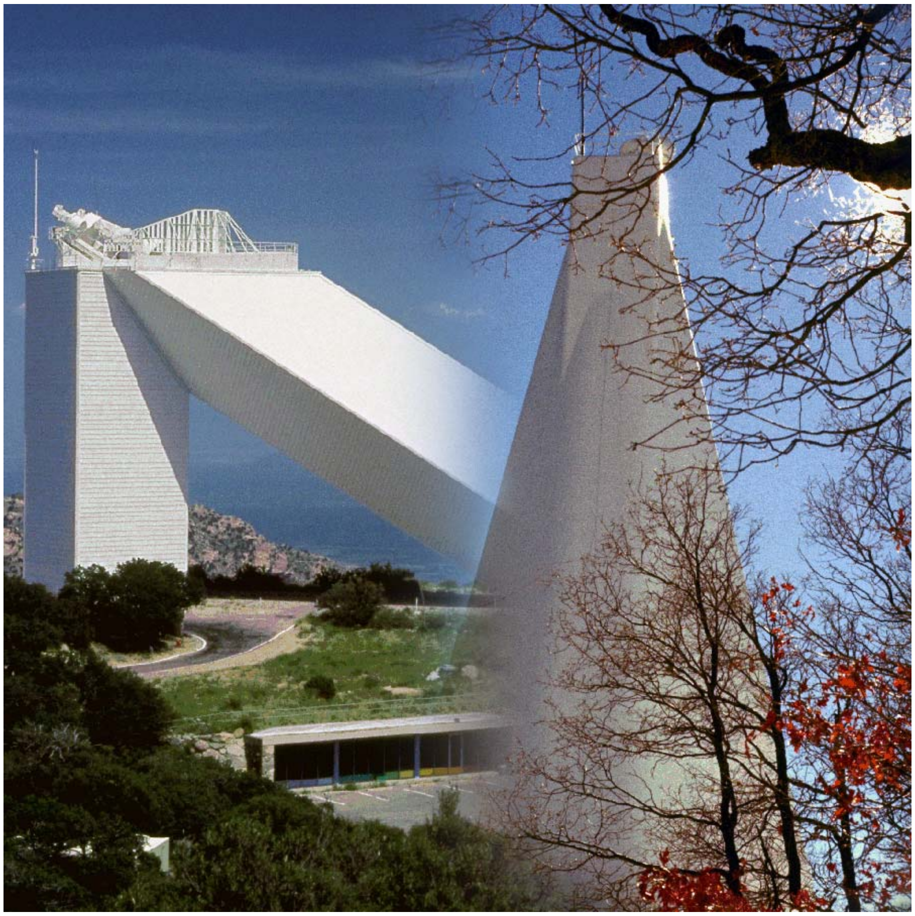
National Solar Observatory



NSO Annual Report FY 2002

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NSO is operated by the Association of Universities for Research in Astronomy under cooperative agreement with the National Science Foundation

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1 INTRODUCTION

This report summarizes scientific, operational, and programmatic activities at the National Solar Observatory (NSO) for the period 01 October 2001 to 30 September 2002.

The NSO, with facilities on Kitt Peak near Tucson, at Sacramento Peak in New Mexico, as well as at several other sites distributed globally, is operated by the Association of Universities for Research in Astronomy, Inc. (AURA), for the National Science Foundation (NSF). The mission of NSO is to advance knowledge of the Sun, both as an astronomical object and as the dominant external influence on Earth, by providing forefront observational opportunities to the research community. NSO fulfills its mission by operating cutting-edge facilities, by leading the development of advanced instrumentation in collaboration with the solar physics community, and by conducting solar research and educational and public outreach programs.

The NSO observing and data reduction facilities are available to the entire astronomical community. The NSO Home Page contains on-line information about NSO services, including telescope schedules and instrument availability, and information about how to apply for telescope time. The NSO Home Page can be accessed through the World Wide Web at *http://www.nso.edu/.*

AURA is a private, non-profit corporation that operates world-class astronomical observatories through its operating centers. NSO is an operating center managed by AURA under cooperative agreement with the NSF. More information on AURA and its organizational structure can be found at *http://www.aura-astronomy.org/.*

The NSO reached several key milestones in its multi-year program to renew national ground-based solar observing assets. Among these milestones were establishment of the Advanced Technology Solar Telescope (ATST) design effort, fielding of the ATST site survey, completion of the Global Oscillation Network Group (GONG) upgrades, and implementation of the first phase of the Diffraction-Limited Stokes Polarimeter (DLSP is an upgrade of the Advanced Stokes Polarimeter (ASP)). The major components of the NSO long-range plan include: continuing to lead the development of the 4-m ATST; developing adaptive optics (AO) systems that can fully correct large-aperture solar telescopes; completing and operating the instruments comprising the Synoptic Optical Long-term Investigations of the Sun (SOLIS); and operating the Global Oscillation Network Group (GONG) in its new high-resolution mode. These planned instruments and NSO structure will play key roles in a vigorous US solar physics program.

The NSO encourages broad community involvement in its programs through partnerships to build instruments, develop new facilities and to conduct scientific investigations. Agreements have been established with the High Altitude Observatory (HAO), the New Jersey Institute of Technology (NJIT)/Big Bear Solar Observatory (BBSO), the University of Hawaii, the University of Chicago, and the University of California San Diego for their efforts in the ATST collaboration. Agreements with other members of the twenty-two institutions that proposed to NSF for the design and development of the ATST will be developed as needed. NJIT/BBSO, the Air Force Research Laboratory (AFRL) and the Kiepenheuer Institute (KIS) in Freiburg are continuing their collaboration with NSO to develop high-order solar adaptive optics. NSO and HAO have begun Phase II in the development of the Diffraction-Limited Stokes Polarimeter, a high-resolution version of the Advanced Stokes Polarimeter that will take full advantage of adaptive optics to measure small-scale solar magnetic fields, and will enable diffraction-limited polarimetry at the Dunn Solar Telescope (DST). NSO works closely with the Air Force, NASA and NOAO to provide critical synoptic observations that, in addition to producing noteworthy science, also support space and other ground-based observations and space weather monitoring and prediction.

2 SCIENTIFIC AND KEY MANAGEMENT PERSONNEL

The NSO staff is located in Sunspot, New Mexico and Tucson, Arizona. The observatory director is Dr. Stephen L. Keil who is based in Sunspot but spends time at both operational sites. Dr. Mark Giampapa is deputy director and responsible for the Tucson operations. Mr. Rex Hunter is site manager at Sacramento Peak at Sunspot. NSO and affiliated scientific staff are listed below, along with their primary area of expertise and key observatory responsibilities.

2.1 Sunspot Based Staff

NSO Staff

- K. S. Balasubramaniam – Solar activity; magnetism; polarimetry; Ch., NSO/SP Telescope Allocation Committee.
- Alexei A. Pevtsov – Solar activity; coronal mass ejections.
- Thomas R. Rimmele – Solar fine structure and fields; adaptive optics; instrumentation; ATST Project Scientist; Ch., Sac Peak Project Review Committee.
- Han Uitenbroek – Atmospheric structure and dynamics; radiative transfer modeling of the solar atmosphere.
- K. Sankarasubramanian – Solar fine structure; magnetism; stokes polarimetry.
- Gilberto Moretto – Optical instrumentation; adaptive optics.
- Maud Langlois (NJIT) – Adaptive optics (HOAO and MCAO); instrumentation.

Air Force Research Laboratory Staff at Sunspot

- Richard C. Altrock – Coronal structure and dynamics.
- Nathan Dalrymple – Polarimetry; thermal analysis.
- Joel Mozer – Coronal structure; remote sensing; space weather.
- Donald F. Neidig – Solar activity; Project Scientist, Improved Solar Observing Optical Network (ISOON).
- Richard R. Radick – Solar/stellar activity; adaptive optics.

2.2 Tucson-Based Staff

NSO Staff

- Caroline Barban - Helioseismology.
- Michael Dulick – Molecular spectroscopy; high-resolution Fourier transform spectrometry.
- Mark S. Giampapa – Stellar dynamos; stellar cycles; magnetic activity; NSO Deputy Director; Ch., Tucson Project Review Committee; SOLIS PI.
- 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.
- Frank Hill – Solar oscillations; data management.
- Rachel Howe – Helioseismology; the solar activity cycle.
- Christoph U. Keller – Solar polarimetry; adaptive optics; instrumentation.
- John W. Leibacher – Helioseismology; GONG PI.
- Elena Malanushenko – Structure of the solar chromosphere and transition region; coronal holes.
- Matthew J. Penn – Solar atmosphere; solar oscillations; polarimetry; near-IR instrumentation.
- Clifford Toner – Global and local helioseismology. Image restoration; data analysis techniques.
- Roberta Toussaint – Helioseismology; image calibration and processing; data analysis techniques.

NASA Staff in Tucson

- Rudolph W. Komm – Helioseismology; dynamics of the convection zone.
- Harrison P. Jones – Solar magnetism and activity.

3 SCIENTIFIC PROGRAM

Use of NSO facilities produces a significant number of research papers each year while also providing solar data that support a wide range of solar and solar terrestrial studies and solar activity forecasting. The latter includes data in support of space missions such as SoHO, RHESSI and TRACE and data sent to the NOAA Space Environment Center in Boulder for predicting and understanding solar activity. NSO makes solar data available to a wide audience through its Digital Library (*http://diglib.nso.edu/).* Some of NSO's recent science highlights are described in the following section.

3.1 New Results from the Low-Order AO System at the Dunn Solar Telescope

Using the low-order AO system, T. Rimmele (NSO) and the adaptive optics team were able to observe direct evidence for "convective collapse." This is the process that has been invoked by theoretical models to explain why solar magnetic fields are concentrated in small flux elements of kilo Gauss (kG) field strength, sometimes called the building blocks of solar magnetic fields. It has long been recognized that "flux expulsion," the process by which the convective flows sweep "frozen in" magnetic field into the sites of downflows in intergranular lanes, can only produce fields of order of the kinematic equipartition field strength (400 G). An additional process is needed to explain kG fields. Convective collapse, initiated by radiative cooling at the surface, is the most promising process that is able to produce kG fields. However, direct observations that would provide evidence that this process actually occurs on the Sun have been missing. Adaptive optics has now made observations of this fundamental process possible.

Fig. 1 shows a short time sequence of line-of-sight magnetograms and corresponding narrow-band intensity images taken with the Universal Birefringet Filter in the Fe I 6302 Å line. The effective exposure time was 10 seconds. The AO team observed how a patch of diffuse magnetic field of about 1-arcsec size "collapses" into two distinct, concentrated flux elements of about 0.2-arcsec diameter.

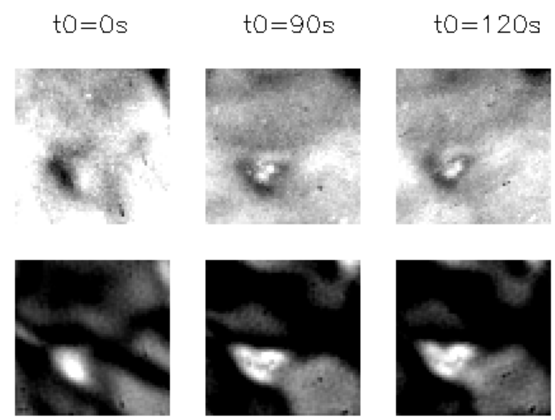


FIG. 1. See reference to figure in text (Sec. 3.1).

The spatial scale can be inferred from Fig. 2, which shows the intensity image at 90 seconds with contours of the LOS-magnetogram overlayed. The diffraction limit of the 76-cm DST at 6302 Å is about 0.2-arcsec, and it is likely that the flux concentrations are actually significantly smaller. As the field is concentrated, what's observed is darkening in intensity at the location of the newly formed field concentrations while their edges become bright. This is likely the effect of radiative cooling in the center of the flux tube and the effect of radiative heating from the immediate,

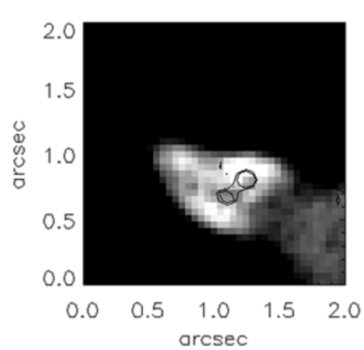


FIG. 2. See reference to figure in text (Sec. 3.1).

hot surroundings of the flux tube (hot wall effect), as predicted by theoretical models. The flux concentration occurs on a timescale of approximately one minute. This also compares well with theoretical predictions.

Although these new and exciting observations provide the first strong and direct evidence for convective collapse, a crucial piece of the puzzle is still missing. Measurements of the actual magnetic field strength before and after the field concentration occurred are needed to verify that a diffuse patch of weak magnetic field has been concentrated into small kG strength flux tubes. Such quantitative observations will soon be possible with the combination of high-order AO and diffraction-limited spectropolarimetry and/or near-infrared polarimetry.

3.2 High-Resolution Near-IR Measurement of Sunspot Magnetic Fields

The low-order adaptive optics (AO) system of the Dunn Solar Telescope (DST) was used for the first time by H. Lin (U. Hawaii) with a near-infrared spectropolarimeter to study the magnetic field of sunspots during an observing run in April 2001. With the help of the AO system, the infrared (IR) observation achieved a resolution of 0.6 arcsec, near the diffraction limit (0.5 arcsec at 0.16 microns) of the DST, and provided excellent sunspot vector magnetic field configuration data. In addition to the near-IR measurements, visible continuum intensity images with 16-arecsec resolution were acquired simultaneously to help with the interpretation of the magnetic field data.

While sunspots may be the most well-known feature on the surface of the Sun, currently they have no satisfactory and universally accepted theoretical explanation. For example, the darkness of a sunspot can be understood by simple energy and pressure equilibrium considerations. Nevertheless, the detailed structure of the magnetic fields inside the sunspots (particularly in the dark umbrae) are still not resolved. Fundamental questions like: "How are the sunspots formed?" and "What is the magnetic field structure of sunspots?" remain unanswered nearly a century after Hale's discovery of sunspot magnetic fields.

Obviously, the ultimate resolution of the sunspot problem depends on our ability to observationally resolve the detailed magnetic and thermodynamic structure of the sunspots. The experiment Lin and his colleagues conducted was specifically designed to address these questions.

Fig. 3 shows one of the high-resolution visible images, the IR continuum intensity map, the magnetized plasma absorption line amplitude A_m map, and the vector magnetic field maps of the sunspot derived from the IR scan data. The most intriguing and important feature of the magnetic field structure of the sunspot in Fig. 3 is the existence of several small-scale features concentrated near the center of the sunspot that display enhanced magnetic field strength and sharp boundaries with the surrounding area. Close inspection and comparison of the magnetic field and continuum intensity maps further revealed that these enhanced magnetic field features are cospatial with the dark umbral nuclei. This finding may appear to confirm the expectation that the darker features inside the sunspot should correspond to regions of stronger magnetic field. Interestingly, however, it was also found that the distribution of the magnetic field strength (*B)* in the dark nuclei ranges from 2500 G to 3000 G, while their continuum intensity remains at a minimum constant value. That is, the continuum intensity in the dark umbral nuclei is *not* directly related to the magnetic field strength. The scattered plot between B and I_C of the sunspot in Fig. 4 demonstrates the decoupling between B and I_C in the dark nuclei.

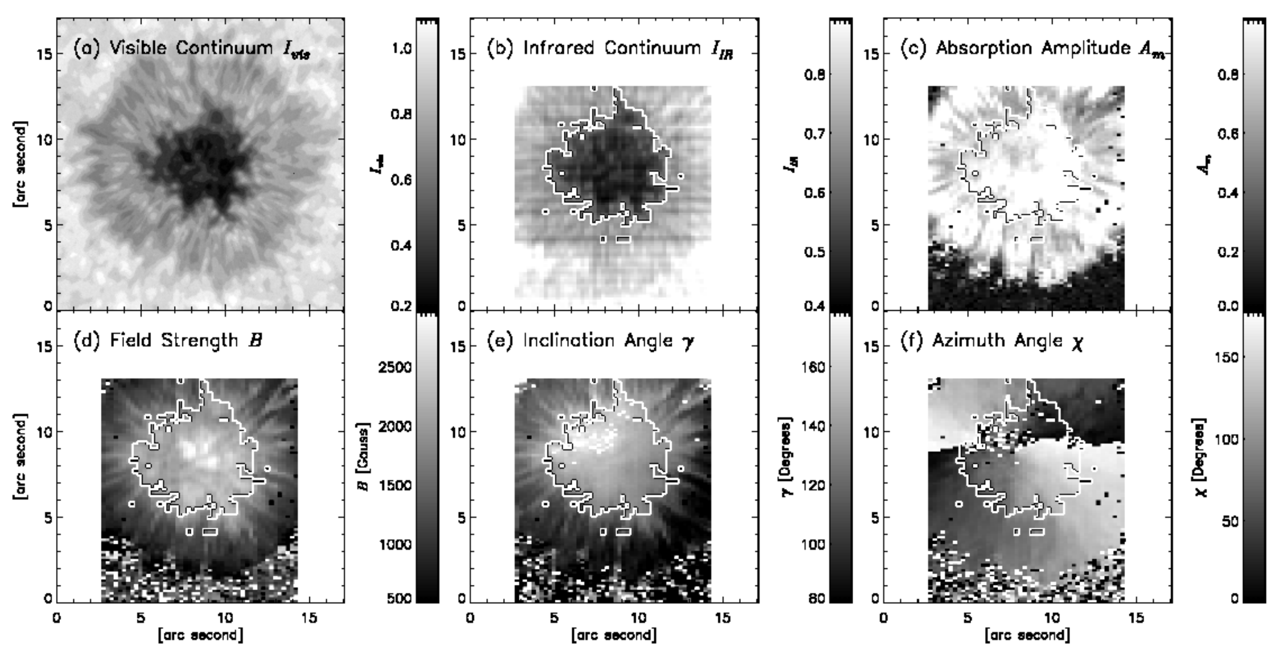


FIG. 3. See reference to Figure in text (Sec. 3.2).

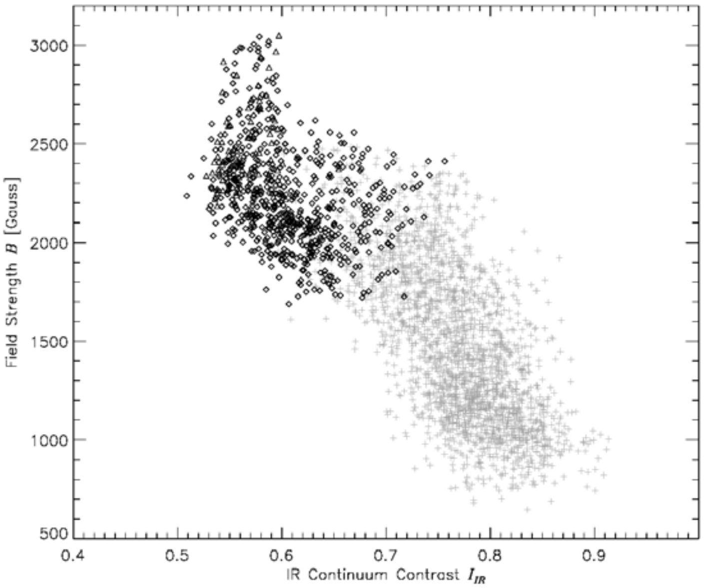


FIG. 4. See reference to figure in text (Sec. 3.2).

Although the enhanced magnetic field features were found to be closely associated with the darkest part of the umbra, the apparent decoupling between B and I_C is puzzling. Cooling of the plasma inside the sunspot has been considered the primary magnetic field intensification mechanism in current sunspot theories. However, the decoupling between B and I_C suggests that a new, heretofore unknown, magnetic field mechanism is responsible for the intensification of the sunspot magnetic field in the dark nuclei. This mechanism, if proven to be true, will certainly enhance our understanding of the physics of sunspots, and help to eventually solve the sunspot mystery. Obviously, the improved capability of the Advanced Technology Solar Telescope to observe the Sun with high magnetic field sensitivity and spatial resolution simultaneously will greatly benefit this endeavor.

3.3 GONG++ — First Results

During FY 2002, the Global Oscillation Network Group (GONG) completed the acquisition of the computing hardware necessary to support the new, high spatial resolution science, "GONG++," as well as the "upstream" GONG Classic processing which had previously been based on a "sneaker net" of workstations with data being passed between them via an exabyte tape archive. The first GONG++ results are highlighted in Fig. 5.

The plots in Fig. 5 show subsurface flow maps at four different depths inside the Sun. These so-called "solar subsurface weather maps" are unique tools to address the question of the origin of solar activity, which can adversely affect telecommunications and power grids on the Earth.

The maps are also essential for understanding astrophysical fluid dynamics, such as meridional circulation and the flows around and under sunspots.

The maps shown in Fig. 5 were constructed starting from GONG+ data obtained on Jan. 11, 2002. The images from the six different GONG sites were merged, and then analyzed with a method known as ring diagram analysis. This method follows approximately 200 regions on the Sun for a little over a day, removes the curvature of the solar surface, and measures the local distortion of the wave field caused by the flows in the 15,000 km immediately below the surface. These distortions are then used to create the flow maps. The background of each map shows the GONG+ magnetogram for that day.

See Sec. 5.1 for more details about GONG.

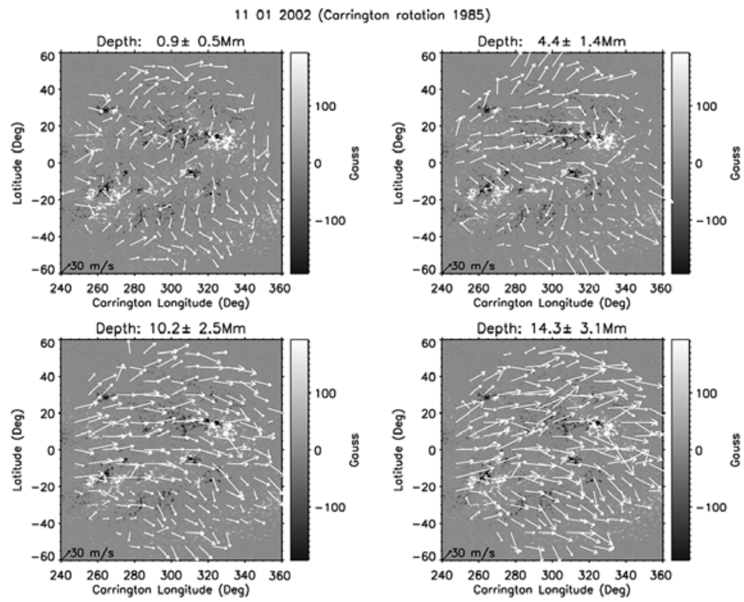


FIG. 5. See reference to figure in text (Sec. 3.3).

3.4 Extreme Limb Observations with the McMath-Pierce FTS and Image Stabilization System

On two recent McMath-Pierce observing runs (13-18 April and 26-30 August 2002), T. Ayres (U. Colorado) and C. Plymate (NSO) used the 1-m Fourier transform spectrometer (FTS) to record the 5-micron rovibrational bands of carbon monoxide (CO). The goal was to better characterize the properties of thermal inhomogeneities at the top of the photosphere.

The CO bands are very sensitive "thermometers" for the high layers of the solar atmosphere. In fact, the CO lines go into emission off the solar limb for an arcsecond or so (although still radiating at a surprisingly low temperature of 3600 K)—a phenomenon discovered by W. C. Livingston (NSO) about ten years ago. The off-limb CO emissions are thought to arise in "cool clouds" that inhabit the low chromosphere.

Most recent observations of the 5-micron CO bands have used D. Rabin's (formerly NSO, now NASA/GSFC) Near Infrared Magnetograph (NIM) to obtain long-slit stigmatic spectra, taking advantage of the spatial/spectral multiplex capability of NIM's 256 × 256 InSb camera. The 14-m main spectrograph that feeds NIM, however, suffers significant scattered light—which reduces spectral resolution significantly, an important consideration for the narrow CO lines. On the other hand, the FTS has unsurpassed resolution and essentially zero scattered light, but can record only a single spatial point at a time. Furthermore, the long integrations to scan a single interferogram (4 minutes) render the FTS susceptible to seeing fluctuations and image motion.

Recently, however, C. Keller (NSO) and Plymate developed a tip/tilt image stabilization system for the all-reflecting 1.5-m telescope, which is the largest in the solar world (and thus best suited for thermal-IR work).

During a test run in April with the tip/tilt system on the FTS, Plymate and Ayres conducted a series of observations of the CO region, scanning very close to the limb as well as across it. The observing conditions were poor, however, due to passage of a cold front. Nevertheless, the "low-order AO" system delivered remarkable stability in the translimb spectra, and hints of the CO lines in emission in several of the off-limb scans. This effect usually is recorded successfully only in very short (200-400 ms) NIM exposures that "freeze" the seeing.

In the subsequent run in late August, the FTS was operated in a high-order alias to shorten the integration time to 40 seconds without sacrificing resolution, and a redundant IR bandpass filter was removed to improve sensitivity. The morning of 27 August brought superb observing conditions: clear with light haze and a steady 20 mph breeze; the seeing was very good. The conditions held for most of the morning, and the observers were able to take a long sequence of FTS interferograms using the tip/tilt system, stepping from a point approximately 5 arcsec inside the limb out to about 5 arcsec outside the IR continuum edge. Now, the CO off-limb emissions were very clearly visible, as seen in Fig. 6. The continuum intensity roll-off was as sharp as that reported recently by Ayres (ApJ 575, 2002) in frame-selected NIM exposures obtained under good seeing conditions, but using traditional limb guiders. In the new high-resolution spectra, critical profile substructure is apparent which is washed out in the lower resolution NIM spectrograms.

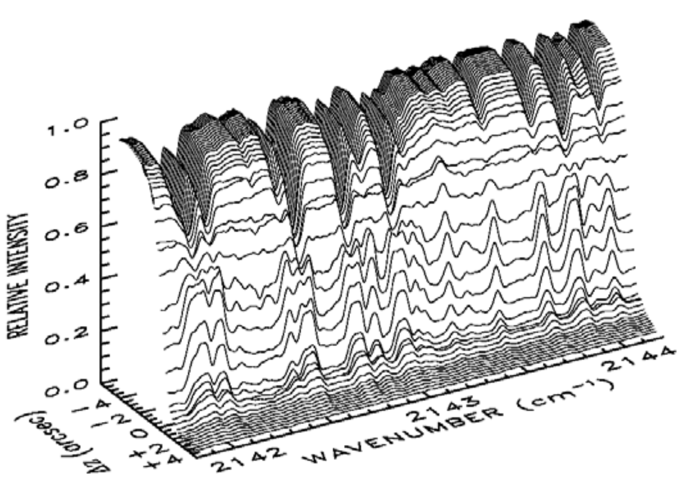


FIG. 6. Surface plot of translimb FTS spectra. Negative displacements (Δz in arcsec) are inside the limb; positive displacements are off-limb. All of the on-disk absorptions are CO lines. They "go into emission" as the surrounding continuum fades away above the limb. Several of the stronger off-limb emissions have "central reversals" when the emission core begins to form (e.g., 2142.5 cm^{-1}), and some of the relatively strong off-limb features (e.g., 2143.3 cm^{-1}) are represented by only weak absorption features on the disk.

These data represent a major breakthrough in understanding the formation of the off-limb CO emissions. Not only that, but a new window has been opened onto the important translimb regime, which is the key interface between the radiation dominated photosphere and the mechanically heated chromosphere-corona (which spawns the "space weather" that can affect the Earth and its near-space environment). In particular, each FTS scan covers a broad swath of the thermal infrared spectrum, from 3.6-5.6 microns (limited by the chosen bandpass filter): one sees many CO lines in emission off-limb, as well as chromospheric hydrogen recombination lines (from high-lying levels), and even hydroxyl (OH) features in the shorter wavelength region (although these do not extend as far off the limb as the much stronger CO bands). To make an equivalent "atlas" of the translimb spectrum using the NIM would require nearly five hundred independent grating settings, with perhaps several hundred frames at each (to seeing-select the sharpest images). The FTS can record that interval in only 40 s.

The new translimb scans demonstrate that a deceptively simple tip/tilt system has the ability to transform the world's highest resolution solar spectrometer, long relegated mainly to a workhorse of laboratory atomic physics and atmospheric chemistry, back into a frontline instrument for solar studies. Of course, using the image stabilization on the NIM itself offers even greater promise, if the scattered light and resolution issues can be solved. Better yet, the tip/tilt corrector is only the first step; a breadboard version of a full AO unit for the McMath-Pierce already is being tested, serving as a prelude to the potential IR capabilities of the next generation large solar telescope, ATST.

3.5 The Effect of Coherent Scattering on Radiative Losses in the Solar Ca II K Line

Despite decades of observations and theoretical calculations, we still lack a clear understanding of the nature of chromospheric emission in the Sun and other stars. Current theoretical models range from traditional one-dimensional semi-empirical models, which require a continuously present chromospheric temperature rise on top of a 4400 K temperature minimum, to radiation-hydrodynamic models, which derive their chromospheric emission from intermittent shock dissipation. Despite their large differences, the two types of models are very similar in the sense that each has severe problems when confronted with detailed spectroscopic observations. For instance, the traditional hydrostatic models cannot explain the presence

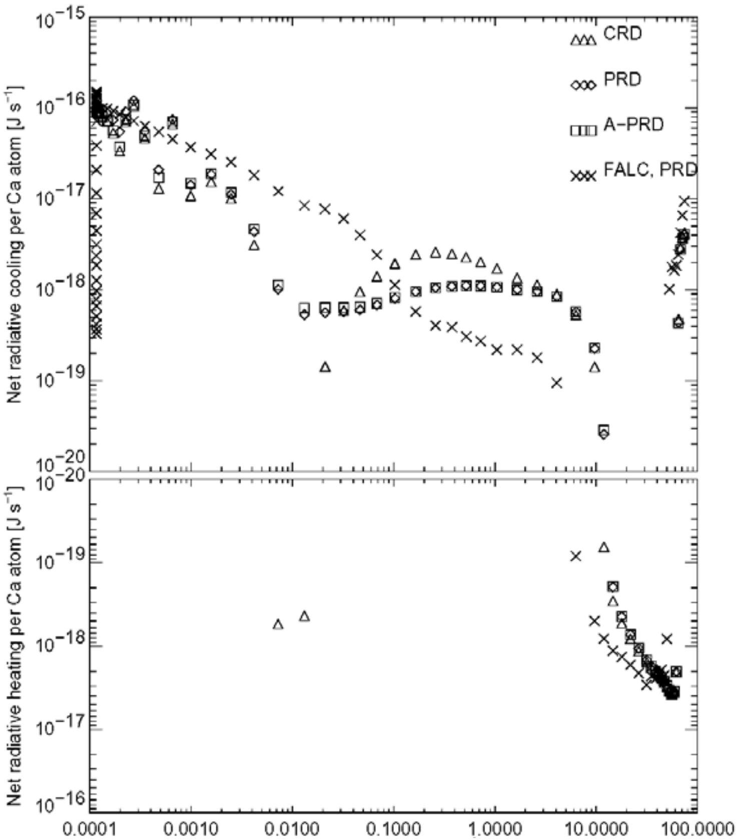


FIG. 7. Comparison of the time-averaged net radiative losses in the Ca II K line for CRD (triangles), angle-averaged PRD (diamonds), and angle-dependent PRD (squares) for the chromospheric dynamics model. Top of the atmosphere is to the left, bottom to the right. Coherent scattering reduces radiative losses in the K line by a factor of 2 to 3 in the middle of the atmosphere. Even though time-averaged chromospheric emission from the dynamic model and the traditional hydrostatic model are very similar, the radiative losses in the latter (crosses) are very different on average.

of 3700 K gas as indicated by the deep absorption line cores of the CO molecule observed near the solar limb, while radiation-hydrodynamic models often predict intensity variations with much larger amplitude than is observed.

Even though the average amount of chromospheric emission from both types of models is very similar, their average temperature structure, and corresponding chromospheric energy budget, are very different: where the traditional model requires a continuous temperature rise from the temperature minimum outward to produce the observed amount of chromospheric emission, the dynamic one shows an average temperature which gradually declines until a sharp transition appears to the hot corona, far above the location of the chromosphere in the traditional models. The manner in which the models' energy budget is determined is also very different. In semi-empirical models the temperature stratification is adjusted so that the calculated spectrum matches the observed over a wide array of observables. In the dynamic models only the mechanical input flux at the bottom can be varied, the rest follows from the physical laws implemented in the simulation. The temperature structure in particular is a direct result of the running balance between mechanical and radiative sinks and sources.

In the chromosphere, shock wave dissipation is balanced by radiative losses in strong lines of hydrogen and resonance lines of high abundance metals, with highest losses coming from the K line of singly ionized calcium. Even in state-of-the-art simulations (Carlsson & Stein, ApJ 481, 1997) the radiative losses in these lines are calculated with the assumption of complete frequency redistribution (CRD), which neglects the substantial effects of coherent scattering in these strong lines, mainly to reduce the computational problem to manageable proportions. However, with the advent of an efficient yet accurate technique to take account of coherent scattering (so called partial frequency redistribution, or PRD, (Uitenbroek, ApJ 557, 2001)), it is now possible to evaluate the effect of coherent scattering on the radiative losses in the K line even in dynamic models, which require the use of angle-dependent PRD, a more involved form of redistribution which also accounts for coherency in the angle of scattering. Fig. 7 shows that coherent scattering leads to radiative energy losses in the K line that are considerably different from the CRD case, and should be taken into account for realistic estimates of these losses.

3.6 Io as Probe of the Plasma Torus

The McMath-Pierce main telescope is famous as a facility for solar research; however, it also has superb capabilities for nighttime observations that take advantage of its low scattered light properties (there is no central obscuration) and its high-resolution stellar spectrograph. It is well suited for observations of faint emission lines superimposed on strong continuum sources, such as a planetary satellite where the apparent distance from the nearby bright planet is important. For example, every year since 1990 (with an exception for 1995), McMath-Pierce observations have been made of the neutral oxygen red (6300 Å) emission from the atmosphere of Io (Oliversen *et al*. JGR 106, 2001). These observations are unique; in fact this is the only facility in the world that has observed this emission while Io is in sunlight. Extensive observations of Io's atmosphere at all parts of its orbit are important for a better understanding of Jupiter's dynamic magnetosphere.

Jupiter's rapidly rotating magnetosphere and Io's intense volcanism combine to create dynamical physical features in the Jovian system, including Io's atmosphere and plasma torus. Volcanic SO_2 gas and SO_2 surface frosts are the ultimate sources of an extended atomic sulfur and oxygen atmosphere. The atmosphere is constantly changing as it is shaped, excited, and lost through ionization and collisionally driven escape due to the impacting plasma. This plasma torus, composed mainly of sulfur and oxygen ions, rotates with Jupiter. (The Jovian rotational period is 9.925 hr while Io's orbital period is 42.5 hr).

Observations by Oliversen (NASA/GSFC) and colleagues show that Io atmospheric emission intensities are correlated with Io's position in the plasma torus. This is critical to understanding Io's highly variable and dynamic atmosphere and the plasma torus. For example, as Io traverses the denser regions of the plasma torus, the atmospheric emissions get brighter. This means Io is a probe of conditions within the three-dimensional plasma torus. Io responds to spatial changes within the torus, thus providing a unique local perspective. Other remote plasma torus observations unavoidably intermix a range of physical conditions as they look through the torus, integrating along the line of sight.

Additionally, a correlation between the [O I] emission intensity and line width indicates that molecular dissociation of SO_2 (and SO) by torus electrons may contribute to the emission through production of excited oxygen atoms.

Further studies, supported by NASA, are ongoing to investigate the time-dependent behavior of Io's atmosphere and global properties of the torus.

3.7 Imaging Polarimetry in the Ultraviolet

Since 1994, J. Stenflo and A. Gandorfer (ETH Zürich), in collaboration with C. Keller (NSO), have carried out a series of observing runs at the McMath-Pierce facility with their polarimeter system ZIMPOL (Zürich Imaging Polarimeter). As seeing and gain-table noise are eliminated with this system so that the polarimetric precision becomes limited only by photon statistics, noise levels as low as 5×10^{-6} have been achieved in combination with high spectral resolution. At this level of precision, *everything* in the solar spectrum is polarized, even in the absence of magnetic fields. In linear polarization, we see a spectrum that is as richly structured as the intensity spectrum, but which has a very different appearance, since the underlying physical processes are different. It is as if the Sun has presented us with an entirely new and unfamiliar spectrum, and we have to start all over to identify the spectral structures that we see. This new spectrum in linear polarization has therefore been called the "second solar spectrum."

Since its first implementation the ZIMPOL system has been continually upgraded, and new, more powerful versions have been put to use at NSO as they have become available. While the first generation (ZIMPOL I) could only image two of the four Stokes parameters simultaneously, the second generation (ZIMPOL II) had the capacity of imaging the full Stokes vector (by creating four simultaneous image planes on a single CCD detector chip). ZIMPOL I and II, however, could not be used for wavelengths below about 4500 Å. This was a serious limitation, since both the structural richness of the "second solar spectrum" and the polarization amplitudes increase greatly toward shorter wavelengths.

Therefore, during the last couple of years, considerable investment has been made to develop specially designed CCD sensors in collaboration with the company EEV. These sensors have high efficiency throughout the UV, all the way down to the atmospheric cutoff near 3000 Å, while possessing an architecture that allows the fast (kHz range) ZIMPOL-type charge-shifting technology. To achieve high quantum efficiency in the UV, holes had to be etched in the polysilicon gate layer above the pixels, creating an Open Electrode Structuring (OES). The new, UV-sensitive ZIMPOL system was used for the first time at NSO in an exploratory observing run in March 2002. The run exceeded expectations, both in terms of system performance and in terms of the astounding richness of the polarized UV spectrum. It was like digging in a newly discovered "gold mine." Only a glimpse of what was observed is described here.

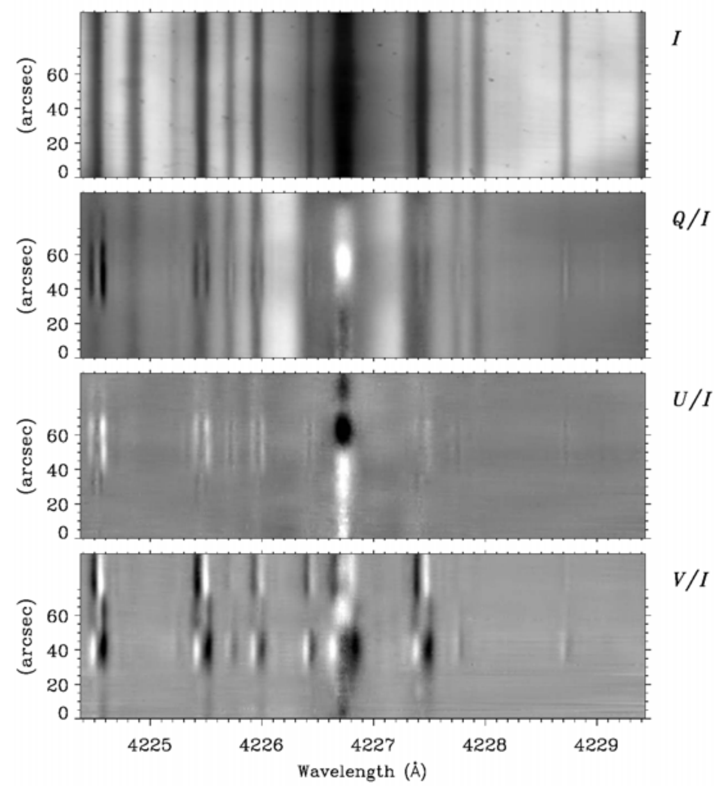


FIG. 8. Stokes vector image of the spectral region around the Ca I 4227 Å line. The recording was made in a facular region 20 arcsec inside the limb.

Fig. 8 shows the four Stokes vector images of the spectral region around the Ca I 4227 Å line, which has the strongest scattering polarization in the visible spectrum. The spectrograph slit has been placed 20 arcsec inside and parallel to the solar limb in a facular region. While the circular polarization (*V/I*) shows the familiar anti-symmetric signatures of the longitudinal Zeeman effect, the linear polarization in the Ca I line is due to scattering polarization (while the transverse Zeeman effect shows up in many of the blend lines). The strong variations along the spectrograph slit of the linear (*Q/I* and *U/I*) polarization in the Ca I line core are due to the Hanle effect from the spatially structured chromospheric magnetic fields. The Hanle effect is a new tool to diagnose aspects of solar magnetic fields that cannot be seen with the Zeeman effect. The ambiguities that often occur in the interpretation of the Hanle signatures can be removed by using combinations of spectral lines with different sensitivities to the Hanle effect. Since the UV presents a much greater selection of such lines than other spectral regions, the UV range is of unique importance for the application of Hanle diagnostics.

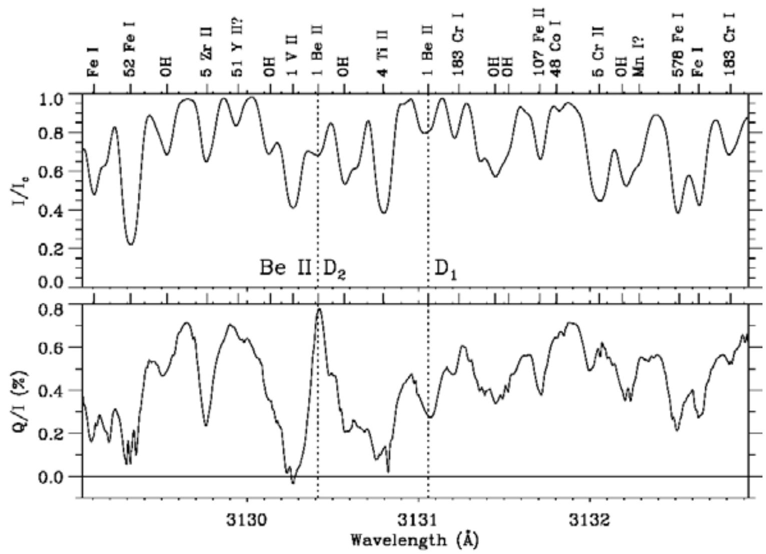


FIG. 9. The spectrum in intensity (top panel) and degree of linear polarization (bottom panel) in the spectral region around the Be II D_2 (3130.414 Å) and D_1 (3131.058 Å) lines. The recording was made in a quiet region at the heliographic South Pole, 6 arcsec inside the limb. The vertical dotted lines mark the resonant wavelengths of the two beryllium lines.

Fig. 9 gives another example of what the UV region has to offer. The recording was made with the spectrograph slit positioned 6 arcsec inside and parallel to the solar limb at the heliographic South Pole, covering the wavelength range around the Be II resonance doublet at 3130.414 and 3131.058 Å. Since the recording was made in a very quiet region, the scattering polarization did not show spatial structuring, so we could average the 2-D spectra along the spectrograph slit to produce the 1-D spectra in Fig. 9. At these UV wavelengths the continuum is strongly polarized, and the majority of the lines suppress (depolarize) the continuum. In contrast, the left Be II line exhibits a strong, positive (electric vector parallel to the limb) polarization peak, while the right Be II line depolarizes the continuum.

The two Be II lines are due to transitions with a quantum-number structure, including hyperfine-structure splitting, that is identical to the well-known Na I D_2 and D_1 lines at 5889.97 and 5895.94 Å, which have polarization signatures that remain enigmatic. Using the notation D_2 and D_1 in Fig. 9, the general quantum-mechanical expectation is that the D_2 line should be polarized, while the D_1 line should be unpolarized. Though various diagnostic applications of such observations are possible (determination of beryllium abundance, radiative transfer physics, Hanle diagnostics), the focus of these initial, exploratory observations is to identify the multitude of phenomena in the second solar spectrum and to clarify the underlying physics.

3.8 Imaging Polarimetry of Jupiter and Saturn with ZIMPOL

In March 2002, D. Gisler and H. Schmid (ETH, Zürich) obtained imaging polarimetry of the planets and bright stars using the Zürich Imaging Polarimeter (ZIMPOL) at the 1.5-m McMath-Pierce telescope. J. Stenflo, A. Gandorfer (ETH, Zürich) and C. Keller (NSO) observed the Sun with spectropolarimetry during the day (see Sec. 3.7) and Gisler and Schmid observed at night. The aim of these test measurements was to gain experience with this type of instrument for stellar (nighttime) applications.

The ZIMPOL-technique is based on a fast, electro-optical polarization modulator working in the kHz range, in combination with a special CCD camera performing the on-chip demodulation of the modulated signal. ZIMPOL has been used very successfully for polarimetric measurements of the Sun. In fact, the polarimetric accuracy was improved by about two orders of magnitude in S/N. Gisler and Schmid have adapted the ZIMPOL-technique for nighttime astronomy in order to exploit its unprecedented measuring accuracy.

Gisler and Schmid performed their first tests at Kitt Peak using a ferro-electric liquid crystal (FLC) retarder plate—where the optical axis can be switched by 45°—as a polarization modulator. The FLC allows lower modulation rates of 1 kHz, instead of the 40 kHz rates of piezo-elastic modulators. Thus, the FLC enables longer integration times of up to 40 seconds. This is because the CCD demodulation shifts are limited to about 10^5 modulation cycles due to anomalous charge transfer effects in the CCD. The slower modulation also reduces CCD heating. In this case, the thermoelectric cooling achieved a lower temperature of -30° C instead of the norm of -10° C. The FLC modulator was combined with “spare parts” from the solar ZIMPOL instrument for the observing run.

Gisler and Schmid’s tests with the McMath-Pierce telescope are very promising. For Jupiter and Saturn, high-quality maps for the linear polarization in four narrowband filters centered at 4500 Å, 5500 Å, 6000 Å and 7300 Å, with a width of 200 Å, were obtained. Fig. 10 shows the reflected sunlight from Jupiter and Saturn at 5500 Å. The other maps are qualitatively the same except for some small but significant color trends. Both planets have a low polarization at the disk center, because the scattering angle is close to 180° (backscattering), as is always the case for the outer planets observed from Earth. Both objects exhibit a limb polarization perpendicular to the limb that is much stronger at the poles than at the equator.

The perpendicular limb polarization is caused by a well-known second-order scattering effect. Photons reflected after one scattering in the planet atmosphere are practically non-polarized, because the scattering angle is close to 180°. After the first scattering, photons travel predominantly parallel to the planet surface before being reflected toward us by the second scattering process. Because the polarization angle induced in a scattering is perpendicular to the propagation direction of the incoming photon, a polarization perpendicular to the limb results. The polarization at the poles is much higher because the Rayleigh scattering atmosphere is deeper, or the effective cloud level is lower than in the warmer equatorial regions. In the rings of Saturn, practically no polarization structure is seen as expected from a mixture of reflecting solid debris bodies.

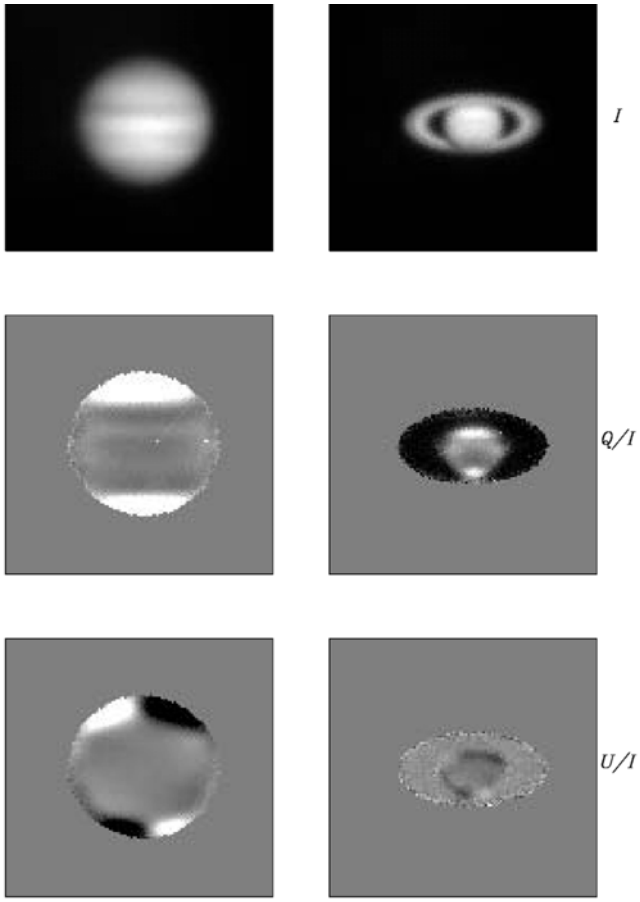


FIG. 10. Images of the intensity *I* and Stokes parameters *Q/I* and *U/I* for Jupiter and Saturn at 5500 Å. The images are not properly corrected for the telescope polarization. The polarization, however, is displayed relative to the polarization at the center of the planet disk, which is set to zero (the intrinsic polarization is very small). The gray scale in the Stokes polarization images goes from -1% (black) to +1% (white). The maximum polarization at the poles of Jupiter is higher than +5%.

Much has been learned from this observing run and the observers are confident that the ZIMPOL technique has a huge potential for astrophysical polarimetry. However, further improvements are required, such as lower dark-current and read-out noise levels for the CCD with an improved cooling system, or the development of an achromatic modulator system for broadband imaging polarimetry. The effort is warranted as the new 8-10-meter telescopes provide sufficient light collecting power to obtain a very high polarimetric accuracy for bright objects. For example, a spectropolarimetric accuracy of $\Delta = 10^{-4}$ with a spectral resolution of 300 can be achieved for a 9th-magnitude object with an integration time of one hour. For broadband imaging, this polarimetric accuracy is possible for a 13th-magnitude object. Such an improvement in measuring accuracy will open up many new opportunities for investigations of stellar magnetic fields, or scattering gas and dust structures near stars and active galactic nuclei.

3.9 12-Micron Magnetometry with Visible Tip-Tilt Image Stabilization

In April 2002, the Celeste spectrometer was used with the McMath-Pierce tip-tilt image stabilizer, operating in the visible, to test whether this technique would improve measurements of solar magnetic fields in the thermal infrared (IR). Combined with a computer-controlled wave-plate polarization analyzer and synchronized telescope guider stages, Celeste creates high-resolution infrared (12.32-micron) maps of active regions in all four Stokes parameters. The Celeste detector array double-samples the diffraction-limited spot of the telescope, but the effective limit on the spatial resolution of spectral-image scans is set by atmospheric motion and telescope tracking errors.

G. McCabe, D. Jennings and D. Deming (NASA/GSFC) and C. Keller and C. Plymate (NSO) were able to demonstrate that the tip-tilt system, operating in the visible, successfully eliminates the unwanted motion in the IR image.

Short integration time measurements of the solar limb recorded with and without the tip-tilt mirror activated show how image motion is removed in the infrared using 1-D. Fig. 11 compares limb profiles for 10 scans (each 1/10 sec). Note that the dip in the curve near the middle is the extension of the Mg I emission line beyond the solar limb. In the left frame, the spread in the data due to limb motion in the non-stabilized case is approximately 3 arcsec. Thus, without stabilization, a time average of the measurements is degraded by a significant smearing of the limb. In the right frame, the limb motion during stabilization is reduced to less than 1 arcsec.

Measurements of Stokes parameters in a sunspot were made to compare closed-loop and open-loop tip-tilt operation. Limb guiders were not used, to avoid any contribution of the telescope control system beyond tracking errors, which accumulate slowly on the scale of the data read times. Manual guide corrections were made between closed-loop integrations to compensate for telescope drift, and to maintain the position of the image near the center of the range of travel (20 arcsec) of the tip-tilt mirror. In Fig. 12, the plot of Stokes V shows the difference in appearance of the spectral profiles for the closed-loop and the open-loop cases. A larger separation of sigma components is distinctly seen in the red curve (closed-loop), as compared with the white curve (open-loop). Also, the line-of-sight magnitude of B is larger in the data with tip-tilt turned on. Since the average slit position on the spot is biased in the direction of telescope drift, we can't yet say for sure whether these differences are completely due to image stabilization, i.e., they may be partly due to looking at different places in the spot. It is clear from the data that the tip-tilt system is providing improved image stability at 12 microns. It is anticipated that use of the tip-tilt correction will produce higher precision in magnetic field maps. The full potential of this improvement in the IR will be realized with the Advanced Technology Solar Telescope and its planned adaptive optics facility. McCabe *et al.* plan to develop this technique further in upcoming runs at the McMath-Pierce telescope.

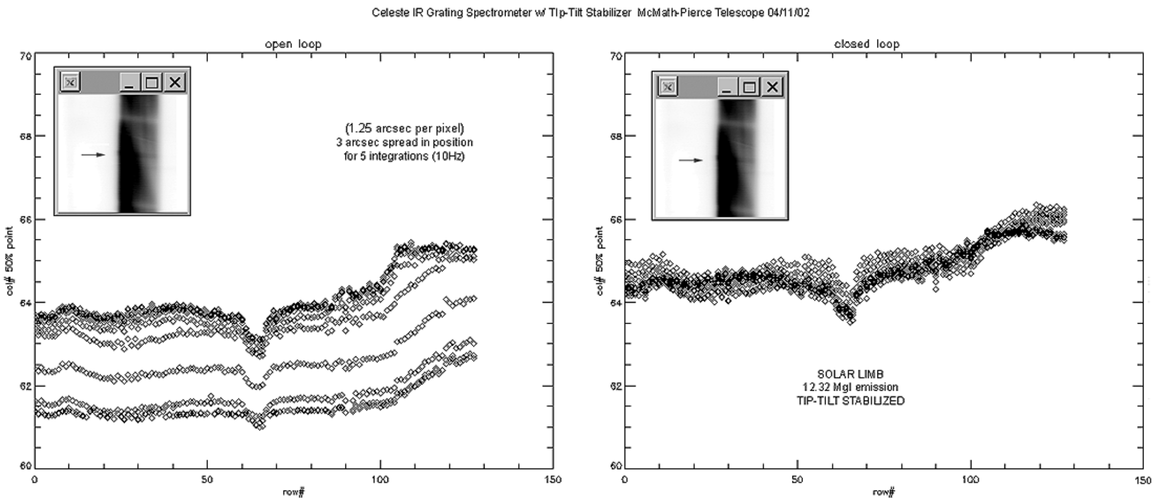


FIG. 11. See reference to figure in text (Sec. 3.9).

The Celeste instrument system was built by NASA/GSFC (G. McCabe, D. Jennings, D. Deming) with funds provided in part by the NASA Solar Physics Program. The adaptive optics image stabilizer was developed at the NSO by C. Keller and C. Plymate.

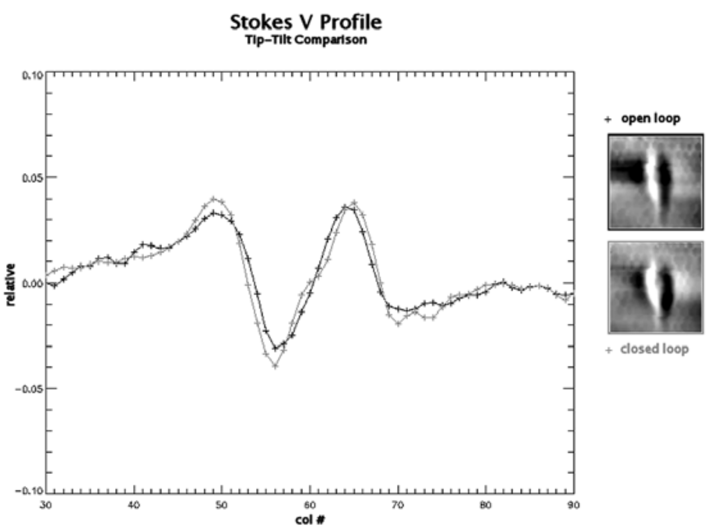


FIG. 12. See reference to figure in text (Sec. 3.9).

3.10 Vector Magnetic Fields in Prominences with the Advanced Stokes Polarimeter and Principal Component Analysis

A. López Ariste and R. Casini (UCAR/HAO) recently developed an inversion code to infer the magnetic field vector in prominences using pattern recognition techniques (ApJ 575, 2002). The code treats the full Stokes profiles in the He D_3 line at 5876 Å. The necessary data required a telescope capable of precise spectropolarimetry and with low scattered light. Several telescopes were tested. THEMIS in the Canary Islands was the first one to provide the required data. The NSO Evans coronagraph, which had already provided good Stokes profiles in the 1980s with the Stokes I and II instruments, may be used in the future. The third choice was the Advanced Stokes Polarimeter (ASP) on the Dunn Solar Telescope (DST) at Sunspot. After two initial runs in June 1997 and March 2001 that identified the instrumental constraints, a new run was scheduled for the last week of May 2002.

The ASP was set in the 30-Hz mode to ensure maximum exposure time compatible with a reliable constant speed of the rotating waveplate (something that could not be ensured in the 15-Hz mode). The requirement of simultaneously observing the Na D_1 and D_2 lines (5895 Å and 5890 Å, respectively), with the He D_3 line was attained by using a shorter (f = 500 mm) camera lens, which reduced the spectral dispersion so that the detector recorded roughly 25 Å in total. The smaller focal length also reduced the separation of the two orthogonally polarized beams so that just one chipset of the ASP camera, *Bert*, was used to record both beams. Another consequence was the reduced spatial sampling (1 arcsec per pixel) which helped increase the signal-to-noise ratio.

From May 25 through May 30, under very good seeing conditions, we were able to scan about 20 prominences reaching up to heights of approximately 50 arcsec above the solar limb, at 1-arcsec steps. The slit was kept parallel to the limb at all times. Calibration of the instrument was done following the usual ASP procedures, with the addition of an ND filter to avoid camera saturation at disk center for such long exposure times. The recorded data proved to have a good signal-to-noise ratio in all four Stokes parameters. In some time series, time and spatial averages have resulted in profiles with noise levels down to 1×10^{-5} with absolute polarization measurement. No modification of the usual calibration procedures was necessary.

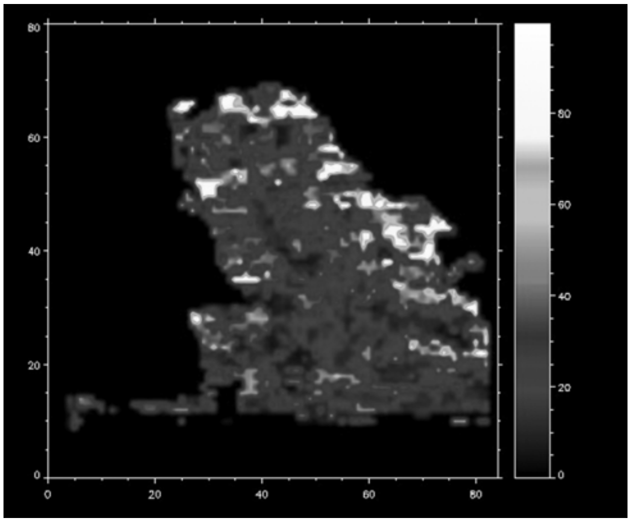


FIG. 13. Field strength map of the He D_3 line of a solar prominence.

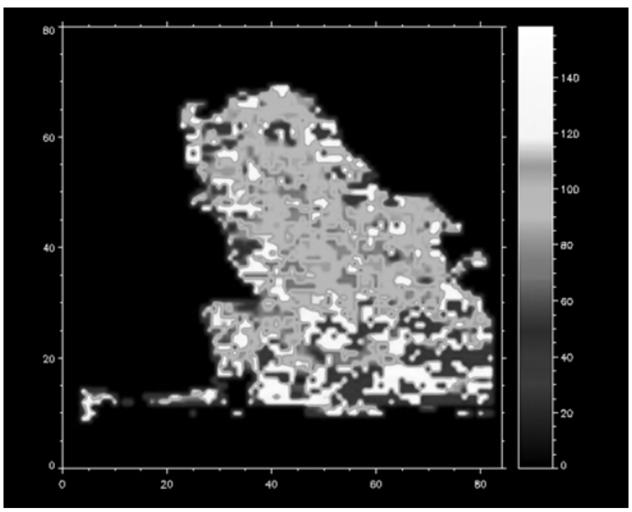


FIG. 14. Field inclination map of the He D_3 line of a solar prominence.

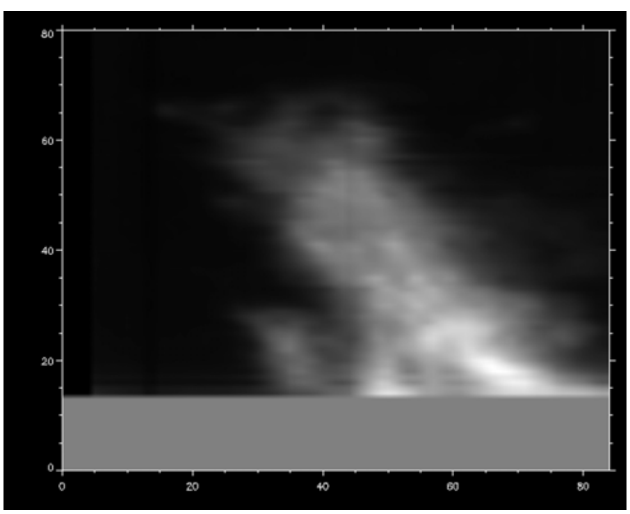


FIG. 15. Field intensity map of the He D_3 line of a solar prominence.

After reduction, the data were inverted with the code described by López Ariste and Casini. This code uses a line formation model for the He D_3 line, originally described by Landi Degl'Innocenti (1982), which considers the five lowest atomic terms of the triplet configuration of He I. In particular, this code provides a full quantum treatment of the Hanle and Zeeman effects, accounting also for the alignment-to-orientation transfer mechanism that is essential to achieve agreement with the observed Stokes V profiles. The code assumes optically thin plasmas, with constant temperature and electron density. Otherwise, the magnetic field vector and the geometry of the scattering event in the prominence are considered free parameters of the model.

Principal Component Analysis uses a database of synthetic profiles to compute eigenprofiles for all four Stokes profiles. Those eigenprofiles are used to reconstruct any observed profile using just a few coefficients. The coefficients from the observed profiles are compared to those present in artificial databases created under known magnetic fields and geometries. This comparison constitutes the core of the inversion process.

The code was tested first with synthetic profiles with very good results: error levels were of the order of 2 to 3 G in field strength and a few degrees for most of the angles involved in the model. The tests also showed that Stokes V is fundamental for a correct determination of the magnetic field. The Stokes V profile of the He D_3 line in prominence conditions results from the addition of two contributions: one originating in the alignment-to-orientation transfer mechanism that creates symmetric, intensity-like profiles, the second from the longitudinal Zeeman effect that produces the better known antisymmetric profile. The Zeeman contribution is the smallest one, casting serious doubts on the past inferences of magnetic fields in prominences using Zeeman-based magnetograph techniques. The richness of the Stokes V profiles determined by the combination of these two contributions is what makes Stokes V the most important piece of information for the inversion, as the tests show.

Figs. 13, 14 & 15 show one of the prominences observed on 25 May 2002 at 16:33 UT at PA 61.8°. This prominence was seen along almost its axis. The three maps show the peak intensity of the He D_3 line, the field strength and the field inclination (90° for a horizontal field). In this preliminary stage of the inversion code, a few general conclusions can be drawn: the fields are mainly horizontal (in agreement with the work of Leroy and Bommier in the 1980s) including the lowest parts of the prominences and in particular their feet. The predominant field strengths are in the 20 G regime, but fields as high as 80 G appear as well. These high fields have been closely scrutinized, but their Stokes V profiles show unambiguous Zeeman signatures that exclude any possible bias of the inversion code toward high fields. It is important to notice that previous Hanle diagnostics suffered from Hanle saturation that made it very difficult to diagnose fields above 30 or 40 G, when present.

The use of Stokes V, together with Stokes Q and U, allows us to infer the correct field strengths for such high values. These results should be accepted with some caution due to the assumption of optically thin plasma and the possible presence of subpixel velocity or field structure.

4 MAJOR PROJECTS

4.1 Advanced Technology Solar Telescope Project

In last year's (FY 2001) report, we described the beginnings of a community-wide project to develop the next generation, facility-class telescope to advance high-resolution solar physics and the measurement of solar magnetic fields — the Advanced Technology Solar Telescope (ATST). What follows is a progress report on the ongoing ATST design effort.

With its 4-meter aperture and integrated adaptive optics, the ATST will resolve areas on the Sun over an order of magnitude smaller than current meter-class solar telescopes. Its high photon flux and broad spectral coverage will allow it to make sensitive magnetic field observations at heights from the photosphere into the corona. Observations have established that the photospheric magnetic field is organized in small fibrils, or flux tubes, with sizes below current resolution limits. Theory and models predict that these fibrils have scales of just a few tens of kilometers (≤ 30 km) and that they play fundamental roles in solar dynamo processes, atmospheric heating, and solar activity. Resolving and measuring the properties of the magnetic field at its fundamental scale is thus a primary goal for the ATST. A complete description of science goals, and project information, can be found at *http://atst.nso.edu*.

TABLE 1
Summary of Top Level Science Requirements

APERTURE	4 m
FO	3 arcmin minimum; goal of 5 arcmin
Resolution	*Conventional AO Case*: Diffraction limited within isoplanatic patch for visible and IR wavelengths. *MCAO (upgrade option):* Diffraction limited over >1 arcmin FOV.
Adaptive Optics	Strehl (500nm): >0.3 median seeing; >0.6 good seeing
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	In the NIR and IR
Instruments	Well instrumented - access to a broad set of diagnostics, from visible to thermal infrared wavelengths.
Operational Modes	Flexibility to combine various post focus instruments and operate them simultaneously; Flexibility to integrate user supplied instruments.
Lifetime	30 – 40 years

4.1.1 ATST Science Working Group

Current membership of the Science Working Group (SWG) can be found *at http://atst.nso.edu/swg/members.html*. The SWG met several times during the past year to quantify many of the preliminary observing capabilities specified for the ATST to meet its science goals. For example, the measurement of small magnetic flux elements generates specifications for aperture size, polarization accuracy and sensitivity, atmospheric and telescope seeing properties, scattered light, and instrument performance. Table 1 lists the top-level requirements specified in the Science Requirements Document (SRD).

More detailed requirements and derived observational performance requirements can be found in the SRD. The SRD is a living document that will evolve as trade studies are completed and risks assessed. It is available on the ATST WWW site, or directly from Project Scientist Thomas Rimmele (*rimmele@nso.edu*). Community inputs into the requirements and ATST science capabilities are welcome.

4.1.2 ATST Project Organization

Over the past year, we have established a project organization and recruited individuals for key positions. The ATST project team pulls from a broad range of resources. These include new hires at NSO specifically for the ATST project, contributions from members of the existing NSO staff and individuals working from other organizations directly with the project team, and efforts by Co-PI and collaborating teams. Key positions that have been filled with new hires include: Jim Oschmann, Project Manager; Rob Hubbard, Systems Engineer; Mark Warner, Mechanical Engineer; Ron Price, Opto-Mechanical Engineer; Gilberto Moretto, Optical Engineer; Bret Goodrich, Software and Control Systems Engineer; Steve Wampler, Software Engineer; Ruth Kneale, Systems Librarian and web coordinator; and Dave Dooling, Education and Outreach Officer. Participating NSO scientific staff members include: Thomas Rimmele, Project Scientist; Christoph Keller (Visible Polarimetry); Matt Penn (Near-IR Polarimetry); K. S. Balasubramaniam (Narrowband Filters); Han Uitenbroek (Thermal IR); and Frank Hill (Site Survey). Participating NSO technical staff include: Jeremy Wagner, Deputy Project Manager; Steve Hegwer, Site Survey Project Manager; Steve Fletcher, Site Survey Software Engineer; and Jerry Duffek, Mechanical Designer. The Air Force Research Laboratory is providing Nathan Dalrymple, Thermal Engineer, and Richard Radick, Site Survey Scientist. John Briggs, of the University of Chicago, is on loan as Site

Survey Engineer. We expect increasing participation by the NSO and partner staffs as the project progresses.

The engineering team reports to Jim Oschmann and the science team to Thomas Rimmele. Steve Keil is the Project Director.

Participation by the Co-PI's and some of the other collaborating institutions consists of both design and science activities. Agreements for the primary efforts in instrumentation and support of the site survey have been established through MOU's. The following agreements are in place:

- **High Altitude Observatory** (Visible Light Polarimeter Design; Near IR Polarimeter Contributions).
- **University of Hawaii** (Sky Brightness Monitor and Dust Monitor; Near IR Polarimeter Design (Lead); Site Survey Operations on Haleakala and Mauna Kea).
- **University of Chicago** (Site Survey Project Engineer; Theoretical Support for Science Working Group).
- **New Jersey Institute of Technology** (Site Survey Operations at Big Bear; Tunable IR Filter Design).
- **University of California, San Diego** (Scattered Light Trade Studies).

Additional participation by international collaborators is being sought and we anticipate agreements for their participation in the near future.

4.1.3 Design Progress

Recent management and systems engineering activities have concentrated on defining the breakdown of work to be done during the design phase. We have considered possible subcontracting options that may be available during the construction phase and have organized the breakdown of these options with interface requirements and organization in mind. These include an initial Interface Control Document (ICD) organization, creation of a Work Breakdown Structure (WBS) that is consistent with the subsystems, creating an accounting number system that matches both the WBS and ICD organization, and reworking the detailed plans and schedules for the project.

Design efforts have centered on off-axis optical concepts based upon an f/3 primary mirror and on an f/2 primary mirror. Both concepts are being considered to bracket the potential cost. While the f/2 concept provides a smaller (thus less expensive) overall structure, it makes the thermal and perhaps other problems more difficult. Considerable effort has been focused on investigating the requirements as well as a few concepts for the prime focus heat stop, which is considered to be one of the key components of the telescope. Success here may indicate how fast a primary we may be able to deal with; this is a cost and feasibility concern. Initial analysis suggests that the heat stop designs consistent with the f/2 primary mirror design are reasonable, but further analysis is being performed. Considerations for large amounts of lab instrument space have been included in all concepts, but variations that impact cost have been studied. Recent progress has identified some reasonable transfer optical designs that are being worked in conjunction with the telescope and facility concepts. We have solicited input from the instrument groups as to what type of input beam they would prefer.

Fig. 16 shows the concept considered prior to the end of FY 2002. We continue to look at this and other options in order to make rough performance, cost, and risk trades during the conceptual stage.

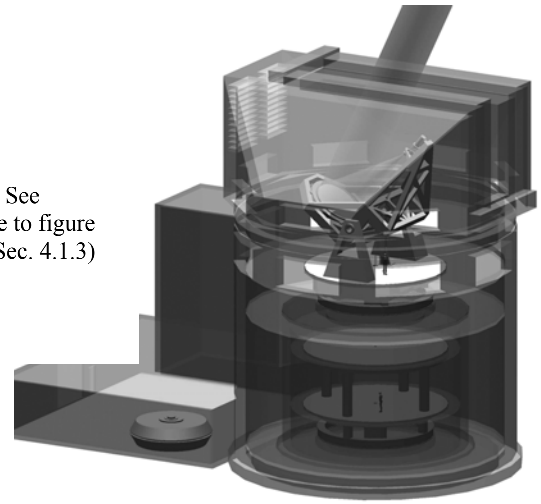


FIG. 16. See reference to figure in text (Sec. 4.1.3)

With regard to the primary mirror, informal meetings have been held with six potential suppliers for their initial thoughts on pursuing fast, off-axis mirrors. More discussions and detailed studies with four of these sources on the issues related to manufacturing this mirror are being established.

N. Dalrymple and Myung Cho (AURA New Initiatives Office) have completed initial thermal models for a candidate primary mirror. Cho has completed a first-order finite element model and has built an air temperature profile, solar loading, and a cooling concept to size the magnitude of the thermal control requirements for the primary mirror. His modeling will eventually include thermal temperature differences to the air, thermal gradients throughout the mirror blank, and the resulting distortions to the surface of the mirror. Dalrymple has developed first-order analytic models, which compare with the basic finite element model. The first order model will be useful for quick evaluation of various control strategies.

4.1.4 Site Survey

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

The ASWG helped to determine ATST siting criteria, will verify the validity of the site testing procedures, and provide advice to the site survey scientist in developing a ranked list of the sites. This list will be presented to the Project Scientist who, after verifying—in consultation with the ASWG—that the science objectives of the ATST can be met, will recommend siting of the ATST to the NSO (Project Director). Once the Project Director has the Project Scientist's final recommendation for siting, he will make the final site selection in consultation with the NSF Astronomy Division.

Site Survey Towers and instrumentation have been installed at:

- Big Bear Solar Observatory, California;
- Mees Solar Observatory, Haleakala, Hawaii;
- Observatorio Rouque de Los Muchachos, La Palma, Canary Islands, Spain;
- Sacramento Peak, New Mexico;
- San Pedro Martir, Baja California, Mexico;
- Panquitch Lake, Utah.

Data are being forwarded to Tucson and analyzed using a standard data reduction package. The current plan is to run the survey for one year, ending in Nov 2003. Once we have determined which site or sites offer the best fit with our specifications and we have made our selection, further testing to determine the best location for the ATST at the given site and to determine precise wavefront conditions for the design of the adaptive optics system will be performed.

4.1.5 Plans

A detailed work breakdown structure (WBS) and schedule for the design and development phase is in place. This includes major milestones such as reviews, setting up the review process and working with the partnership to establish remaining work packages. Each engineer responsible for a WBS element has or will detail the plans and schedules for individual areas within the WBS, including initial estimates of schedules for the construction phase.

In support of design activities, error budgets were established for key observing scenarios including on-disk observations with adaptive optics, seeing limited on-disk observations, seeing limited coronal observations, and polarization. Models required to support the major system trades include: thermal control, especially with respect to seeing effects and alignment and mirror figure, and stray light control with consideration for surface roughness, dust and contamination, cleaning and protection strategies and baffling. Design and analysis supporting the major reviews include telescope configuration, optical approach, enclosure concepts and instrument interface and facility requirements. The optical approach includes off-axis designs and iterations with partners on potential instrument designs such as visible and near-IR spectral polarimeters that are consistent with the telescope and facility conceptual designs.

The plan calls for three major reviews to be held during the design and development phase. These include:

- **Conceptual Design Review (Spring 2003)**
  <u>*Major trades:*</u>
  - Telescope mount configuration (Alt-Az vs. equatorial or Alt-Alt).
  - Optical design concept (off-axis vs. on-axis).
  - Enclosure concept (open, ventilated non-co-rotating, co-rotating, tightly integrated, closed).
  - Instrument facility layout (Coudé, Nasmyth, Gregorian, etc.).
  - First order analysis of system performance, for preferred approach(s).
- **Preliminary Design Review (2004)**
  - Preliminary design of the baseline approach established during the conceptual design phase.
  - Instrument integration and operational considerations.
  - Involvement of partner and manufacturing organizations in the process where possible.
  - Establishment of construction costs and contingency; including draft integration, testing and commissioning plans.
  - Submission of Construction Phase proposal prior to Preliminary Design Review.
- **Critical Design Review (2005)**
  - Preparing construction detailed design and specifications.
  - Procurement planning.
  - Integration, test and commissioning planning.
  - Operational planning.

To aid in refining these plans, an informal design workshop was held in October 2002. Representatives from all of the collaborating institutions, potential additional partners from Europe, and a group of engineers with recent large telescope experience attended to discuss the current design effort, straw man concepts, expected costing, and schedule. The workshop served to focus the community on trade-off issues, associated risks, the need to make some up-front decisions and get started on long-lead items, such as the primary mirror.

4.2 High-Order Adaptive Optics

NSO, in partnership with the New Jersey Institute of Technology (NJIT) and the Kiepenheuer Institute (KIS) in Germany is developing high-order solar adaptive optics (AO). The development of high-order AO systems for use on the 65-cm telescope at Big Bear Solar Observatory (BBSO), and the 76-cm Dunn Solar Telescope (DST) at Sacramento Peak is well underway. The high-order AO system will upgrade each of these high-resolution solar telescopes and greatly improve scientific output of each facility. The resulting systems will also serve as proof-of-concept for a scalable AO design for the much larger Advanced Technology Solar Telescope. The solar AO program is funded by the NSF Major Research Instrumentation Program and through substantial contributions by partner institutions.

The overall system designs for both the DST and BBSO are complete. All subsystems are in hand and the major hardware components have been tested.

The two deformable mirror systems, one for BBSO and one for the DST, were delivered to Sac Peak by Xinetics, Inc. The deformable mirrors were tested using an interferometer, and they performed as expected, meeting all target specifications.

The interim Dalsa WFS camera, with a frame rate of 955 Hz has been integrated with the processing unit. This camera will be used for the first-light AO system tests. A contract for the design and fabrication of a fast wavefront sensor camera, based on a CMOS device developed by JPL, has been issued to Baja Technologies in Tucson. A “smart” interface for this camera has been designed. This interface is flexible and can be reprogrammed to accommodate different formats. A 200 × 200 format can be implemented at sufficiently high rates of ~2500 Hz. The CMOS camera development is making good progress. The camera has delivered the first images, and a prototype will be available for testing at the DST in Nov. 2002.

The Digital Signal Processor (DSP) systems, which perform all computations for sensing and reconstructing the wavefront, have been delivered by Bittware. Extensive tests of I/O and processing speeds were performed with this 80-processor parallel system. Both the BBSO and the NSO DSP systems are in hand and have passed all tests. The interface between DALSA camera and DSPs, and the interface between the DSPs and the deformable mirror drive electronics, both designed in-house, were integrated with the wavefront sensor processing unit and the deformable mirror system. The DSP system software development is nearing completion and first engineering runs with the goal of closing the high order AO loop for the first time at the DST are scheduled for November and December of 2002.

The optical setup for the high-order AO system has been installed at the DST. The optical performance of the system has been evaluated using a newly developed single mode fiber optics interferometer. The AO optics was found to deliver excellent image quality at the instrument focal plane. The high-order AO will feed the newly developed Diffraction-Limited Spectro-Polarimeter (DLSP).

At BBSO, a new observing room that will house the AO system and post-focus instrumentation was created by remodeling office space. The optical design for the BBSO AO system has been completed and all optical components have been ordered. The light has been redirected from the dome floor to the floor below, where the AO system and the two scientific optical benches were installed. Visible and near-IR narrowband Fabry Perot filter systems, in combination with polarization analyzers, will be used to measure magnetic fields.

Long-exposure PSF estimation is an important tool for post-processing AO-corrected data and PSF estimates will be provided as a standard product of the AO system. The long- exposure PSF can be estimated from the covariance matrix of the residual (closed-loop) wavefront sensor signals and knowledge of r_0. This method was developed for wavefront curvature, sensor based nighttime AO systems by J.P. Veran. Jose Marino, a graduate student at NJIT, is now working at Sac Peak on refining the method and applying it to solar data, such as narrowband images and spectra. He has carried out observing runs at the DST to record fast, high-order wavefront sensor data simultaneously with long-exposure images. Both closed- and open-loop data were recorded. Jose is also collaborating with ONERA in Paris/France and the Gemini Project on the development and application of the PSF estimation method. This collaboration is supported by the Center for Adaptive Optics.

Maud Langlois, an expert in multi-conjugate adaptive optics (MCAO), has joined the AO team. Prior to joining NSO she worked on MCAO laboratory experiments at the University of Durham, England and on adaptive optics at the University of Arizona/Steward Observatory. Maud is developing reconstruction algorithms for the high-order AO systems at NSO and BBSO and will spend a considerable amount of her time developing MCAO for the Sun. Gilberto Moretto was also hired by NSO as an optical scientist and is spending part of his time supporting the solar AO effort.

4.3 SOLIS

SOLIS (Synoptic Optical Long-term Investigations of the Sun) is a project to make optical measurements of processes on the Sun, the study of which requires well-calibrated, sustained observations over a long time period. The project was conceived in 1995, proposed to NSF in Jan. 1996 as part of a “Renewing NOAO” proposal, and received partial funding in Jan. 1998. The design and construction phases have required nearly five years and the 25-year operational phase will start early in 2003. A Science Advisory Group provides expert advice from a wide range of the user community. The HAO, Lockheed-Martin Solar and Astrophysics Laboratory, Office of Naval Research (ONR) and NASA have been active partners in the SOLIS program.

As funded, SOLIS consists of three instruments that will initially be mounted on the top of the existing Kitt Peak Vacuum Telescope. The mounting is transportable. The three full-disk instruments on a common mount are as follows:

(1) A Vector Spectromagnetograph (VSM) to measure the strength and direction of the photospheric magnetic field, the line-of-sight component of the chromospheric magnetic field, and the spectral line characteristics of the helium chromosphere. (2) A Full Disk Patrol (FDP) that provides digital, one arcsec pixel images of the full disk showing the intensity and line-of-sight velocity in a number a spectrum lines at high cadence. (3) An Integrated Sunlight Spectrometer (ISS) furnishes Sun-as-a-star spectra at both high and medium spectral resolutions with emphasis on high photometric precision and stability. A major component of SOLIS is data processing, distribution and archiving. SOLIS will be most productive when working in concert with other observing projects, both in space and on the ground. In particular, NASA's Ramaty High Energy Solar Spectroscopic Imager (RHESSI; scheduled for launch in

2005), the Japanese SOLAR-B (09/2005), and NASA's STEREO (12/2005).

This report covers October 2001 through September 2002 of the design, construction, testing, and startup phases of the 25-year SOLIS project. During the report period emphasis was on completion of construction, and assembly and testing of elements of the SOLIS system. A major effort was switching to new cameras for the VSM after the original camera vendor delayed the project by about a year and ultimately defaulted.

The equatorial SOLIS mount has been tested at a temporary site co-located with the GONG prototype. Motion in right ascension and declination is directly driven by powerful torque motors without any gears. Alignment and flexure errors of the mount were measured by pointing to numerous stars.

The VSM optical alignment was completed when it was discovered that some of the high-reflectivity silver coatings had degraded significantly. This required removing and recoating the 58-cm primary mirror with an improved enhanced silver coating. Some additional optics will be recoated with protected gold at the expense of slightly degraded throughput and polarization cross talk. According to laboratory tests, the image quality delivered by the VSM telescope and spectrograph is excellent. The cameras are producing 16-bit pixel data at a continuous rate of 48 megapixels per second. The data acquisition system that sorts and accumulates this flood of data (according to the state of polarization transmitted by ferroelectric modulators) passed bench testing but when moved to the telescope developed a problem that is currently being solved.

Software has been prepared and tested to reduce observations made by the VSM. The highest priority is to make reduced maps like those that have been produced at the Kitt Peak Vacuum Telescope for the last 28 years. The VSM and the old instrument will be operated simultaneously for at least one solar rotation to allow the old and new data sets to be linked. In addition, new vector magnetic field measurements will be taken and processed. With advice from a group of community experts, a quick-look reduction algorithm was selected and implemented. The quick-look results will be used to start a more accurate reduction. The accurate-reduction algorithm was also selected and implemented. Some higher-level data products have been developed using currently available data and others are under development.

A powerful data processing and storage facility is required to handle SOLIS data. A storage area network has been developed that is presently capable of holding one day of SOLIS raw and reduced data, and a group of 14 processors operating under Linux is available to do near real-time data reduction. A change in the archiving plan emerged as a result of the dropping price of hard-disk storage. Instead of using a large tape library to archive SOLIS data, a RAID hard-disk farm as the primary archive was purchased. A small tape library unit that requires reloading every few days will capture relatively raw data at the telescope as a backup. With this approach, hard disks can be added as needed as the SOLIS archive expands with time. The initial purchase handles at least two years of SOLIS data.

Work on the ISS has centered on continued development of accurate flat fielding algorithms. A nearly two-orders-of-magnitude improvement in both speed and accuracy to a widely used algorithm (originated by J. Kuhn and H. Lin (U. Hawaii) and D. Loranz (Truckee Meadows CC)) was developed. This has important benefits not only for the ISS but also for the large-format cameras used in the FDP. Laboratory testing of the ISS revealed a temperature-dependent wavelength shift. This was reduced by replacing a certain metal piece with Invar. The main source of spectrum drift is now changes of the index of refraction of air related to barometric pressure changes. In other words, the ISS is intrinsically stable to a level smaller than factors beyond our control.

The lowest priority, and least unique, SOLIS instrument is the FDP. It uses two narrowband filters to isolate specific wavelengths. One is fixed at 1083 nm and the other is tunable between 380 and 670 nm. The 1083 nm filter was finished and used in a temporary setup to support a community high-cadence flare observing campaign. It produced nice images at 60 frames per second and a few small flares were recorded using a digital camcorder. Completion of the visible filter has been delayed by higher priority work. In its place, an old H-alpha filter was refurbished and will be used for early FDP observations. This filter produced very nice images of solar activity during a short testing period.

The major SOLIS effort in FY 2003 will be to transition SOLIS to successful initial operation. We will also respond to a request by the NRC ten-year plan, "Astronomy and Astrophysics in the New Millennium," with a proposal to build two additional SOLIS units to be placed at distant longitudes to form a SOLIS network.

5 NSO OPERATIONS AND UPGRADES

The advent of solar adaptive optics and its routine use at the Dunn Solar Telescope, as well as the increased use of IR detectors at the McMath-Pierce Solar Telescope and Evans Solar Facility, mark the major changes in NSO operations. The NSO telescope upgrade and instrument development program is guided by the scientific and technical imperatives for developing a new Advanced Technology Solar Telescope. Telescope and instrument upgrades and operations are reviewed and supported on the basis that they serve as necessary preludes to the ATST initiative while concurrently serving the needs of the scientific community. Details of the scientific and technical operations can be found at *http://www.nso.edu.* Brief summaries of the primary projects and operational changes are provided in this section.

5.1 GONG

The Global Oscillation Network Group (GONG) is an international, community-based project designed to conduct a detailed study of the internal structure and dynamics of our closest star, the Sun, by measuring acoustic waves that penetrate throughout the solar interior. In order to overcome the limitations of observations imposed by the day-night cycle at a single observatory, GONG is operating a six-station network of extremely sensitive and stable solar velocity mappers located around the Earth, obtaining nearly continuous observations of the "five-minute" pressure oscillations. GONG is also operating a distributed data reduction and processing system to support the coordinated analysis of these data, and a data management system to archive and distribute the data products. GONG data are considered public domain and available to anyone.

A Scientific Advisory Committee, consisting of P. Gilman (HAO), R. Noyes (Harvard-Smithsonian CfA), P. Scherrer (Stanford), M. Thompson (Imperial College, London), A. Title (Lockheed-Martin), J. Toomre (U. Colorado/Chair), and R. Ulrich (UCLA), continues to provide overall scientific guidance to the project. In addition, a Data Management and Analysis Center Users' Committee, consisting of T. Appourchaux (ESA/ESTEC), S. Basu (Yale), D. Braun (Northwest Research Associates), P. Stark (UC-Berkeley), S. Korzennik (Harvard-Smithsonian CfA), and J. Schou (Stanford/Ch.), provides important community input to this critical part of the project.

The GONG stations are hosted by, and operate in close collaboration with, major international astronomical facilities: NJIT/BBSO in California, HAO's site on Mauna Loa in Hawaii, the IPS Radio and Space Services' Learmonth Solar Observatory in Western Australia, the Physical Research Laboratory's Udaipur Solar Observatory in India, the Instituto de Astrofísica de Canarias' Observatorio del Teide on Tenerife in the Canary Islands, and CTIO in Chile.

The project's Tucson-based operations staff maintains daily contact with the automatically operating site instruments, monitoring the state of the instruments. Each of the network instruments generates a 200-parameter database which is transmitted to the Tucson station once a day to facilitate the review and analysis of the functioning of the remote instruments, including fault diagnosis and the detection of performance anomalies and long-term trends. When problems occur, or a quick response is required, the network operations "on call" duty responder can be readily accessed via phone, fax, or e-mail. Our collaborators at the host observatories also monitor the instruments locally.

Despite the less-than-hoped-for duty cycle during the first quarter of GONG+ operations, the network has settled down and performance and reliability are very good. With the instrument upgrade behind and a full solar cycle run in front, GONG is transitioning from a project to a flagship program. The science operations face the challenges of aging components and outdated electronics, but can also look to the opportunities of increased bandwidth, which should result in real-time data verification and diagnostics, better performance, and new science.

The Data Management and Analysis Center (DMAC) completed the reduction of the raw data from GONG's seventh year of operation: eleven, 36-day-long, GONG months (numbers 60-70) with an average fill factor of 0.78. This period included the transition from GONG Classic to GONG+, which occurred during months 61-63. The decline in the fill factor compared to the previous year (0.85) is attributable to downtime associated with the installation of the GONG+ cameras.

Data reduction activities over the past year included the identification of mode frequencies from the 108-day-long time series centered on GONG-months 56-67.

The project began a campaign to re-pick the mode frequencies from all existing GONG time series after the application of multiple optimized tapers to the three-month-long time series. This campaign has produced mode frequency sets for GONG months 2-67. In addition, a second campaign was started to fit the mode frequencies to orthogonal polynomials as defined by Ritzwoller and Lavely. These products are also now available for GONG months 2-67.

The data from these and other processing steps continue to be archived in the Data Storage and Distribution System, which is also responsible for the distribution of archived scientific data products to the community. Requests are typically received by email and via GONG's web site, where Internet transfers satisfy most data distributions. During the past year, these distributions exceeded 1.2 Terabytes compared to 232 Gigabytes in the previous fiscal year. GONG is transitioning to a completely open data access policy.

After completing the camera upgrade project (GONG+) in 2001, the instruments now collect full-resolution images, and in much the same way as before, the data is returned to Tucson to be calibrated and merged. The added factor of sixteen areal resolution, in addition to the collection of continuous line-of-sight magnetograms, presents a formidable task for the current DMAC data reduction pipeline. Therefore, once merged, the data is processed maintaining the same ℓ coverage as before ($\ell < 200$) and producing the same data products. In order to exploit the full scientific potential of the GONG+ data, the project has undertaken another phase, GONG++, which includes implementing a high-performance data handling system and processing pipeline. With the hardware in-house, the GONG++ pipeline architecture and software, which will focus on high-ℓ global *p*-mode processing and local helioseismology methods, should become fully operational in FY 2003. The first GONG++ results are highlighted in Sec. 3.3.

The project had the pleasure of hosting scientific visits for S. Jefferies (Maui Scientific Research Center), P. Venkatakrishnan (Udaipur Solar Observatory), S. Basu (Yale/IAS), and M-J Goupil (Meudon).

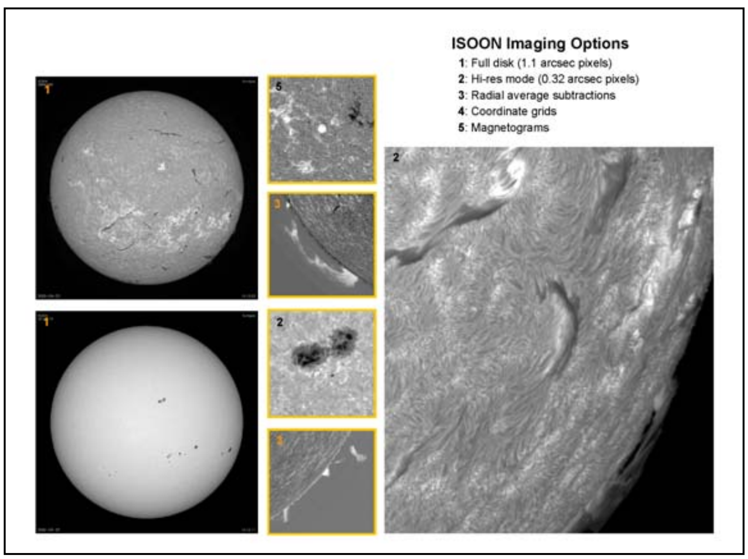
GONG's 2002 annual meeting was held in Big Bear, CA, October 28- November 1, 2002, and hosted by NJIT. The meeting was held jointly with the SoHO helioseismology experiments.

5.2 ISOON

ISOON (the Improved Solar Observing Optical Network) was completed through prototype demonstration, although its deployment as an operational system at three sites worldwide was cancelled by the USAF. Ownership of the functioning ISOON prototype system has been transferred to the Air Force Research Laboratory at NSO/Sac Peak, where it will be used for research and limited support to space weather forecasting. ISOON represents a class of instrumentation intermediate to patrol telescopes and major solar telescope facilities, and can be dedicated to interests of a synoptic nature, especially those involving transient activity such as flares, prominence eruptions, Moreton waves, and active region evolution.

ISOON is a semi-autonomous, remotely commandable system that provides imaging in H-alpha, continuum, and line-of-sight magnetic fields. It features high-precision 12-bit photometry, registered images with constant magnification and orientation, and tunable filter system. Both full-disk and high-resolution formats are available. Helium 10830 images will be available in the near future. The ISOON analysis software operates on a remote computer and includes a library of functions including still images and movies, coordinate overlays, radial average subtractions, automatic flare patrol, automatic sunspot areas, locations, and counts, point and click for zoom, 30-day database, intensity measurement tools, and others.

Further information as well as real time images and movies are available at *http://www.nso.edu/sunspot/isoon/descript.html.*



5.3 Digital Library and Virtual Solar Observatory

In addition to its dedicated telescopes, the NSO operates a Digital Library that provides synoptic data sets over the Internet to the research community. Since the inception of the Digital Library in May 1998, close to 40,000 science data files have been distributed to about 14,000 unique computers. These figures exclude any NSO or NOAO staff members.

The advent of the Internet is the key enabler of alternate modes of observing and data delivery. The Internet enables direct interaction between astronomers at remote locations with the on-site observers and it allows rapid data dissemination. It will also allow observers to schedule observations with SOLIS automatically.

NSO has made its entire set of daily solar images from the KPVT, FTS data, and a portion of the Sacramento Peak spectroheliograms available on-line. The holdings of the NSO Digital Library are currently stored on robotic CD-ROM jukeboxes and are searchable via a web-based interface to a relational database. SOLIS will soon begin to generate processed data at a maximum rate of 240 GB per day, with requirements for rapid archiving and user access. Thus, a higher capacity storage system is now being installed. This server will eventually be equipped with 14 TB of on-line disc storage, sufficient to hold about 7 years of SOLIS data as well as the current Digital Library.

In order to leverage further the substantial national investment in solar physics, NSO is participating in the development of a Virtual Solar Observatory (VSO) and the European Grid of Solar Observations (EGSO). The VSO, and its European counterpart the EGSO, will initially comprise a collaborative distributed solar data archive and analysis system with access through the WWW. The overarching goal 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 the web pages at

5.4 Kitt Peak

5.4.1 Large-Format Infrared Array and Controller

The McMath-Pierce facility is the world's only large solar telescope without an entrance window, thus giving it unique access to the solar infrared spectrum beyond 2.5 μm. NSO has focused its in-house instrumentation program on the 1-5 μm region. The McMath-Pierce also carries out observations in the important 12-μm region through collaboration with NASA's Goddard Space Flight Center.

NSO's plan for 1-5 μm observations takes full advantage of NOAO's investment in the ALADDIN infrared array development project. With 16 times as many pixels, higher quantum efficiency, lower read-out noise, and better immunity from electronic interference, the 1K × 1K ALADDIN-based camera will be superior to the current 256 × 256 (NIM) camera in every respect and will enable new types of scientific observations, such as vector magnetograms of weak-field concentrations and high-cadence studies of chromospheric dynamics.

A high-quality ALADDIN-III array has been identified and assigned to NSO by NOAO at no cost to NSO. A contract for the camera controller was signed with Mauna Kea Infrared (MKIR), and is nearing completion. In a collaboration with NASA, NSO will obtain a suitable initial science dewar. A funding source for the final science dewar has not been identified. The initial system will be ready by late FY 2003.

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

5.4.2 Seeing Improvement

Tests of potential improvements to the telescope seeing have been conducted during the last several years, which helps to understand internal seeing in a solar telescope, a crucial prerequisite for the design of the ATST. Further tests and modification will be driven by the need for more information for designing the ATST. The performance of such improvements will be assessed with a high-order wavefront sensor that has been developed for the adaptive optics project (see Sec. 5.4.3).

5.4.3 Adaptive Optics

The infrared adaptive optics project at the McMath-Pierce telescope is making rapid progress. During FY 2002 the tip-tilt system was commissioned and made available for scientific use on a shared-risk basis. Every observing run with this system has provided spectacular new scientific insights, such as the detection of CO emission off the solar limb using the Fourier Transform Spectrometer. Those data indicate significantly lower temperatures in the chromosphere than previously thought. During FY 2003, the tip-tilt system will be converted into a fully supported user instrument. In parallel, the adaptive optics system with a 37-actuator mirror has been developed. First tests at the East Auxiliary telescope have shown the dramatic improvements in image quality. During FY 2003, the system will be optimized and made available on a shared risk basis. Towards the end of FY 2003, the system will be available as a general user instrument.

5.4.3 McMath-Pierce Telescope Control System

Upgrades to the telescope control system (TCS) are needed to ensure that the facility remains competitive and maintainable. Until the end of FY 2003, only minor planning and test efforts are envisioned due to limited resources. The latter includes the investigation of a new guider approach that will be finished and, if successful, commissioned during FY 2003. The TCS upgrade will take advantage of existing engineering experience within NSO, experience gained in the SOLIS project, as well as experience being gained with the commercial TCS of the upgraded East Auxiliary telescope.

5.4.4 East Auxiliary Telescope Upgrade

The upgrade of this telescope was funded by the NASA Near-Earth Asteroid program as part of their follow-up program. A prototype CCD imager system was built during FY 2002, and an operational system was designed using data from this system. Construction of the operational system is nearly complete. The limiting magnitude of East Auxiliary telescope is in the range 19–20. NASA has indicated that limiting magnitudes in the range 20–21 are significantly more important than the 19–20 range, and as a consequence, operation of the East Auxiliary telescope for follow-up observations will be of secondary importance. However, use of the CCD imager system with the McMath-Pierce telescope is feasible and should yield measurements in the 20–21 magnitude range. Minor changes will be made to the CCD imager system so as to allow operation either with the East Auxiliary or the McMath-Pierce telescope. This will provide a capability to support the full range of NASA requirements.

5.5 Sacramento Peak

5.5.1 Low-Order Adaptive Optics

The low-order adaptive optics (LOAO) system is completed and available for users requesting time on the Dunn Solar Telescope (DST).

The LOAO system can be used to feed a corrected image to the HAO/NSO Advanced Stokes Polarimeter (ASP) the Universal Birefringent Filter (UBF), the UBF combined with a Fabry-Perot filter for narrowband imaging, dual IR and visible Fabry-Perot filters, and several other broad- and narrow-band imaging devices (G-band, H-alpha, K-line, white light). The corrected image can be fed to several of these devices simultaneously.

5.5.2 Advanced Stokes Polarimeter Upgrade

The Advanced Stokes Polarimeter (ASP) was developed by the High Altitude Observatory with help from NSO. Plans to upgrade the ASP include a new diffraction-limited spectro-polarimeter (DLSP) that will permit different image scales, from high-resolution (at the diffraction limit of the Dunn Solar Telescope (DST)) to lower resolution with a larger field-of-view. This project consists of two phases: Phase 1 integrates the DLSP with the low-order AO system and existing CCD hardware on Port 4. Using the existing ASP modulation and demodulation unit, Phase 1 will be used to observe Stokes profiles with reasonable spatial resolution (0.3 arcsec); Phase 2 integrates the DLSP on Port 2 with the high-order AO system and new CCD hardware. A new modulation and demodulation package will be included in order to make the instrument stand alone. With the new CCD hardware, the spatial resolution would be equal to that of the DST.

The DLSP instrument is completed and now being tested at the DST using the low-order adaptive optics and the ASP control system. The instrument saw first light on March 13, 2002. The initial results show that the performance of the instrument in the high-resolution mode is better or comparable to that of the ASP. Note that the spatial resolution achieved using the ASP is around 0.8 arcsec.

NSO and HAO are currently in the design process for Phase 2, integrating the DLSP with AO76. The optimistic completion target date for Phase 2 is August 2003.

5.5.3 CCD Upgrade

The primary goal of this upgrade is to provide a reliable and stable image-capture system for the DST. Additional benefits include providing interchangeable camera/computer configurations on a day-to-day basis, and easing the required maintenance effort.

Over the past year, several modifications/alterations have been made to the image-capture system that has changed its complexion. These changes have had an impact on the originally scheduled completion date of December 2001.

The original system had the following specifications: a) seven SUN AXi motherboards housed in rack-mount enclosures, four with DLT 8000 and three with 8mm 4.5 GB drives; b) removable 36 GB capacity hard drives; c) PCI backplane; d) room for hardware expansion; and e) SOLARIS operating system. The new configuration now consists of a) seven SUN Blade 100's running the Solaris OS; b) a 500 GB Sun Fibre Channel SAN; c) a DLT tape library with 4 DLT 8000's, 30 cartridge capacity; d) all required interconnect hardware; and e) off-table media-transfer stations for transfer of data from DLT to media of choice.

Software development is proceeding and hardware selection has been completed. Procurement of the hardware will occur in November 2002, followed by installation of the hardware in the December 2002/January 2003 time-frame. Initial software integration will occur concurrently. Systems testing will occur in the first quarter of 2003, with the current image-capture system staying online during that time.

5.5.4 IR Camera

NSO and the University of Hawaii Institute for Astronomy agreed to collaborate in the development and scientific use of infrared camera systems. Specifically, this refers to the joint use of the 256 × 256 TCM2620-based IR camera, capable of IR imaging up to 5 μm, and the 256 × 256 NICMOS IR camera used mainly for polarimetry for wavelengths between 1-2 μm. The goal of this collaboration is to maximize the scientific output from these devices and to support ATST technology development with SOLAR-C, as described in the ATST design and development proposal.

The existing TCM2620 engineering-grade array was recently replaced by a scientific focal-plane array. The camera is now up and running and the new Rockwell array is performing as advertised. The camera is now being moved to Haleakala for trial runs.

5.5.5 Dual Fabry-Perot Filter

A new, narrow Fabry-Perot (FP) etalon was ordered and purchased from JDS Uniphase. Two RS-232 controller upgrade packages to software control the z-modulation were also purchased during that time.

Further software and hardware support and upgrade for the dual Etalon system has been put on-hold temporarily. Project management has relegated the implementation priority for the dual-FP system to a low level, in light of higher priorities for AO, DLSP, ATST Site Survey and new CCD camera software systems.

6 Educational and Public Outreach

NSO has a comprehensive public affairs and educational outreach plan that includes public programs, media information, elements of distance learning (Internet) education, K-12 education, undergraduate and graduate research, teacher research and research-to-classroom experiences. A scientist at each site has responsibility for the local educational and public outreach program, with additional support provided by other members of the scientific and support staff and, during the summer, by resident students.

6.1 Higher Education (Undergraduate, Graduate, and Teacher Research and Education)

During summer 2002, NSO hosted eight undergraduate students as part of the NSF-sponsored Research Experiences for Undergraduates (REU) program: Joy Chavez (U. Houston); Marjorie Frankel (Wellesley); Adam Kraus (Kansas State U.); Mary Melton (Texas A&M); William Plick (Connecticut College); Erika Roessler (Northern Arizona U.); Carol Thornton (U. Virginia); and Adria Updike (Smith).

For a third year, NSO received a supplement to its REU funding that supports teacher participation in the Research Experiences for Teachers (RET) program. The following science teachers spent the summer working with NSO staff scientists: Ben Briggs (Cross Middle School, Tucson); Demetria Fenzi-Richardson (Sarracino Middle School; Socorro, NM); William Rogers (Cloudcroft Middle School, NM); and Nate Van Wey (Perry High School, Massillon, OH). NSO also participated in the Teacher Leaders for Research-Based Science Education (TLRBSE) program with NOAO. NSO scientists provided projects and hosted a 4-day workshop at Sac Peak for 12 teachers.

In addition to undergraduate students, NSO has a Summer Research Assistantship (SRA) program for qualified graduate students. The following graduate students were awarded internships during summer 2002: David Byers (Utah State); Michael Eydenberg (New Mexico Institute of Mining & Technology); Vasily Maleev (St. Petersburg State U.); Emilie Rousset (France) and Michelle Rooney (Colorado State). Throughout the year, NSO also hosts graduate students who have NSO scientific staff as PhD thesis advisors. The following students have been in residence at NSO/Sacramento Peak and use NSO facilities as part of their thesis project: Klaus Hartkorn (Kiepenheuer Institute); Jose Marino (NJIT); Larry Murray (NJIT); and Chun Yang (NJIT).

6.2 K–12 Education

NSO actively participates in several programs to enhance science education in grades K–12. The participation occurs through formal programs and informal commitments of staff members to local education. NSO staff are mentors to high school students in local challenge programs in Alamogordo and Cloudcroft, NM school districts and in

Tucson, AZ. Staff provide lessons and demonstrations at the Tohono O'Odham Reservation schools. They also produce classroom material through participation in Project ASTRO in both New Mexico and Arizona. This year, NSO hosted the Project ASTRO workshop in Sunspot for teachers and astronomers.

6.3 Other Public and Educational Outreach

NSO is a strong participant in the Southwest Consortium of Observatories for Public Education (SCOPE). SCOPE is a consortium of research institutions in the southwest that promotes public awareness of astronomy through access and education. The consortium includes NSO, Apache Point Observatory, Kitt Peak National Observatory, McDonald Observatory, National Radio Astronomy Observatory/Very Large Array, and the Whipple Observatory. This valuable collaboration results in excellent interaction among the public and educational outreach staff of these groups and includes cooperative promotion, visitor center display sharing, and the ability to leverage our limited funding into additional outreach opportunities. We produce materials that describe solar astronomy and the effects of the Sun on the Earth for dissemination by SCOPE. In Fall 2001, NSO hosted a SCOPE meeting at its Sacramento Peak site.

6.4 NSO Visitor Center

NSO hosted approximately 21,000 visitors this year. Visits begin at the Sunspot Astronomy and Visitor Center (Visitor Center), where all the necessary visitor conveniences, including vending machines, a gift shop, host/hostess, and interpretive information are provided. In addition to stopping at the Visitor Center, all visitors are encouraged to take guided or self-guided tours of the facilities at NSO. Each year, NSO provides approximately 100 guided tours, about half of which are to school groups.

The Visitor Center houses a wide range of interactive displays. These educate the visitor on topics related to the science and research being done at NSO and nearby Apache Point Observatory and to astronomy in general, and to the effect of the Sun on the Earth's environment.

6.5 NSO Public Web Pages

The NSO WWW site (*http://www.nso.edu*) contains several public outreach areas. These include a live solar image that is updated once per minute so the public (and the scientific community) can see how the Sun is behaving in Hα. These images allow the observer to quickly assess the state of solar activity. Virtual tours of the NSO sites, including telescope descriptions, are available. There is an interactive solar tutorial that provides information about the Sun and its processes. There is also an "Ask Mr. Sunspot" area where questions can be asked about the Sun and astronomy in general. Answers are posted on the WWW and indexed so visitors can easily look at past answers by subject. A data archive is also available. While intended for scientific research, it is also accessible by the general public and to students working on solar projects.

7 OBSERVING AND USER STATISTICS

In the 12 months ending 30 September 2002, 105 observing programs, 14 of which were thesis programs, were carried out at NSO. Associated with these programs were 103 scientists from 54 US and foreign institutions.

NSO Observing Programs by Type (US vs Foreign)

12 Months Ending Sept-2002	*Nbr*	*% Total*
Programs (US)	71	68%
Programs (non-US)	20	19%
Thesis (US)	7	7%
Thesis (non-US)	7	7%
Total Number of Unique Science Projects*	**105**	**100%**

**Includes observing programs conducted by NSO/NOAO staff scientists.*

Users of NSO Facilities by Category

	Visitors				NSO/NOAO Staff
	US	*Non-US*	*Total*	*% Total*	
PhDs	67	22	89	81%	14
Graduate Students	4	5	9	8%	-
Undergraduate Students	4	0	4	4%	-
Other (Research Tech.)	7	1	8	7%	12
Total Users	**82**	**28**	**110**	**100%**	**26**

Number of Users by Nationality

Canada	3	Ireland	3
China	1	Italy	4
France	3	Japan	1
Germany	4	Mexico	1
Greece	1	Switzerland	6
India	1	United States	108

Institutions Represented by Visiting Users**

	US	*Non-US*	*Total*	*% Total*
Academic	24	11	35	64%
Non-Academic	14	6	20	36%
Total Academic & Non-Academic	**38**	**17**	**55**	**100%**

***Note: Total number of institutions represented by users do not include departments or divisions within an institution as separate entities (e.g., US Air Force and NASA are each counted as one institution even though several different sites/bases/centers are separately listed in the data base.*

INSTITUTIONS REPRESENTED BY USERS

US Institutions (35): American Institute of Physics; California State University-Los Angeles; California State University-Northridge; Cambridge Research and Instrumentation; Carnegie Institution of Washington; College of William & Mary; Connecticut College; East Carolina University; Edinboro University; Harvard-Smithsonian Center for Astrophysics; Haverford College; High Altitude Observatory/NCAR; Jet Propulsion Laboratory; Lawrence Livermore National Laboratory; Lockheed Martin Solar & Astrophysics Lab; NASAGoddard Space Flight Center; NASA/Langley Research Center; National Oceanic & Atmospheric Administration; New Jersey Institute of Technology/Big Bear Solar Observatory; New Mexico Institute of Mining & Technology; Philips Lighting; Reed College; San Jose State University; Sandia National Laboratories; Southwest Research Institute; Space Telescope Science Institute; St. Olaf College; Texas A&M University; University of Arizona; University of Colorado; University of Hawaii, IFA; University of Wisconsin, Madison; University of California, Berkeley; University of Virginia; US Air Force, Los Angeles AFB; US Air Force/Philips Lab; Utah State University; Wellesley College.

Foreign Institutions (17): University of Calgary; University of Waterloo; Chinese Academy of Sciences; Institut d'Astrophysique de Paris (CNRS); Observatoire de Paris; Observatoire de Pic-du-Midi; Kiepenheuer Institut für Sonnenphysik; University of Patras; Udaipur Solar Observatory; Queens University; Osservatorio Astrofisico di Arcetri; Osservatorio Astronomico di Capodimonte; University of Florence; University of Naples; National Astronomical Observatory of Japan; Universidad de Monterrey-Mexico; ETH, Zurich.

7.1 User Statistics – Archives and Data Bases

7.1.1 NSO/Sacramento Peak

Combined FTP Archive & WWW User Demographics (NSO/SP)		
Demographic Group	**Requests**	**Traffic**
U.S. Science (*.gov, .edu, .mil*)	17.2%	21.2%
Other U.S. (*.com, .net, misc.*)	62.3%	66.3%
Foreign	16.9%	10.6%
Unresolved	3.6%	1.9%

FTP Archive Statistics

There were 502,150 successful user requests serving 5,454 distinct files to 28,528 distinct hosts. A total of 104.571 Gbytes were served averaging 293.435 Mbytes per day.

FTP User Demographics (NSO/SP)		
Demographic Group	**Requests**	**Traffic**
U.S. Science (*.gov, .edu, .mil*)	14.1%	24.2%
Other U.S. (*.com, .net, misc.*)	72.6%	68.0%
Foreign	11.2%	6.6%
Unresolved	2.1%	1.2%

FTP Products (NSO/SP)		
Demographic Group	**Requests**	**Traffic**
Realtime Flare Patrol Images	68.1%	76.6%
Flare Patrol Movie Archive	1.2%	2.1%
RISE/PSPT Images (realtime and archive)	2.9%	3.8%
Corona Maps	22.2%	4.3%
Sunspot Numbers	1.6%	0.2%
NASA Orbital Debris Observatory	0.3%	1.7%
Other	3.7%	11.3%

World Wide Web Statistics

There were 2,292,963 successful user requests serving 29,339 distinct files to 122,949 distinct hosts. A total of 31.728 Gbytes were served averaging 89.016 Mbytes per day.

WWW User Demographics (NSO/SP)		
Demographic Group	**Requests**	**Traffic**
U.S. Science (*.gov, .edu, .mil*)	17.8%	11.2%
Other U.S. (*.com, .net, misc.*)	60.1%	60.6%
Foreign	18.2%	24.0%
Unresolved	3.9%	4.2%
WWW Products (NSO/SP)		
Demographic Group	**Requests**	**Traffic**
Realtime Images	8.2%	9.1%
Other Images	8.9%	30.0%
General Icon and Background Images	25.2%	9.1%
Public Relations Pages	15.1%	11.0%
Telescope Home Pages	14.0%	3.9%
NASA Orbital Debris Observatory Home Page	2.3%	4.9%
Adaptive Optics Pages	1.5%	7.1%
ATST Pages	2.3%	5.9%
Other	22.5%	19.0%

Note: The statistics in Sec.7.1.1 exclude the internal use of these services from within the NSO/Sac Peak Local Area Network. The numbers do not include NSO/Tucson. Historical use trends can be found at http://www.sunspot.noao.edu/WEB REPORTS/trends.html.

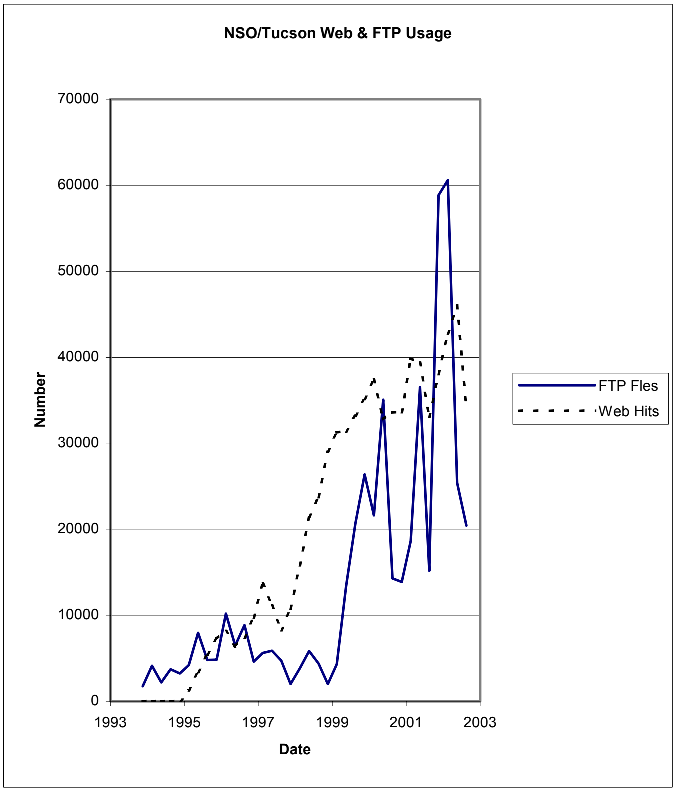
7.1.2 NSO/Tucson

FTP User Demographics (NSO/Tucson)			
Demographic Group	*Users*	*Log-Ins*	*Downloads*
U.S. Science (*.gov, .edu, .mil*)	14.0%	31.0%	71.0%
U.S. Public Schools	29.0%	8.0%	6.0%
Foreign	29.0%	41.0%	18.0%
Unresolved	28.0%	20.0%	5.0%

- 3,097 FTP users.
- 112,751 FTP logins.
- 237,758 files downloaded via anonymous FTP.
- 160,929 web page hits (not counting in-line images).
- 1,655,113 web page hits (including in-line images).
- Distribution of downloaded data products by number of files:
  1. 24% KPVT (magnetograms; synoptic maps, helium images).
  2. 8% FTS (spectral atlases, general archive).

1. 3% Sac Peak spectroheliograms (Hα, Calcium K images.
2. 65% GONG (magnetograms, spectra, time series, frequencies.

- Digital Library access was used for 13% of file downloads.



8 PUBLICATIONS

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