measure the Doppler shift of the star. Since these absorption cell reference lines are carried by the starlight, automatically take into account the problems

associated with CCD drift and guiding uncertainties. After 8 years of work they achieved long term precision of 13 m/s, an extraordinary accomplishment.

In 1986 Geoff Marcy and I began a project to find a better absorption cell than the hydrogen-fluoride cell used by the Canadians. In addition to being extraordinarily dangerous, HF has only a handful of reference lines in the near IR where stars have little Doppler information. A 6 month investigation in the chemistry laboratory and chemistry library led to the use of an Iodine absorption cell, which has thousands of lines over 1,000 angstroms in the visible.

Iodine provides an extraordinary density of lines. Every stellar line is blended with several Iodine lines. When untreated, tiny changes in the point-spread-function of the spectrometer lead to differential blends of Iodine and stellar lines, and consequently systematic measurement errors of 10 m/s or more. Based on an idea from Jeff Valenti, we began an attempt to directly solve for the point-spread-function of our observations from the shapes of the embedded Iodine lines in our spectra. The crucial information needed was the true underlying spectrum of the Iodine absorption cell.

We made the first of many ongoing pilgrimages to the NSO Solar Observatory in 1991 to have our original Lick Observatory Iodine cell scanned with the FTS at a resolution of ~300,000 and a S/N ~ 500. With this "sacred spectrum" of our Iodine cell, we worked an additional 3 years to develop the forward modeling software necessary to recover the spectrometer point-spread-function directly from our individual observations. By 1995 we were able to achieve unprecedented Doppler precision of 3 m/s, leading to the discovery of 5 of the first 6 extrasolar planets.

Since 1995 the the Iodine absorption cell technique has become the de facto world standard. We have since calibrated Iodine cells with the NSO FTS for groups at the University of Texas (McDonald Observatory), Harvard (AFOE, Mt. Wilson), Keck Observatory, the Anglo-Australian Telescope, the 8-m VLT 2, the 6.5-m Magellan, and the new Korean National Telescope.

Our group using NSO FTS calibrated Iodine cells at Lick, Keck, and AAT have contributed two-thirds of the known extrasolar planets. We expect these programs will go on leading the world and opening up new realms of phase space over the next two decades. In the past year we have begun an initiative to achieve precision of 1 m/s at Keck and the AAT. Later this year we will begin taking data on a custom 2.4-m "Robotic Planet Finder" at Lick also with the goal of reaching 1 m/s. At this level of precision we will be able to find "Rocky" terrestrial planets in small orbits and saturn-mass planets at 5 AU.

The NSO FTS remains a critical element in our research.
We will be calibrating an Iodine cell for the 8-m Japanese National "Subaru" Telescope in July. This telescope and Iodine cell are currently being used as part of an international search for "Hot Jupiters". This program has already yielded only the second bright nearby transit planet. We anticipate scanning more Iodine cells at the NSO FTS in the future, including for the next generation 20 and 30-m telescopes. We will also have existing cells rescanned as software upgrades of the McMath FTS now routinely yields a resolution of a million.

Paul

Date: Sat, 21 May 2005 00:13:34 -0700
To: nso@nso.edu
From: **Connie Walker** <cwalker@noao.edu>
Subject: **Letter of support - NSO role in student & teacher training & education**
Cc: cplymate@noao.edu, spompea@noao.edu, scroft@noao.edu, garmany@noao.edu Mime-

Dear Dr. Ayres,

I have been informed that you are requesting write-ups on the role NSO has played and will continue to play in student and teacher training and education. I run the solar research segment of a program called the Teacher Leaders in Research Based Science Education (TLRBSE).

The National Solar Observatory has been heavily involved in student and teacher training and education. They have made significant contributions to the TLRBSE program over the past four years and is actively engaged in preparations for this year's cohort of TLRBSE teachers. Four years ago, the program brought 10 teachers to Sac Peak to observe, using a multi-wavelength approach to study the Sun. During the past 3 years the TLRBSE teachers have observed on the McMath Pierce, where a Zeeman split IR spectral line study has been conducted each year. If it were not for the effort of several astronomers, K.S. Balasubramaniam, Han Uitenbroek and Alexei Pevtsov at Sac Peak, and Frank Hill, Matt Penn, Carl Henney and Christoph Keller and especially Claude Plymate at the McMath-Pierce telescope, the solar unit of the program would have never succeeded. They have assisted with developing research questions, with gathering data used in an on-line preparatory course, as advisors during the DL course, with teaching the teachers how to observe during the summer institute, with answering their questions on content, data reduction, analysis and interpretation of the data. And with subsequent teacher/'student observing runs during the year.

Specifically, TLRBSE is an NSF-funded Teacher Enhancement Program hosted by the National Optical Astronomy Observatory (NOAO) in Tucson, AZ. Consistent with national priorities in education, TLRBSE seeks to retain and renew middle and high school science teachers. Within the exciting context of astronomy, TLRBSE integrates the best pedagogical practices of Research Based Science Education with the process of mentoring. One means by which participants are provided training in astronomy content, pedagogy, image processing and leadership skills is through a 15-week distance-learning course and an in-residence, two-week institute at Kitt Peak National Observatory and the National Solar Observatory (NSO). At the observatories, teachers are the researchers on one of four research projects, including a solar astronomy unit. The teachers learn the tools to do data reduction and analysis; ask and answer questions on content; propose a research question; discussing alternative hypotheses; are taught how to operate the telescope and take, calibrate, reduce and analyze data; and learn to interpret and report results among piers and pundits. Subsequently the teachers observing experience and knowledge gained are transferred to the classroom, where students (and the teacher-mentees) learn science by doing science. Staff support by astronomers and education specialists continues with efforts to sustain a professional learning community that outlives the research experience. Further observing experience is available during the academic year. Students and teachers submit research papers to the RBSE on-line journal. Teachers and their teacher-mentees present at the annual National Science Teacher Association conferences.

How high the quality of results from students is depends on how well the teachers understand the research content, methods and scientific process. This is one of the main reasons the TLRBSE program was developed. To give you an example of its success, a draft of paper by two high school students for the upcoming on-line RBSE journal is attached. (The article is still a draft. We are asking the students to correct some units in the paper.) Permission to reproduce the article must be requested from Stephen

Pompea, Director of the TLRBSE program (spompea@noao.edu). Further information on the TLRBSE program may be viewed at http://www.noao.edu/outreach/tlrbse.

Feel free to contact me or Dr. Pompea with any questions.
Connie

Connie Walker, Ph.D.
Senior Science Education Specialist
Astronomer

National Optical Astronomy Observatory
950 N. Cherry Ave.
Tucson, AZ 85719

Phone: 520-318-8535
Fax: 520-318-8451
Email: cwalker@noao.edu
http://www.noao.edu/education/noaoeo.html

FROM: Dr. Vojtech Rušin

Dr. Steve Ke i l
Director
Sacramento Peak and Kitt Peak
National Optical Observatories
Sunspot
New Mexico
U.S.A.

Dear Steve,

Let me express several words to the coronal research provided at Sacramento Peak coronagraphs and facilities.

The solar corona is the outermost layer of the solar atmosphere and its particles extend very far behind of our Earths. There are several emission coronal lines that can be observed in the visible part of the electromagnetic spectrum, e.g., the green corona (530.3 nm), the red corona (637.4 nm) and the yellow lines (569.4 nm and 544.6 nm) that reflect different physical parameters (density, temperature, magnetic fields) in the solar corona, so, the corona reflects very well photospheric activity, and, a study of individual coronal lines is very useful tool to study the solar activity, indirectly magnetic fields as well, and their influences to the space weather. To know better the Sun as the nearest star, observation of the solar corona is not only useful, but necessity as well. I do not want to discuss all obtained results that improved our present knowledges related to the solar corona, the Sun, and to the space weather, however, I would like to say three examples.

1) Distribution of the green line intensities showed for the first time so called extended solar cycle and poleward migration.
2) Time-latitudinal distribution of the green corona can be used to predict occurrence of minimum and maximum of solar cycles with very high precision.
3) Synoptic data sets are useful tool to study connection between the photosphere and corona and prominences.

On the hand, there are still many opened questions in the solar corona research, e.g., polarization in the emission coronal lines (and indirectly to study of coronal magnetic fields), distribution and connection of the coronal activities to the photospheric magnetic fields, to the active regions and coronal holes during cycle activity, rotational rates of the coronal features with respect to the heliographic latitudes and longitudes, oscillations (5 min or shorter or longer), time-latitudinal distributions, long term variations, etc.

Sacramento Peak observatory has a long tradition in the solar corona research. It has stable atmospheric conditions and many observational days over a year. Many scientists in the world are using Sacramento Peak coronal data not only for a study of solar corona properties, the solar emission corona connection with other solar features, but for a long time variations in the solar corona, especially in the green corona. And, a highly correlation between the green corona intensities and other solar indices, e.g., sunspot number, the 2800 MHz flux, is improving our knowledges of solar activity. The ground-based coronal observations are irreplaceable for a long-term solar corona irradiance because satellite and space probe observations have short-term durations, and, different sensitivity for this purpose.

I, personally, and my colleagues from the Astronomical Institute of the Slovak Academy of Sciences, Slovakia, and very grateful for a cooperation with the Sacramento Peak coronal staff, and we strongly recommend to continue in the solar corona research in future. There are only for coronal stations in the world that continuously or with a small break observe the solar emission corona (Sacramento Peak, Kislovodsk-Russia, Norikura-Japan, and Lomnický Štít-Slovakia).

I express my congratulation to NSO/SP long ramp plans to evolve its facilities, and especially, to keep and extend the ground-based coronal research.

Yours sincerely,

Dr. Vojtech Rušin
Astronomical Institute
Lomnický Štít coronal station
050 60 Tatranská Lomnica
Slovakia
(vrusin@ta3.sk)
Tatranská Lomnica, June 30 2005

Date: Wed, 29 Jun 2005 14:35:14 -0600 (MDT)
from: **Dick Altrock** (505) 434-7016 <altrock@nso.edu>
To: skeil@nso.edu
Subject: Senior Review input
Cc: ppiano@nso.edu

Steve,

Well, you know how important the ESF is to me. 100% of all of my scientific output comes from the coronal scans. I attach below some of my recent work.

In addition, the data are made available through publication in Solar Geophysical Data (Online) ["Coronal Line Emission (Sacramento Peak), 2004" and "Sacramento Peak Coronal Line Synoptic Maps, 2004"] and on the NSO web site. I am responsible for assuring data quality and quantity, upgrading products, and providing daily data to AFWA, NOAA/SEC, other civilian space weather operations centers, and the

scientific community. Notification of posting of new data on the NSO web site are sent by email to space weather forecasting centers in the U.S., Canada, Australia and Japan, including AFWA and NOAA/AFWA.

Alerts of unusually strong coronal activity (CORONALERTS) issued by email to ~60 customers worldwide. Forecast centers and individual researchers may receive digital files of coronal scan and image intensities (as opposed to GIF or PostScript images) by email at their request. Archived images and intensity files are also stored on the NSO web site for research use. USAF and civilian forecast centers receive coronal data products for making predictions of solar disturbances responsible for satellite and C3I system disruption, and numerous other customers in government, academia and industry receive coronal data that is used for a variety of purposes. Craig estimated that last year the coronal data on the web site were accessed from outside our LAN approximately 100,000 times.

Observers such as V. Rusin, M. Rybansky and others incorporate these observations into a global long-term database that is used for many studies. They also intercompare the ESF observations with coronal observations from other observatories.

I studied the variation of sky brightness and transparency at our operating location at Sac Peak. Found that volcanic activity has major effects, sometimes lasting for years. Perhaps more important is the observation that over the last 20 years sky brightness has increased by 50% and transparency has decreased by 10%.

I continued to inter-calibrate NSO ground-based coronagraph observations with space-based observations from the SOHO satellite and with other ground-based coronal data sources to determine an absolute calibration for all sources of coronal emission-line data.
Inter-calibration of existing coronal observations enables reconstruction of the long term record of solar variability. The paper, "Comparison of the Sacramento Peak Fe XIV Index With a Model Index Computed from Differential Emission Measure Maps", by J.W. Cook, J.S. Newmark and me has been accepted for publication in The Astrophysical Journal. We compare the Sacramento Peak Fe XIV 530.3 nm green line index with a model index time series for the period of operations of the Extreme-ultraviolet Imaging Telescope (EIT) onboard the Solar and Heliospheric Observatory (SOHO), covering the years 1996-2002, from cycle minimum past the peak of the current activity cycle 23. We compute a differential emission measure (DEM) map for each day using images from the four channels of EIT at 17.1 nm, 19.5 nm, 28.4 nm, and 30.4 nm. From the daily DEM map we then calculate a daily synthetic Fe XIV 530.3 nm intensity image. The Sacramento Peak index is an average intensity, measured using a circular aperture 1.2 arcmin in diameter, sampling the off-limb corona in 3 degree steps around disk center. It is taken at several different heights beyond the daily white light limb. We modeled the daily index values, for the aperture center at 1.15 Ro and at 1.25 Ro from disk center, as the weighted average intensity within an annulus covering 1.11 - 1.19 Ro and 1.21 - 1.29 Ro superposed on the daily synthetic intensity image.

We compare the observed index with our model results, and find a high correlation of the short-term values, but a long-term systematic difference in the absolute values. We examine the accuracy of the respective calibrations, and argue that the model results, based on the calibration of the EIT images used to produce the daily DEM maps, are more plausible in absolute value.

Began a collaboration with Rachel Howe and Roger Ulrich to determine the relationship between the 18-year cycle of activity that is observed in the solar corona and variations of the rotation of the convection zone of the sun known as torsional oscillations. There is an obvious morphological connection between these two disparate regions of the sun. Determining the cause of the connection between the sub-surface region of the sun where activity originates and its manifestation in the upper atmosphere of the sun could lead to major new discoveries in the operation of the solar dynamo that is responsible for all activity. We

find that there is an apparent connection between these two phenomena that extends from the equator to latitudes as high as 70 to 80 degrees.

Published a sole-authored paper, "Use of Ground-Based Coronal Data to Predict the Date of Solar-Cycle Maximum", in a refereed journal (Solar Physics). Prediction of the exact date of the maximum of the 11-year solar activity cycle is a matter of disagreement among solar scientists and of some importance to satellite operators, space-system designers, etc. Most predictions are based on physical conditions occurring at or before the solar-cycle minimum preceding the maximum in question.
However, another indicator of the timing of the maximum occurs early in the rise phase of the solar cycle. A study of the variation over two previous solar cycles of coronal emission features in Fe XIV from the National Solar Observatory at Sacramento Peak has shown that, prior to solar maximum, emission features appear above 50O latitude in both hemispheres and begin to move towards the poles at a rate of 8O to 11O of latitude per year. This motion is maintained for a period of 3 or 4 years, at which time the emission features disappear near the poles.

This phenomenon has been referred to as the "Rush to the Poles". These observations show that the maximum of solar activity, as seen in the sunspot number, occurs approximately 19 2 months before the features reach the poles. In 1997, Fe XIV emission features appeared near 55O latitude, and began to move towards the poles. Using the above historical data from cycles 21 and 22, we will see how the use of progressively more data from cycle 23 affects the prediction of the date of solar maximum. The principle conclusion is that the date of solar maximum for cycle 23 could be predicted to within 6 months as early as 1997. For solar cycle 24, when this phenomenon first becomes apparent later this decade, the average parameters for cycles 21 - 23 can be used to predict date of solar maximum.

Published a sole-authored paper, "The Temperature of the Low Corona During Solar Cycles 21 to 23", in a refereed journal (Solar Physics), Observations of the forbidden coronal lines Fe XIV 530.3 nm and Fe X 637.4 nm obtained at the National Solar Observatory at Sacramento Peak are used to determine the variation of coronal temperature at latitudes above 30 degrees during solar activity cycles 21, 22 and 23. Features of the long-term variation of emission in the two lines are also discussed. Temperatures at latitudes below 30 degrees are not studied, because the technique used to determine the coronal temperature is not applicable in active regions. The polar temperature varies cyclically from approximately 1.3 to 1.7 MK (millions of Kelvins). The temperatures are similar in both hemispheres. The temperature near solar minimum decreases strongly from mid-latitudes to the poles. The temperature of the corona above 80 degrees latitude generally follows the sunspot cycle, with minima in 1985 and 1995 - 1996 (cf. 1986 and 1996 for the smoothed sunspot number, Rz) and maxima in 1989 and 2000 (cf. 1989 and 2000 for Rz). The temperature of the corona above 30 degrees latitude at solar maximum is nearly uniform; i.e., there is little latitude-dependence. If the maximum temperatures of cycles 22 and 23 are aligned in time (superposed epochs), the average annual N+S temperature (average of the northern and southern hemisphere) in cycle 23 is hotter than that in cycle 22 at all times both above 80 degrees latitude and above 30 degrees latitude. The difference in the average annual N+S maximum temperature between cycles 23 and 22 was 56 kK near the poles and 64 kK for all latitudes above 30 degrees. Cycle 23 was also hotter at mid-latitudes than cycle 22 by 60 kK. The last 3 years of cycle 21 were hotter than the last 3 years of cycle 22. The difference in average annual N+S temperatures at the end of cycles 21 and 22 was 32 kK near the poles and 23 kK for all latitudes above 30 degrees. Cycle 21 was also hotter at mid-latitudes than cycle 22 by at least 90 kK. Thus, there does not seem to be a solar-cycle trend in the low-coronal temperature outside of active regions.

Date: Wed, 29 Jun 2005 15:39:57 -0600 (MDT)
From: Dick Altrock (505) 434-7016 <altrock@nso.edu> Message-Id:
To: ppiano@nso.edu, skeil@nso.edu
Subject: senior review input

Here is some background material on the coronal observations and the products available on the NSO web site.

Dick

Coronal Observations
National Solar Observatory
Observations are made at the National Solar Observatory at Sacramento Peak with the Fisher-Smartt Emission Line Coronal Photometer (ELCP).
This instrument photoelectrically records the solar corona when fed with the John W. Evans Solar Facility 40-cm-aperture Coronagraph. It operates at high precision due to its ability to subtract the sky background from the signal in emission lines through use of a lockin amplifier oscillating at a rate of 100 kHz between the continuum and lines at 637.4 nm (Fe X), 530.3 nm (Fe XIV) and 569.4 nm (Ca XV), which are formed at approximate temperatures of 1, 2 and 3 MK, respectively. A 1.1 arcmin aperture is scanned around the limb daily from 1.15 to 1.45 solar radii (Ro) for Fe X and Fe XIV, and 1.15 solar radii for Ca XV. The output of the ELCP is sensed by a photomultiplier, digitized and recorded every 3 degrees of latitude. Absolute intensities in millionths of the brightness of the center of the disk at each wavelength are obtained by calibrating the system through a neutral density filter. All Fe X and Ca XV scans are adjusted to have at least one absolute zero intensity data point. The lower-height Fe XIV scans are adjusted for zero level by determining the zero level of an upper scans (1.45 or 1.35 Ro) and subtracting that amount from the lower scans.

The pseudo-full-disk maps are produced by joining together 14 days of data and projecting it onto a sphere. The most recent scan is on the left of the map, and the data on the central meridian are from 7 days prior to the date of the map. Data are incremented from the central meridian at 12.857 degrees per day. Missing data are interpolated.
West-limb maps, which show the farside of the Sun on the day they are produced, have been given an effective date two weeks into the future, so that they may be compared with East-limb maps of the same date. Maps are currently produced for Fe XIV and Ca XV and are normally available for each Monday through Friday, excluding holidays.

Sacramento Peak Coronal Synoptic Maps
These maps are derived from the daily National Solar Observatory Coronal Scans. For each Carrington Rotation, maps are presented of Fe XIV 530.3 nm, Ca XV 569.4 nm and Fe X 637.4 nm intensities at 0.15 Ro above the limb. The maps usually combine data from both the East and West limbs to make as complete a map as possible. The limbs utilized are shown at the bottom of the map. The data have been shifted in time by + or - 6.75 days to display the intensity at Central Meridian Passage (CMP).

For the large-scale structure described by the Fe XIV and Fe X maps, it is assumed that the evolution between East limb and West limb observations of the same longitude on the same rotation is negligible. Numbers at the top of the map are the day of the year (DOY) of CMP, with 0000 UT at the tick mark. Heliographic longitude in ten-degree intervals is displayed at the bottom of the map. Latitude in ten-degree intervals is displayed on the left. No correction is required for the Bo angle.
Also at the top of the Fe XIV and Fe X maps are indicators for interpolated (missing) data ("I") and opposite-limb data ("E" or "W").

For example, if the map is based on West-limb data, which would be indicated by the legend "W+E" at the bottom of the map, the indicator "E" means that missing W-limb data has been filled in with data from the East limb. Intensities plotted for longitudes having more than two consecutive interpolated days are probably of little value. Evolution of intensities at the limb is sufficiently slow that interpolation over one or two consecutive days is acceptable. The calibration technique has time-variable errors; therefore, THE INTENSITY SCALE SHOWN HERE IS ONLY APPROXIMATE. If precise intensities are required, contact R. Altrock.

The intensities are both contoured and shaded. Contour levels in millionths of the intensity of the center of the solar disk at the wavelength in question are indicated at the bottom of each map. The shading and contour levels vary with the time of the solar cycle. However, some generalities should always hold. For Fe XIV, starting at the top or bottom of the map, there will usually be some regions that we have defined to be polar coronal holes. This definition only takes into account the intensity of the region and not its magnetic field. These regions are unshaded (white). Equatorward from there will be a region of solid black. This defines the border of the polar holes (thus the legend "coronal holes are shown as white bordered by black"). In the case where the polar coronal holes extend all around the sun, this border will be a more-or-less continuous black region extending from the left to the right side of the map. Isolated low-latitude coronal holes will appear as a black region with a white hole within. Going further equatorward from the poles, one will usually encounter lighter shading, until an active region is reached. Here the shading algorithm is reversed, and the brightest regions are again unshaded (white). Thus, white regions bordered by solid black are coronal holes, and white regions bordered by light shading are active regions.

For Fe X there is no indicator for coronal holes. Thus the shading algorithm is single-valued. Dark shading is darkest, light shading is next brightest and white is brightest.

National Solar Observatory Coronal Scans -- Photoelectric scans of the solar corona are made daily at Sacramento Peak with the three-line coronal photometer in Fe XIV 530.3 nm, Fe X 637.4 nm and Ca XV 569.4 nm. The intensity of the corona is recorded at 120 points around the limb with an aperture of 1.1 arcmin. The contribution of the sky background is removed by chopping between the line and adjacent continuum at a rate of 100 kHz. The scan heights shown here are 0.15 Ro above the limb.

The display is in the form of a polar plot of the intensity around a circle representing the sun with a radius of 10 millionths of the intensity of the center of the solar disk at the given wavelength. The intensity at the circle is zero. Tick marks are separated by 10 millionths. The calibration technique has time-variable errors; therefore, THE INTENSITY SCALE SHOWN HERE IS ONLY APPROXIMATE. If precise intensities are required, contact R. Altrock. Solar North is at the top. Observation times are shown in UT.

Fe XIV is plotted as a solid line, Fe X as a dotted line and Ca XV as X's. The noise level for Fe XIV and Fe X is normally on the order of 0.1 millionth. Ca XV points are only plotted if they fall above a variable threshold, the value of which is determined by the noise level present on that day. It is usually < 1 millionth. Points plotted represent a determination by the reduction analyst that Ca XV was present at the indicated latitudes. If Ca XV observations were made, and the reduction analyst determined that no activity was present above the threshold, a legend will be displayed, "NO CA XV ACTIVITY TODAY".

Fe XIV, formed near a temperature of 2.0 MK, is useful for determining the presence of coronal holes and large-scale active regions. Coronal holes appear in these plots as a rapid decrease in the intensity to (time-variable) levels below a few millionths. Fe X, formed near 1.0 MK, shows the coolest regions in the solar corona. Emission is often present in coronal holes. Ca XV is formed only at temperatures above 3 MK, and shows those active regions having a high probability of energetic flare activity.

From: Craig DeForest

I'm writing to you to advocate continued support of the Dunn Solar Telescope. The Dunn is a uniquely accessible facility that continues to be very important for the observing community. The Dunn has a unique combination of large amounts of laboratory space, high telescope optical quality, and frequent good seeing. Particularly with the new high-order adaptive optics system and recent renovations, the Dunn is uniquely well suited to custom, innovative solar observations.

I have recently used the DST to test a new technology, stereoscopic spectral imaging, that promises to enable studies of the high frequency wave field in the chromosphere and of small scale, rapid magnetic evolution in the photosphere. Future observing runs will involve building up a custom instrument to discover the behavior of magnetic field in and around the small intergranular bright points observed in the G-band. The accessibility and high quality of the Dunn instrument are both key to this measurement: other sites such as La Palma have excellent but unreliable seeing, and other telescopes do not have the combination of high optical quality and large amounts of laboratory space in which to set up a custom observing rig.

I strongly urge you and your affiliated funding bodies to continue supporting the Dunn for regular observations at least until the ATST becomes available: it is a unique and extremely important asset to the experimental solar physics community.

Warm regards,
Craig DeForest
Senior Research Scientist
Southwest Research Institute

From: Dr. Gianna Cauzzi, Arcetri Astrophysical Observatory (Florence, Italy)

On behalf of the solar group at the INAF - Arcetri Astrophysical Observatory (Florence, Italy), I would like to express our continuous interest in the NSO facilities. Members of our group have been utilizing the NSO telescopes and instrumentation, particularly at the DST, since the early 1980's. Our scientific interests resided primarily in solar activity, whose study greatly benefits from a multi-wavelength, multi-instrument observations approach, as testified in recent years by the great success of 'coordinated' observing programs involving both space and ground-based observatories. The NSO facilities have been perfectly suited to this task, combining state of the art instrumentation with great flexibility towards the particular needs of any given program.

Such unparalled qualities, and the availability of the AO system, have prompted our group in seeking the installation at the DST of a double interferometric system (IBIS), recently developed in Arcetri. IBIS, designed to obtain high spectral, spatial and temporal resolution data over an extended field of view, has been successfully installed at the DST in June 2003, and became an NSO facility since January 2005. In June 2005, an MoU was signed between INAF and NSO to maintain this status for a further 2 years. In this framework, a joint effort between NSO, HAO and Arcetri staff is currently underway to upgrade IBIS for use in polarimetric mode, to study solar magnetism at the smallest scales. We thus expect a continuous collaboration with NSO staff and scientists for the foreseeable future.

Dr. Gianna Cauzzi
Astronomer
INAF-OAA

From: **"Seykora, Edward Joseph**" <SEYKORAE@MAIL.ECU.EDU>
Subject: Re: NSF " Senior Review"
Date: Thursday, July 14, 2005 10:17 AM

For a large number of years now the National Solar Observatory has been at level funding, and yet has continued to provide important facilities and data to the user community. Clearly it has continued this mode of operation at some expense in terms of lost real funding and manpower. In light of the level funding in times of increased costs the National Solar Observatory has constantly reviewed all facets of its operation in order to increase efficiency and reduce cost. This has been an on-going process through the years, in order to provide its service to the user community, while also directing efforts toward technical innovation for future instruments and facilities such as adaptive optics systems, SOLIS and ATST.

Examples of more cost effective facility use are the Evans Solar Facility and Hilltop Solar Facility. Many of the synoptic observations carried out at these facilities are now or soon will be run on the SOLIS instruments or ISOON. The Evans Facility, as mentioned by Steve, is open to users which can or are willing to learn to operate it or pay for its operation and observer support. The 40-cm coronagraph is the only user coronagraph in the US, and it is thoroughly instrumented for user operation. This instrumentation includes Littrow Spectrograph, spectroheliograph, and a Universal Spectrograph which may be used with the 40-cm coronagraph or the 30 cm coelostat. Likewise the Hilltop Facility which has a spar with the white-light and H-alpha flare patrols, the coronal one-shot coronagraph, and a multi-band solar photometer as well as a coelostat that feeds an optical bench are open to users under their own support. The High Altitude Observatory has or is planning to use both facilities for some experiments in coronal vector magnetic field measurements. For several years now NSO only provides emergency and some preventative maintenance at the Evans and Hilltop facility.

It is my understanding that the strategic plan or "road map" for NSO calls for support at the DST and McM-P facilities through 2013-2014 and partner supported operations (minimal NSO support) at the Evans Facility until 2010-2011. Any departure from this plan, in my opinion is, not acceptable. This plan allows for an orderly transition to the ATST and decommission of the existing facilities. This transition also allows, as it has been pointed out, users observing access to the instruments and facilities of NSO as well as test beds for new instruments for ATST.

In the long term, ~10 years, decommission of our present facilities may or may not be an expensive undertaking depending on decisions made in the near future. If our present facilities are maintained and used up to or near the time of decommissioning, they would represent a valuable asset to a university, consortium of universities, or other public or private institution. This would be the best and least expensive decommissioning of facilities and may result in a stronger solar community. Of course at the other extreme a decommission and removal of a facility, especially those in National Forests, would be very expensive in that it would probably be necessary to return the area back to its natural state.

Best wishes,
Ed

HIGH ALTITUDE OBSERVATORY

HAO input to the NSO Senior Review

The High Altitude Observatory and the National Solar observatory have had a long tradition of working closely in both science and instrumentation. HAO has several programs that rely on assets at NSO. HAO scientists pursuing programs in high-resolution Stokes Polarimetry and coronal polarimetry both develop instruments located at NSO Sacramento Peak and collaborate with NSO staff to develop user instruments.

Examples include the Advanced Stokes Polarimeter (ASP), which has served as a workhorse instrument with many scientists using it to measure the 3 dimensional vector magnetic field associated with sunspots, magnetic pores, prominences, the quiet solar atmosphere, and solar activity. The combination of the Dunn Solar Telescope and the ASP has significantly advanced our understanding of solar magnetism. Currently HAO and NSO are collaborating on a Diffraction Limited Spectro-Polarimeter (DLSP) which takes advantage of the diffraction limited images delivered by the NSO adaptive optics system. HAO and NSO are also collaborating on The Spectro-Polarimeter for Infrared and Optical Regions (SPINOR), which will permit diffraction limited polarimetry in the infrared and in several spectral lines in the visible and IR simultaneously. Both DLSP and SPINOR will be permanently available to the NSO user community.

HAO has developed a tunable filter that was installed on the NSO Coronal One-Shot telescope (so called because it can image the entire corona out to 0.5 solar radii from the disk) in the Hilltop Facility. Using this combination, HAO scientists are obtaining maps of the vector coronal field as well as of coronal velocities. The instrument will be operated on a daily basis to verify the ability to measure coronal field and its evolution. HAO is also proposing to modify the Evans Solar Facility 48 cm coronagraph to obtain higher-resolution coronal magnetic field maps. The project is a precursor to an effort to develop a larger aperture coronagraph capable of making high-resolutions maps of coronal fields associated with magnetic loops in the corona. When combined with photospheric vector magnetograms (DLSP and SPINOR), whitelight coronal measurements (the HAO Mark II coronagraph on Mauna Loa), and shortwave length measurements of coronal eruptions made from space (TRACE, SOHO, Solar-B and SDO), this will lead to a fundamental understanding of coronal magnetic stability and coronal mass ejections.

One of the HAO scientific cornerstones is the study of the solar dynamo. A major tool-for this is helioseismology. HAO scientists rely on the NSO GONG telescopes for a significant part of their helioseismic work.

HAO plans to continue its use of NSO/SP facilities for both science and instrument development until these are replaced by the ATST. Thus we strongly support their continued operation and we will continue to devote resources and manpower to keeping the instrumentation available there at the cutting edge of solar science. The joint HAO/NSO development programs are laying a solid foundation for ATST instrumentation.

To whom it may concern,

I am a solar physicist working for Lockheed Martin Advanced Technology Center in Palo Alto, CA. For my research I like to combine space observations from SOHO/MDI and TRACE with ground based observations with ASP (Advanced Stokes Polarimeter) and DLSP (Diffraction-Limited Spectro-Polarimeter) at the Dunn Solar Telescope at Sacramento Peak.

The ASP observations have a better resolution than MDI high resolution magnetograms, and DLSP observations from the Dunn telescope enable us to record vector magnetograms in great detail.

On May 1-15, 2005, I have been working with the group of Dr. H. Socas-Navarro (HAO, Boulder), on the development of SPINOR (Spectro-Polarimeter for Infrared and Optical Regions). SPINOR will permit simultaneous observations of multiple lines anywhere in the wavelength range 0.4 to 1.6 microns. There is a large potential scientific pay-off for observations combining simultaneous visible and IR spectro-potarimetry. Furthermore, it is mated to the new NSO adaptive optics system, permitting measurements of consistently better angular resolution than ASP.

My sunspot observations in May were supported by SOHO/MDI and TRACE. I plan to do another observing run from June 22 - July 6, 2005. I hope to use DLSP and record filtergrams in H-alpha and CA. My observations will be supported by TRACE and by SOHO/MDI.

I do the analysis and data reduction in collaboration with the scientific group at Sacramento peak. The developed software will also be of great use for the future solar B satellite. Solar B is planned to be launched in 2006, and will record the first space based vector magnetograms. The knowledge and experience from NSO will be invaluable.

Kind regards,

Dr. Mandy Hagenaar hagenaar@1msa1.com
Solar and Astrophysics Laboratory
Organization ADBS, Building 252
Lockheed Martin Advanced Technology center
3251 Hanover Street, Palo Alto, CA, 94304
Phone: (650) 354-5313 Fax: (650) 424-3994

DEPARTMENT OF THE AIR FORCE
AIR FORCE RESEARCH LABORATORY (AFMC)

26 July 2005
Dr. Joel B. Mozer
Chief, Space Weather Center of Excellence
AFRL/VSBX
29 Randolph Road, Hanscom AFB, MA 01731-3010

Dr. Wayne Van Citters
Director, Division of Astronomical Sciences
National Science Foundation
4201 Wilson Boulevard
Arlington, VA 22230

Dear Dr. Van Citters

The Air Force Research Laboratory, Space Vehicles Directorate (AFRL/VS) maintains an enduring partnership with the National Solar Observatory (NSO) that dates back to the inception of the NSO and its predecessor component, the Sacramento Peak observatory (NSO/SP). This partnership involves both fiscal and human capital support to activities at NSO/SP. The research enabled as a result of this relationship is critical to meeting the Air Force's goal of accurate and reliable 72-hour forecasts of geomagnetic storms and other space weather hazards that impact our national defense.

Many of the facilities that are currently available as national assets at NSO/SP were built by AFRL/VS and its predecessor organizations. Shortly after WWII, SPO was established under the auspices of the Air Force Cambridge Research Laboratories to support research on the impact of solar activity on DoD missions and systems. In 1976, operation of the facility was turned over to the National Science Foundation. Since then, the Air Force has continued to maintain a detachment of scientists and technical personnel at the site and to contribute to its operation under the terms of a Memorandum of Agreement between the AF and the NSF. Historically, four to five AFRL/VS scientists have resided at NSO/SP.

AFRL is committed to a continued long-term synergistic relationship with the NSO. This arrangement is significant and valuable to the Space Vehicles Directorate because it facilitates continuous interaction between AF scientists and the broader community of solar physicists, as well as providing access to the state-of-the-art facilities available at NSO/SP. Three instruments, in particular, are crucial for meeting our research needs: the Dunn Solar Telescope (DST) for high-resolution, multispectral observations of solar active regions, the Evans Solar Facility for long-term monitoring of the solar corona, and the Improved Solar Optical Observing Network (ISOON) telescope for autonomous monitoring of solar conditions. Without access to these facilities for research and development, AFRL/VS would not have the capability to meet the DoD's requirements of space weather forecasting. In coming years, access to the NSO's Synoptic Optical Long-term Investigations of the Sun (SOLIS) magnetograph and the prospective Advanced Technology Solar Telescope (ATST) will augment the value of AFRL's ongoing relationship with the NSO.

In summary, the Air Force Research Laboratory, Space Weather Center of Excellence is deeply committed to the National Solar Observatory, and relies extensively on its continued strong presence at NSO/SP.

Sincerely,

JOEL B. MOZER
JOEL B. MOZER, Chief, AFRL/VSBX

From: "HaoSheng Lin" <lin@ifa.hawaii.edu>
To: "Steve Keil" <keil@nso.edu>
Subject: Re: Senior Review Paragraph
Date: Monday, August 01, 2005 4:29 PM

At the Institute for Astronomy (IfA) of University of Hawaii (UH) we are conducting research to measure and understand solar magnetic field throughout the atmosphere, from photosphere through corona. This requires the development of new instruments and techniques for which the Dunn Solar Telescope at Sacramento Peak is the best suited platform available. Instruments that we have designed and tested there include a near-IR spectropolarimeter for high resolution and high polarimetric precision photospheric and chromospheric magnetic field observations. This instrument is in the final stage of development and is expected to be released for public use in the first quarter of 2006. IfA is also collaborating with NSO/SP to construct a new facility IR spectropolarimeter with funding from National Science Foundation. This new instrument utilizes a large format IR camera and advanced spectrograph design to achieve a six-fold increase in the throughput of the instrument to better utilize the high-resolution capability of the higher-order AO system of the DST. Finally, IfA is developing a fiber optics imaging IR spectropolarimeter that will take full advantage of the AO system and delivers spectropolarimetric data with the full resolution of the DST.

We foresee a continued strong use of the DST until the advent of the ATST on Haleakala.

Cheers,
Haosheng

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service
National Centers for Environmental Prediction
Space Environmental Center
325 Broadway
Boulder, CO 80303
Telephone: (303) 497-3311

August 1, 2005

Dr. Steven Keil, Director
National Solar Observatory
PO Box 57
Sunspot, NM 88349-0057

Dear Steve Dr. Keil,

The Forecast and Analysis Branch of the Space Environment Center (SEC), part of NOAA's National Weather Service, provides continuous monitoring and forecast services for the nation and the international community. A critical element in preparing SEC's forecasts of activity is knowledge of the topology of the magnetic field associated with sunspots. These magnetic fields, when non-potential, can drive a solar flare event that may disrupt systems and activities at earth. The National Solar Observatory (NSO) measurements of photospheric magnetic field made available daily on-line that is, magnetograms of the longitudinal component of the magnetic field, are vitally necessary when SEC Forecasters formulate near-term solar flare predictions. In addition, NSO Calcium XV "yellow line" data, indicative of particularly hot active regions at the limbs of the disk, are helpful for forecasts of subsequent strong flare activity.

Another important forecast from SEC is the impact of an interplanetary disturbance on the geomagnetic field. The disturbance transits from the Sun in a manner modulated by the speed of the ambient bulk solar wind. SEC runs the "Wang-Sheeley-Arge" solar wind model to characterize into which it is pushing that important parameter. A fundamental input to this model is the global solar magnetic field, built up from NSO's daily measurements over a solar rotation.

Other NSO data used by SEC forecasters include derived coronal hole locations, both from daily He1083 observations and from the longer time-series synoptic maps. Coronal holes are sources of the high-speed solar wind that disturbs Earth's magnetic field. Other synoptic maps utilized by SEC include the magnetic flux map, depicting a Carrington rotation of magnetic measurements. These magnetic flux maps are used for outlooks of solar activity that may result from pre-existing solar magnetic field concentrations.

In sum, NSO measurements are vital for SEC to provide high quality services to NOAA's space weather customers.

Sincerely,

Ernie

Ernest Hildner, Director
Space Environment Center

Appendix I

ACRONYM GLOSSARY

AFRL	Air Force Research Laboratory
AFOSR	Air Force Office of Scientific Research
AIS	Advanced Image Slicer
AO	Adaptive Optics
ATM	Atmospheric Sciences (Division of NSF)
ATST	Advanced Technology Solar Telescope
AURA	Association of Universities for Research in Astronomy, Inc.
BBSO	Big Bear Solar Observatory
CDS	Coronal Diagnostic Spectrometer
CfAO	Center for Adaptive Optics
CLEA	Contemporary Laboratory Experiences in Astronomy
CMEs	Coronal Mass Ejections
CoDR	Conceptual Design Review
COS	Coronal One-Shot
CoSEC	Collaborative Sun-Earth Connection
CSUN	California State University - Northridge
DASL	Data and Activities for Solar Learning
D&D	Design & Development
DLSP	Diffraction-Limited Spectro-Polarimeter
DST	Dunn Solar Telescope
EGSO	European Grid of Solar Observations
EIS	Environmental Impact Studies
EIT	Extreme ultraviolet Imaging Telescope
EPO	Educational and Public Outreach
ESF	Evans Solar Facility
ETH-Zürich	*Eidgenössische Technische Hochschule*- Zürich (also ETHZ)
EU	European Union
FASR	Frequency Agile Solar Radio (array)
FDP	Full-Disk Patrol
FTEs	Full Time Equivalents
FTS	Fourier Transform Spectrometer
FY	Fiscal Year
GB	Giga Bytes
GONG	Global Oscillation Network Group
GRASP	GONG Reduction and Analysis Package
GSFC	Goddard Space Flight Center (NASA)
HAO	High Altitude Observatory
HMI	Helioseismic and Magnetic Imager
HSG	Horizontal Echelle Spectrograph
IAC	Instituto de Astrofísica de Canarias
IBIS	Interferometric BI-dimensional Spectrometer
IDL	Interactive Data Language
IFA	Institute for Astronomy (University of Hawaii)
IFU	Integral Field Unit
IR	Infrared

ISOON	Improved Solar Observing Optical Network
ISS	Integrated Sunlight Spectrometer
KPNO	Kitt Peak National Observatory
KPVT	Kitt Peak Vacuum Telescope
LAPLACE	Life and Planets Center (University of Arizona)
LASCO	Large Angle and Spectrometric Coronagraph
LRP	Long-Range Plan
LTE	Local Thermodynamic Equilibrium
LWS	Living With a Star
MCAO	Multi-conjugate Adaptive Optics
McMP	McMath-Pierce (Solar Telescope)
MDI	Michelson Doppler Imager (SOHO)
MHD	Magnetohydrodynamic
MKIR	Mauna Kea Infrared
MMS	Magnetospheric MultiScale
MOU	Memorandum of Agreement
MREFC	Major Research Equipment Facilities Construction (NSF)
MRI	Major Research Instrumentation (NSF)
NAC	NSO Array Camera
NAI	NASA Astrobiology Institute
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NDSC	Network for the Detection of Stratospheric Change
NGDC	National Geophysical Data Center
NJIT	New Jersey Institute of Technology
NOAA	National Oceanic and Atmospheric Administration
NOAO	National Optical Astronomy Observatory
NRC	National Research Council
NSF	National Science Foundation
NSF/AST	National Science Foundation, Division of Astronomical Sciences
NSO	National Solar Observatory
NSO/SP	National Solar Observatory Sacramento Peak
NSO/T	National Solar Observatory Tucson
NST	New Solar Telescope
ONR	Office of Naval Research
PAEO	Public Affairs and Educational Outreach
PFD	Partial Frequency Redistribution
PSPT	Precision Solar Photometric Telescope
RASL	Research in Active Solar Longitudes
RBSE	Research-Based Science Education
RET	Research Experiences for Teachers
REU	Research Experiences for Undergraduates
RHESSI	Reuven Ramaty High Energy Solar Spectroscopic Imager
RISE	Radiative Inputs of the Sun to Earth
SBM	Sky Brightness Monitor
SCOPE	Southwest Consortium of Observatories for Public Education
SDO	Solar Dynamics Observatory
SDIMM	Solar Differential Image Motion Monitor
SHABAR	Shadow Band Ranger

SMEI	Solar Mass Ejection Imager
SOC	Solar Observatory Council (AURA)
SOFIA	Stratospheric Observatory for Infrared Astronomy
SOHO	Solar and Heliospheric Observatory
SOI	Solar Oscillations Investigations (SOHO)
SOLIS	Synoptic Optical Long-term Investigations of the Sun
SPD	Solar Physics Division (AAS)
SPINOR	Spectropolarimeter for Infrared and Optical Regions
SRA	Summer Research Assistant
SRD	Science Requirements Document
SST	Swedish Solar Telescope
SSWG	Site Survey Working Group (ATST)
STEP	Summer Teacher Enrichment Program
SWG	Science Working Group (ATST)
SXT	Soft X-ray Telescope (*Yohkoh*)
TAC	Telescope Time Allocation Committee
TB	Tera Bytes
THIS	Tunable Heterodyne Infrared Spectrometer
TLRBSE	Teacher Leaders in Research Based Science Education
TRACE	Transition Region and Coronal Explorer
UBF	Universal Birefringent
USAF	United States Air Force
VSM	Vector Spectromagnetograph
VSO	Virtual Solar Observatory
WBS	Work Breakdown Structure
WWW	World Wide Web
Yohkoh	"Sunbeam" satellite of the Institute of Space & Astronautical Science, Japan