NATIONAL SOLAR OBSERVATORY

TUCSON, ARIZONA • SAC PEAK, NEW MEXICO

From the NSO Director's Office

Steve Keil

The past quarter has brought several changes and new developments at the National Solar Observatory (NSO). For a complete review of NSO science and projects during fiscal year 2002, we refer you to the NSO Annual Report in the March 2003 volume (35) of *BAAS*, or visit our Web site at *www.nso.edu*.

*

One of the most exciting developments this past quarter was a first-light demonstration of the new, high-order adaptive optics (AO) system. This system increases the number of degrees of freedom over the initial low-order AO system by nearly a factor of five, and will deliver diffraction-limited images in more challenging seeing conditions. Development of the high-order system is part of the joint New Jersey Institute of Technology/NSO Major Research Instrumentation program funded by the National Science Foundation (NSF) and led by Thomas Rimmele. The system is now being refined to become an integral part of the operating system at the Dunn Solar Telescope (DST), and should be completed by the end of the calendar year. The high-order AO system for the Big Bear Solar Observatory 65-centimeter telescope will follow several months later.

*

SOLIS is nearing the final testing and debugging phase. The new Rockwell cameras have been tested and some anomalies are being resolved in cooperation with Rockwell. We expect the three SOLIS instruments to be acquiring sunlight by late March or early April.

*

Following the October 2002 ATST workshop, the ATST Project has concentrated on investigations of enclosure designs and systems error budgeting. The hybrid concept presented in the last *Newsletter* and other efforts can be viewed at *atst.nso.edu*. Considerable effort has been devoted to understanding dome seeing. ATST personnel met with NSF Division of Astronomical Sciences management, NASA, and AFOSR representatives to discuss project schedule and progress, including the need to begin procurement of some long-lead items to maintain the schedule in the ATST proposal and Decadal Survey. The schedule calls for completion of the ATST by the end of the decade. The principal long-lead item is the primary mirror. Because it takes about a year to procure, and twenty or more months to prepare a blank for polishing, waiting to order the mirror until the start of construction will extend the project by approximately two years. The meetings did not identify an immediate solution for obtaining long-lead items, but several options were revealed and the project is currently exploring these. The final site survey tower and instruments are now installed, so all six sites are up and operating. By the time this is published, the sky brightness and dust monitors should have been tested and installed.

*

Recent and pending changes in the operations of the Evans Solar and Hilltop Facilities at Sacramento Peak will have some user impact. Due to continued level funding from the NSF for operations and reductions in Air Force support, we have reduced the hours of operation and available support at the Evans Solar Facility. This facility houses what is still one of the largest and most versatile coronagraphs in the United States. We will now operate the synoptic coronal emission line program three times per week and the Ca II K-line program twice a week. There will be no observing support for other programs; however, proposals from scientists who wish to, and can, operate the facility themselves (after some instruction) will be considered. Now that the Air Force ISOON facility at Sacramento Peak is delivering high-quality Hα and white-light images, we intend to phase out the Hilltop Facility's Hα flare patrol and white-light imaging (both of which still use film), as well as the daily sunspot drawings. Issues regarding the archiving of ISOON data will be addressed first. Sunspot numbers will be generated from ISOON images. We will continue the video Hα program, which provides a live image for target selection, and is available on the Web. Once ISOON is in regular operation, the plan is to supplement these images with high-quality ISOON images.

*

We are delighted to have two long-term visiting scientists join us this year. Dr. John A. (Jack) Eddy will be in Tucson, working on a strategic plan for addressing the Sun-weather-climate (S-W-C) segment of the NASA Living with a Star Program. This effort includes chairing a series of working group meetings of a select group of scientists from appropriate disciplines to address the S-W-C question in the framework of interdisciplinary systems science. Dr. Alessandro Cacciani of the University “La Sapienza” of Rome, Italy began his 12-month tenure in January as a National Research Council Senior Associate at Sac Peak. While here, he will design and construct a magneto-optical filter system and telescope, which measures velocities and magnetic fields in the solar atmosphere.

*

We also welcome Electronics Engineer Tony Spence and Senior Electronics Technician Dylan Sexton to the technical staff at NSO/Sac Peak, where they are supporting the electronics efforts at the DST. They bring a range of experience and training that is already paying off for our users and projects. Tony comes to us from the Physical Science Laboratory at New Mexico State University. He has a strong background in hardware modifications and maintenance, with an interest in instrumentation, sensors, and measurements. Dylan's background in electronics began in the US Coast Guard and most recently involved radio frequency work in the Dallas area and at Los Alamos National Laboratory.

ATST Design Progress

Nathan Dalrymple, Mark Warner, Rob Hubbard & Jim Oschmann

Since holding the Advanced Technology Solar Telescope (ATST) Design Workshop last October, the ATST team has been working to implement several suggestions, and working toward the Conceptual Design Review (CoDR) to be held this summer. As recommended at the workshop, the primary area of concentration is on design, analysis, and testing to support the enclosure trades, to be completed by the next review. Here, we highlight a few key aspects of recent and ongoing engineering efforts in systems, mechanical, and thermal engineering.

Thermal Design

Thermal aspects of our design are major concerns for the ATST, since roughly one kilowatt per square meter of solar radiation strikes the primary mirror and enclosure during daytime observing. One area of emphasis is on the thermal control of the enclosure skin (or floor, in the case of a retractable enclosure). Left uncontrolled, dome skin (or floor) temperature will rise some tens of degrees above the ambient air temperature, producing plumes of hot air over the enclosure that blur the optical beam. One simple solution is to circulate ambient air on the bottom side of the enclosure skin. The Gemini domes possess skin-flushing systems, but the capability has never been tested. A collaborative experiment is planned for February 2003 in which the Gemini dome skin temperature will be monitored at several locations throughout the day with the skin flushing system both on and off. The measured skin temperatures and airflow rates will help validate thermal models of the enclosure (see figure 1).

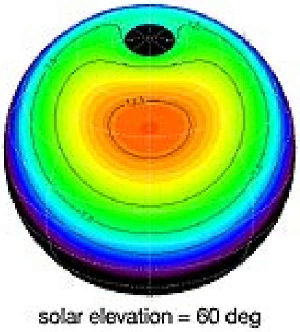

Figure 1. Enclosure skin surface temperature (˚C) predicted by a preliminary thermal model. Assumptions: approximately spherical enclosure; dual skin cooled by active flushing of ambient air; low-emissivity surface (for comparison with Gemini test results); 5 m/s wind; 60˚ solar elevation.

The validated model will then be applied to predict thermal and seeing performance of several ATST enclosure concepts. Design efforts for other thermal subsystems are proceeding along similar lines: analytical and numerical models are being developed to be validated by comparison to measurements, and then applied to concepts to assist the design selection process.

Mechanical Engineering

Recent mechanical design work has focused on updating and refining the 3D SolidWorks model of the telescope mount, optics support structure, pier, and coudé lab (see figure 2). Using this model as a baseline, a series of finite element analyses (FEA) also have been started. This initial FEA effort will serve two basic purposes leading up to CoDR: 1) validate the conceptual structural layout of the telescope assembly; and 2) determine the first-order effects of wind-induced vibration on the assembly. The issue of wind on the structure is particularly important in helping to determine the viability of the various enclosure concepts currently under consideration.

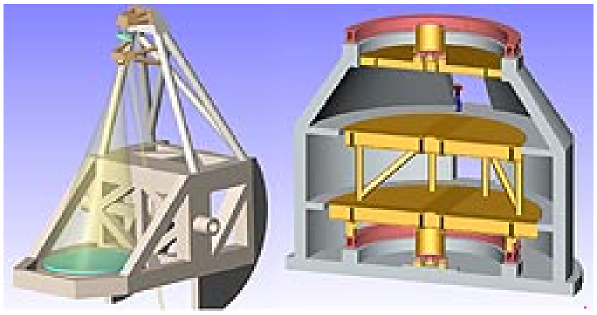

Figure 2. Telescope and coudé area 3D model being prepared for finite element analysis.

A first-order design and FEA of representative floor loading in the coudé area is shown in figure 3. It was done to size and orient major support aspects of the floor, assuming four major instrument stations per level of rotating coudé lab space.

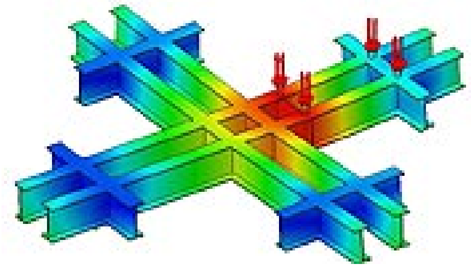

Figure 3. Coudé lab floor loading FEA analysis.

The analysis gives floor deflection due to gravity, measured in microns. The maximum deflection is 20 microns. This is representative of the level of detail contained in the three-dimensional models being prepared for more extensive wind and vibration analysis.

continued

ATST Design Progress continued

Systems Error Budgets
As with any modern telescope project, a well-founded systems approach is essential to the ultimate success of the effort. A fundamental element of the ATST systems engineering effort is the development and aggressive tracking of a set of performance error budgets. Starting with the science requirements, we have identified several critical error budgets that include telescope polarization, throughput, scattered light behavior, and various aspects of image quality. For example, one of the highest-priority (and most challenging) performance requirements placed on ATST designers is for diffraction-limited visible-light images. The science requirement, in this case, is for Strehl ratios greater than 0.6 under good seeing conditions. Overall performance will be degraded by telescope limitations (like optical imperfections in the primary and secondary mirrors), instrumental limitations, and ultimately, by the performance of the adaptive optics system.

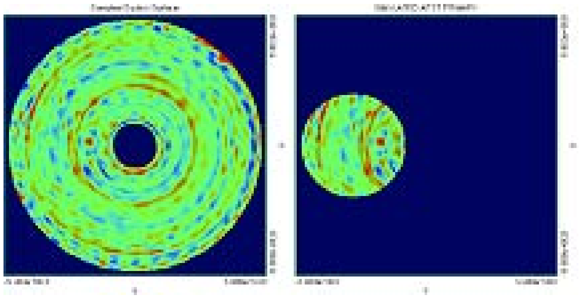

Figure 4. Gemini South 8-meter mirror figure errors after removing 20 low-order Zernike terms (left). This is a good starting point for estimating the performance of the ATST mirror with only low-order correction applied. The section on the right will have additional higher-order terms removed to simulate the effects of our 1000-degree-of-freedom adaptive optics system. This will yield an estimate of residual primary mirror error to be folded into the image-quality error budget.

The error budgeting process begins like a financial budget. The available error is divided ("budgeted") among the various telescope components ("departments") in the system. Then the various budgets are refined using existing data from similar projects, engineering data, manufacturer's input, and computer models. An example appears in figure 4, where we are using manufacturer's data from the finished Gemini primary mirror to better estimate the performance of our own off-axis 4-meter telescope. The project is also evaluating statistical tools to refine and bound error estimates, using some simple commercial packages now available.

For further details about the ATST Project, visit *atst.nso.edu*.

SOLIS

Jack Harvey (NSO)

The last few months exposed some technical problems that set back the SOLIS project. Two problems seriously affected the Vector Spectromagnetograph (VSM). As noted in the last SOLIS report, the high-reflectivity coatings failed on all of the VSM reflective optics. The cause of this failure has not been discovered, in spite of thorough investigations, including electron microscopy and electron beam probing of the failed coatings. We have eliminated the VSM housing as the source of the problem. To get back on track, all of the spectrograph optics, except the grating and an easily accessible fold mirror, have been coated with protected gold. The disadvantage is a few percent loss in overall system efficiency, and higher polarization retardation at the shortest wavelength we use. The retardation issue is minor since the design of the optical system uses canceling reflections to null retardation effects. The advantage is highly stable coatings on optics that are hard to reach inside the instrument. As of this writing, the spectrograph optics have been remounted in the VSM housing and are being aligned.

The primary and secondary telescope mirrors were recoated with improved, high-reflectivity coatings. Thermal control requires use of broadband, high-reflectivity coatings in the telescope. Since a few days after they were recoated, these recoated mirrors have been kept in a sealed environment flushed with either helium or nitrogen gas . Inspection shows no indication of deterioration. Once the spectrograph optics are realigned, the telescope mirrors will be installed and kept in an inert atmosphere as much as possible.

The second major VSM problem involves two cameras that image the split final focal plane of the instrument. These cameras, from Rockwell, have hybrid focal plane arrays consisting of a silicon-sensing layer bound to a CMOS readout multiplexer. The sensors are cooled thermoelectrically to -17°C

continued

SOLIS continued

within vacuum dewers. The format is 1024 × 1024 pixels, but we only illuminate the central 1024 × 256 portion and skip over the unused regions. The arrays are divided into four quadrants that are read out simultaneously at a frame rate of 92 per second.

We have observed strong cross talk between quadrants that are adjacent in the row direction. There is also a smearing of about 100 pixels along rows. Curiously, these effects nearly vanish if the array is operated at room temperature rather than being cooled. Experts at Rockwell are working closely with us to correct this anomalous behavior. If a good solution is not found, we will simply operate the arrays at a higher temperature and compensate for higher noise by using longer integration times.

Some fail-safe circuitry was added to shut down the cameras in case either our system-wide glycol cooling system fails or the thermoelectric cooling of the arrays acts improperly.

Laboratory tests of the Integrated Sunlight Spectrometer (ISS) are continuing. Until the VSM is moved to the GONG site, it is not possible to feed sunlight into the ISS. The emphasis of the lab tests is on perfecting the flat-field method. Construction is underway on a small ISS ancillary system called the extinction monitor. This consists of a camera that simultaneously produces five small images of the Sun at five widely separated wavelengths. These images will be recorded and used to understand the extinction produced by Earth's atmosphere at times when ISS spectra are taken. This will allow the uniformity of integration of the solar disk to be assessed for all spectra.

Infrared Heterodyne Observations at the McMath-Pierce West Auxiliary Telescope

Guido Sonnabend & Daniel Wirtz (University of Cologne)

During the last two weeks of November, the Cologne Tunable Heterodyne Infrared Spectrometer (THIS) was successfully operated at the McMath-Pierce West Auxiliary Telescope. Our heterodyne instrument consists of an optical receiver and common back-end electronics, including an Acousto-Optical Spectrometer (AOS). Inside the receiver, the monofrequency emission of a local oscillator (LO) is mixed with the infrared (IR) radiation coming from the telescope, and is detected on a fast Mercury-Cadmium-Telluride (MCT) detector. In this way, the spectral information is shifted from the mid-IR to the radio range, allowing amplification, filtering, and frequency analysis of the signal using a standard back-end. A photo of the setup at Kitt Peak is shown in figure 1, and a simplified schematic of the receiver appears in figure 2.

Currently, the receiver employs tunable Quantum-Cascade Lasers (QCL) as local oscillators that allow frequency tuning between 8- and 17-microns. These devices significantly expand the frequency region accessible with gas-laser systems (e.g., CO_2 lasers). At present, a frequency resolution of 3×10^7 can be provided, which corresponds to 1 megahertz at a wavelength of 10 microns. The bandwidth is currently limited to 1.4 gigahertz and will be expanded to twice that value soon. The sensitivity of our instrument is comparable to common CO_2 laser systems.

continued

Figure 1: THIS at the McMath-Pierce West Auxiliary Telescope. The cubic aluminium structure on the left is the optical receiver; the 19-inch rack on the right holds the AOS and back-end electronics.

Infrared Heterodyne Observations continued

The engineering run at Kitt Peak explored the sensitivity and frequency stability of the instrument, with a variety of different measurements. First, stratospheric ozone absorption lines were detected against the Moon as a background source. One has to take into account that the Moon's brightness temperature at 10 microns is already down to 20 K. Figure 3 shows 1,600 seconds of integration of an ozone line with a resolution of 1 MHz. The plot shows the detected brightness temperature versus the intermediate frequency, i.e., the observed frequency from the LO position. Due to the transmission at an observing angle of about 35 degrees and losses caused by the coupling of the instrument to the telescope, a background temperature of about 8 K results.

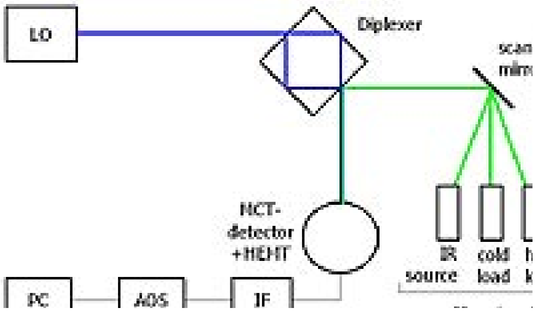

Figure 2: Set-up schematic of the receiver: laser (LO) and signal (switchable between telescope and two loads for calibration) are combined and focused on the detector. After filtering and amplification, the frequency analysis is done using an AOS.

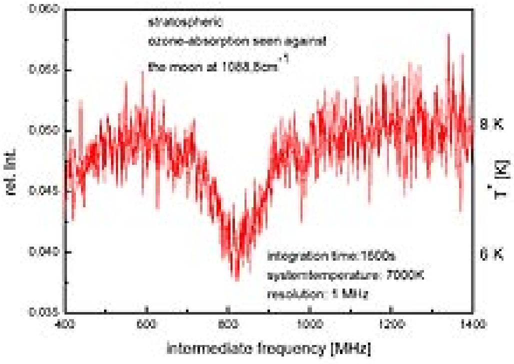

Figure 3: Stratospheric ozone absorption seen against the Moon at a frequency of 1088.8 cm^{-1}.

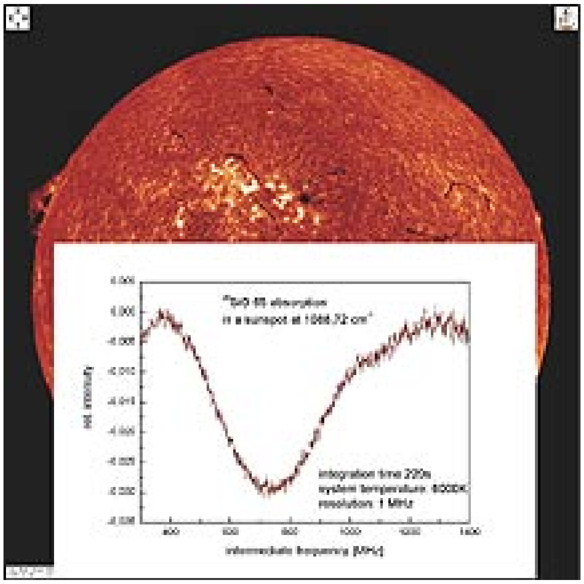

Figure 4: Hα picture of the Sun on 20 November 2002, and the 6–5 P(50) transition of $^{26}Si^{16}O$.

SiO and H_2O absorption lines were also measured in sunspots. Both were detected in the November 20 sunspot shown in figure 4. One can see the rather odd line shape of this SiO absorption feature, which is caused by contributions of different velocity components.

We observed Venus to demonstrate the system sensitivity, especially with regard to future astronomical observations. Since the 1970s, it has been known that natural non-LTE CO_2 emission is present at the illuminated arc. We were able to detect an emission signal of the R(36) transition of CO_2 with a resolution of 20 megahertz (see figure 5). One can see the emission peak sitting on a broad CO_2 absorption that stems from lower altitudes of the Venus atmosphere. It appears that the emission originates at around 80 to 120 kilometers above the surface. There still has to be a proper calibration carried out for this measurement. In particular, a comparison to a calculated atmospheric

continued

Infrared Heterodyne Observations continued

model of Venus has to be done. Keeping this in mind, the temperature of roughly 200 mK for the emission might be wrong by a factor of two.

Having been able to detect a nonterrestrial signal for the first time with THIS, we are looking forward to further observing runs in 2003. Possible targets include ozone observations on Mars that are of great interest for understanding the Martian atmosphere. Furthermore, CO_2 observations and monitoring in Earth's atmosphere and on Mars and Venus are very interesting for the same reasons. The long-term goal is the operation of THIS on the stratospheric observatory SOFIA from roughly 2007 onward. The main goal here will be the detection of cold interstellar H_2 against moderately hot IR sources at wavelengths around 17 microns.

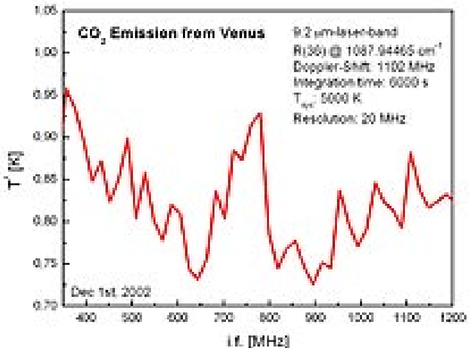

Figure 5: Non-LTE R(36) transition of CO_2 from the illuminated arc of Venus. The emission is located in the middle of the broad CO_2 absorption peak.

Infrared Observations with McMath-Pierce Adaptive Optics

Christoph Keller & Claude Plymate

The prototype adaptive optics system at the 1.5-meter McMath-Pierce Solar Telescope achieved two "firsts" on 22 January 2003. For the first time, solar images in the thermal infrared at 4.8 microns were corrected with adaptive optics. An image of a sunspot close to the solar limb is shown in figure 1. Note the substantial improvement in spatial resolution when using the deformable mirror. On the same day, the system successfully corrected images of the solar limb. This has never been done before with any solar adaptive optics system.

The 37-actuator system was operating with 109 subapertures on the wavefront sensor at an update rate of 955 hertz. More details about the system can be found at *www.noao.edu/noao/staff/keller/irao.*

By the time that this article appears, the prototype system will be available for user observations on a limited, shared-risk basis.

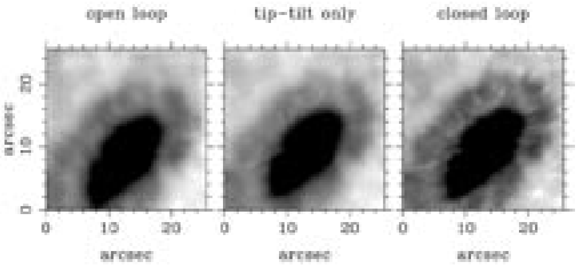

Figure 1: Average of 20 short-exposure images of a sunspot close to the solar limb, observed through a broadband interference filter at 4.8 microns with the McMath-Pierce adaptive optics system. The image on the left was recorded with the adaptive optics system off, the center image was recorded with tip-tilt correction only, and the image on the right was recorded with full adaptive optics correction. All three images are displayed at identical contrast.

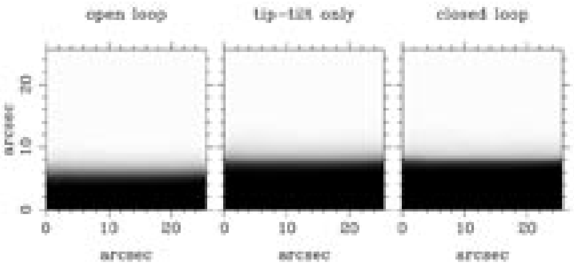

Figure 2: The solar limb at 4.8 microns. With no correction (left), tip-tilt (center), and full adaptive optics correction (right).

The Improved Solar Observing Optical Network (ISOON)

Donald Neidig (Air Force Research Lab/NSO)

The Improved Solar Observing Optical Network (ISOON) was completed during FY 2002 through prototype demonstration, although the US Air Force subsequently canceled its deployment as an operational system at three sites worldwide. Ownership of the functioning ISOON prototype system has been transferred to the Air Force Research Laboratory at NSO/Sacramento Peak, where it will be used for research and limited support to Space Weather forecasting. ISOON represents a class of instrumentation intermediate between 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 semiautonomous, remotely commandable system that provides imaging in Hα, continuum, and line-of-sight magnetic fields. It features high-precision 12-bit photometry, registered images with constant magnification and orientation, and a 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, counts, point and click for zoom, 30-day database, intensity measurement tools, and others.

Additional information on ISOON as well as real-time images and movies are available at *www.nso.edu/sunspot/isoon/descript.html*.