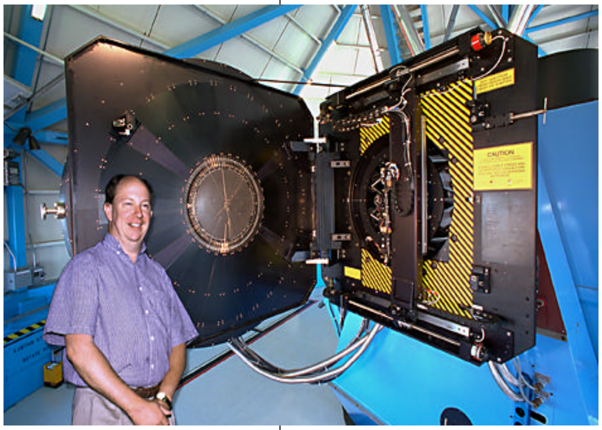
The primary emphasis in the NOAO nighttime program is the construction of optical and near-infrared instrumentation that takes advantage of the wide fields of view offered by the 4-m class telescopes at both sites.

This strategy follows from our assessment that much of astronomy in the early 21st century will depend on publicly available surveys that have been designed to isolate well chosen samples of different classes of objects.

The telescopes accessed through NOAO, including the Gemini telescopes, constitute an observing system, each performing the distinct role for which it is best suited. The Gemini telescopes are optimized for superb image quality over narrow fields of view and with adaptive optics in the infrared. The NOAO telescopes are designed to realize the intrinsic site seeing over fields up to 1° across. In the NOAO nighttime instrumentation program, therefore, the emphasis is on building wide-field instruments to conduct imaging and spectroscopic surveys.

The two highest priority new starts are 4K × 4K IR imagers and a moderate-resolution, wide-field high-throughput spectrograph. The Wide Field of View IR Imager will be used on both the 4-m and the 2.1-m telescopes. At the 2.1-m it will have 1,400 times the field of view of the Gemini IR imager. Surveys that need to cover significant areas to moderate depth will require 1/3 less time at the 2.1-m and will not need scarce Gemini observing time. Similarly, so long as the required 4-m exposure time is less than about one night, the wide-field optical spectrograph will be more efficient than the GMOS spectrograph at Gemini for surveys in the intermediate brightness regime.



Hydra, a fiber spectrograph, and an 8K × 8K CCD mosaic imager *have been deployed at KPNO and CTIO. Both instruments exploit the wide fields-of-view available at WIYN and the 4-m telescopes.*

The other major instrument efforts will be to implement a tip/tilt system on WIYN, which has the goal of improving optical image quality over a 4 arcmin field of view, and in 2002, to start a laser guide star AO system for SOAR.

The NOAO in house instrumentation program will be supplemented with instrumentation obtained from outside groups, usually in return for a commitment of telescope time. At CTIO, these instruments include: 1) the Bernstein-Tyson Mosaic Imager, which has been an exceptionally reliable and productive instrument but which will be withdrawn from service when the NOAO Mosaic is deployed; 2) the Rutgers Fabry-Perot; 3) OSCIR, a mid-IR camera from the University of Florida; and 4) OSIRIS, the Ohio State near IR imager-spectrometer. At KPNO, these instruments include: 1) ONIS, a second IR imager/spectrometer from Ohio State; and 2) Flamingos, an infrared imager and multi-object spectrometer currently under construction at the University of Florida.

The instrumentation that we expect to offer to the community during the next five years is listed in an Appendix.

Technology research and development will emphasize three areas: 1) acquisition, characterization, and optimization of detectors to maintain the NOAO tradition of having the best suite of detectors available anywhere; 2) optical fibers, including applications in the near infrared; and 3) volume-phase holographic gratings, which offer very high efficiency and enable innovative spectrograph design.

The Phoenix spectrograph can achieve resolutions of up to R = 100,000 from 1-5 microns. *It will be used to study the processes leading to the formation of stars and planets.*

Gemini Instrumentation

The international Gemini project is committed to a strategy of obtaining instrumentation from the partner countries. A major task for NOAO is to ensure that the capability exists within the US to provide the complex instrumentation that will fully exploit the capability of these superb telescopes. NOAO is already committed to building the Gemini Near Infrared Spectrometer and is completing work on the near-IR and CCD array controllers. It will modify the Cryogenic Optical Bench to serve as the commissioning instrument for Gemini South, and may modify Phoenix for use at Gemini. NOAO is also overseeing work on the Near Infrared Imager at Hawaii and the mid-infrared imager/spectrometer at Florida.

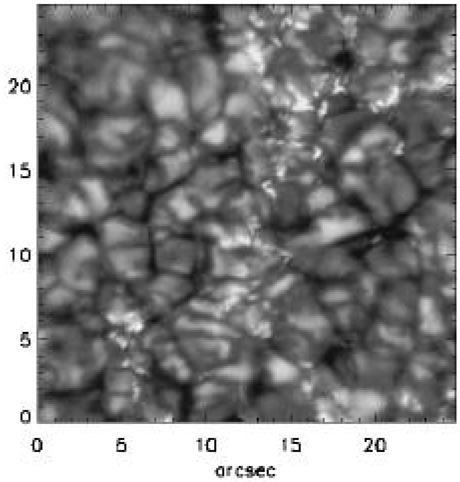
The challenges of building Gemini instruments are many. The instruments must be built to more exacting standards of image performance, long term stability, and reliability than has traditionally been required. The costs are likely to be typically at least $5M per instrument, or twice what NOAO has spent on its most expensive 4-m instruments. Gemini does not fully fund the instruments, which means that subsidies must be found from some source in the US. The management challenges of controlling cost and schedule for instruments of this complexity, size, and degree of innovation have not been fully met by any of the US astronomical instrumentation groups to date.

NOAO will take the lead in addressing these challenges in the US. We must first devise ways of engaging the community in developing the strongest possible proposals for the conceptual design phase so that the US submissions are competitive with those of the other Gemini partners, who have consistently invested more of their own funds in preparing these proposals than has the US. Then we must find the best way to realize those conceptual designs. In some cases, this will mean having the construction done by a university group. In other cases, it may mean forging a collaboration between the leader of the conceptual design phase and an engineering group with the capability of building the instrument. In some cases, NOAO may contract for subsystems and assume responsibility for system integration. In other cases, NOAO itself may take the full responsibility. In all cases, NOAO must be prepared to provide management oversight and support, and it must also have on staff the core expertise in systems, opto-mechanical, electronics, software, and detector engineering required for this class of instrumentation so that it can, as appropriate, assist community groups or take on Gemini instrumentation itself.

The NSO instrumentation program is focused on the development and implementation of the enabling technologies that will be central to the Advanced Solar Telescope and a strong program of understanding solar magnetic variability.

The primary areas of instrumental initiatives in the NSO are the adaptive optics program and the infrared program. Instrument development and scientific applications in these areas rely on the unique capabilities of the Dunn Solar Telescope and the McMath-Pierce Solar Telescope Facility, respectively. In addition, development of near-infrared capabilities at the Evans Coronal Facility will lead to the direct measurement of coronal magnetic fields.

Adaptive optics (AO) corrects for atmospheric distortion of the wavefront in order to achieve diffraction-limited imaging from groundbased telescopes. It is a technology that will make it possible for solar astronomers to address fundamental scientific problems, such as the structure and dynamics of magnetic flux tubes, wave propagation along magnetic elements, and generation and dissipation of small scale magnetic fields.



The solar AO program at Sacramento Peak *has recently achieved a major milestone: the control loop was closed for the first time with solar granulation and small pores as the wavefront sensing target during tests at the Dunn Solar Telescope (DST). The system is designed to correct about 20 spatial (Zernike) modes of atmospheric turbulence. Improved resolution and a reduction of residual jitter were both clearly evident.*

The next stages of the adaptive optics program will have the following goals:

- Speed the operation of the system beyond the current 25 Hz, which is adequate for full atmospheric compensation only under conditions of best seeing and make the AO system and AO-optimized post-focus instrumentation available to the solar community
- Upgrade the Advanced Stokes Polarimeter and other post-focus instruments to support diffraction-limited observations
- Develop a high order AO system with 100 degrees of freedom, which is adequate to achieve atmospheric compensation at the DST under median seeing conditions and diffraction-limited imaging in the near-infrared under good seeing at the McMath-Pierce.

NSO has pioneered the exploration of the solar infrared spectrum. NSO's contributions include all the modern spectral atlases in the range 1.5-18 microns; the discovery and exploitation of the most magnetically sensitive spectral lines known to date; discovery of pervasive spatial and temporal variability in the temperature-minimum region; and the characterization of transient, small-scale magnetic fields in intergranular lanes. Future research will analyze subkilogauss magnetic fields in the photosphere, the magnetic field in the corona, and the complex structure of the chromosphere.

The primary infrared instrumentation effort will be to deploy the 1K × 1K InSb arrays developed under the leadership of NOAO and to collaborate with Rockwell International in the development of fast, deep-well arrays for high precision polarimetry in the spectral region 1-4 microns.

The current NSO instrumentation program is well focused on technologies that will play key roles in implementing and fully exploiting the Advanced Solar Telescope (AST), SOLIS and GONG extensions. Both the adaptive optics and infrared programs are critical to development of the AST. Programs to improve visible and infrared detectors, including very high-speed cameras needed for adaptive optics, telescope control, and polarization measurements for vector magnetometry will provide enabling technology for the AST. Appendix G summarizes these programs.

The observing facilities and instruments offered by NOAO constitute an observing system that will enable a broadbased attack on fundamental questions ranging from the causes of solar activity to the evolution of galaxies in the early universe.

The KPNO and CTIO telescopes offer wide fields of view that are well-suited for imaging and spectroscopic surveys. The Gemini telescopes will provide superb image quality, adaptive optics, and optimization for the thermal infrared. The MMT offers a moderate field-of-view at large aperture, a mosaic imager, multi-fiber spectrograph, and thermal IR instrumentation. The HET is well suited for spectroscopy at very large aperture of single objects and, because of queue scheduling, of variable objects and targets of opportunity.

KPNO, CTIO, and NSO Telescopes

All three NOAO sites have completed projects to bring the imaging performance of existing telescopes up to modern standards. At the Dunn Solar telescope on Sacramento Peak, improvements in thermal control and in the performance of the entrance window have resulted in consistently better image quality. At the Blanco 4-m telescope on Cerro Tololo and the Mayall 4-m telescope on Kitt Peak, multi-year efforts resulted in the installation of active support and thermal control systems for the primary mirrors, ventilation of the domes, replacement of servo systems, and a variety of other improvements that have resulted in median image quality that is at or just below one arcsec. The remaining major project at the Blanco will be improvements to the performance of the tip/tilt secondary. A tip/tilt system is also being developed for the WIYN telescope. Modifications are in progress at the Blanco telescope to accommodate the 8K × 8K mosaic CCD imager and the Hydra spectrograph.

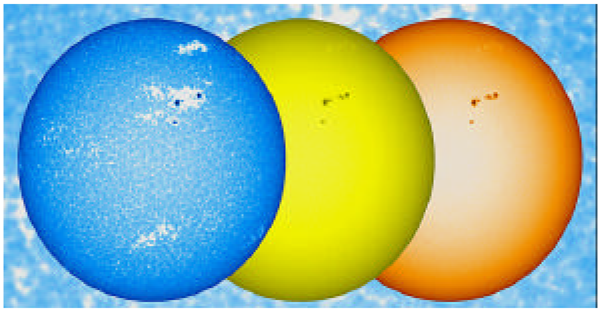
KPNO will install a new guider-rotator with a higher load-bearing capacity and larger field of view at the 2.1-m to accommodate a 4K x 4K wide-field IR survey instrument. CTIO plans to upgrade the optics at the 1.5-m and to reconfigure the instrument package to minimize instrument changes.

The smaller nighttime telescopes are more than 30 years old and suffer from limitations inherent in the designs that were employed at the time they were built. KPNO has already closed two smaller telescopes (an 0.9-m and the 1.3-m) and returned the Burrell Schmidt to its owner, Case Western. CTIO has similarly returned the 1.0-m telescope to Yale. No upgrades are planned for the remaining smaller telescopes at either KPNO or CTIO.

Dome Ventilation
Openings have been installed in both the CTIO and KPNO 4-m domes in order to improve image quality by equalizing temperatures inside and out through natural ventilation.

The 0.9-m at KPNO is currently in high demand because of the availability of the Mosaic CCD imager but will be closed when application pressure diminishes. The Coudé Feed at KPNO, which offers a resolution up to 250,000 that is available nowhere else, will be kept operational as long as funding allows. CTIO will operate the 0.9-m and the Burrell Schmidt as long as funding permits and the quality of the science justifies it.

NSO plans to replace the obsolete telescope control system at the McMath-Pierce Facility. When the Advanced Solar Telescope is built, it will replace both the McMath-Pierce Telescope and the Dunn Solar Telescope. While no major upgrades to these facilities are planned, both facilities will play integral roles in developing the technologies needed for the Advanced Solar Telescope.

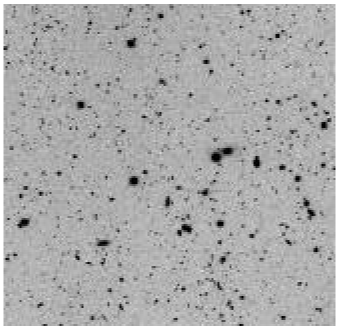


The Precision Solar Photometric Telescope (PSPT) project consists of a network of three specialized telescopes to provide high photometric precision and high spatial resolution full-disk solar images in the Ca II K line and two other continuum wavelengths. These images can be used to study the irradiance contribution of various solar features, ranging in size from small magnetic field elements to large active regions, and to characterize the global temperature structure. NSO will seek funds to operate PSPT for at least a full eleven years to provide data for all phases of the solar cycle.

PSPT/RISE
Images of the Sun in the light of Ca II (left) and two continuum bands obtained with the PSPT telescopes. Quantitative measurements of these images will be used to understand what causes small changes in the total amount of energy emitted by the Sun during the course of the 11-year solar cycle.

At both solar and nighttime telescopes, the emphasis will now turn to instrumentation.

How did galaxies and quasars evolve in the early universe? *Answering this question requires observations with many different facilities, each optimized for a different task: i.e.,* ***an observing system.***

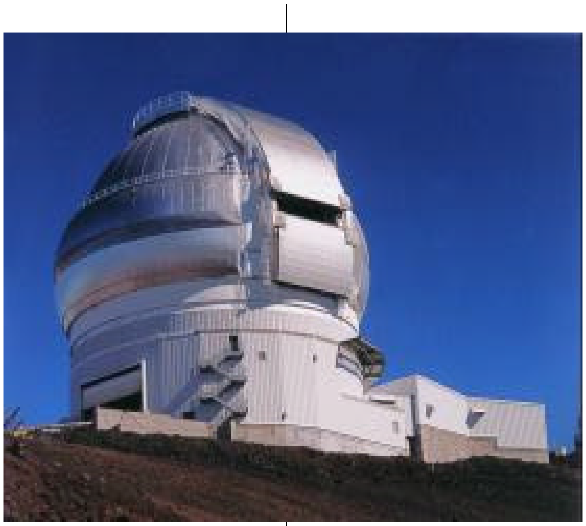


Step 1: *Find the objects with deep, wide-field* ***imaging surveys with 4-m telescopes.***

Step 2*: Classify thousands of objects automatically by color and morphology with* ***software tools*** *(FOCAS, APPHOT)*

Step 3*: Obtain spectra to confirm identifications and obtain redshifts (4-m class telescopes) and to study composition and kinematics* ***(Gemini-class telescopes).***

Gemini and Other Large Telescopes



Gemini North Telescope on Mauna Kea. *Among the new generation of large telescopes, Gemini will be unsurpassed in image quality and performance in the infrared.*

During the next five years, the NOAO user community will gain its first access to the Gemini telescopes. Operational handover of Gemini North is scheduled for 2000 and of Gemini South in 2002. NOAO is responsible for science planning for Gemini in the US and for delivering US-built instruments to Gemini. NOAO is also expected to support the US users of Gemini in all phases of their activities before and after observing runs.

Primary tasks include receiving and reviewing proposals; ensuring that adequate manuals and descriptions of scientific performance are available; answering questions from observers who are planning proposals and reducing data; providing software for reductions of the data; and providing US access to the archive. Except for telescope operations, ***NOAO responsibilities for US users of Gemini are identical to our responsibilities for users of KPNO and CTIO.***

Beginning sometime in the year 2000 and for six years thereafter, we will also be providing access to 27 nights each per year on the HET and the MMT. In the case of the HET, which will be operated in queue mode, NOAO will act as a single user, forwarding approved proposals, receiving data in return, and forwarding that data to the community. Successful proposers to the MMT will be expected to make their own observations. This observing time has been supplied in return for NSF support of instrumentation for these two telescopes. Any expansion of this program to other independent observatories will depend on what applications are received by the NSF.

Finally, NOAO has provided a detector for an IR telescope at the South Pole in return for community access. The time was oversubscribed by a factor of about six to one. This program will conclude in FY 1999, but a new South Pole consortium is being formed, and NOAO is exploring the possibility of continued public access should a new telescope be built at the Pole.

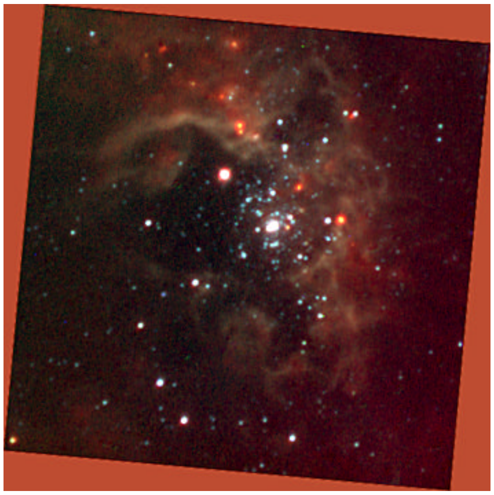
As part of our evolution toward an integrated observing system, we intend, over the next few years, to explore the scientific value and mechanisms needed to integrate space-based programs into the system.

In order to accommodate these larger responsibilities for access, NOAO has already revised its procedures for applying for observing time so that a single proposal form and a single deadline will apply for first phase proposals for all telescopes accessed through NOAO. We will expand the number of time allocation committees (TACs) as required so that no single committee has to read significantly more than 100 proposals. The TACs are currently divided according to broad science areas (galactic and extragalactic) and largely by north and south, but with a special combined TAC for survey proposals. We will add TACs as required to handle Gemini proposals, and we are considering whether successful Gemini proposals should automatically receive whatever supporting time is required on other NOAO telescopes. We are now working with Gemini and the other partners to provide documentation, user support through help desk software, etc., with minimum duplication of effort.

Observing Modes and Data Products

Users of NOAO facilities will have very different requirements and expectations in the future. New telescopes in space are likely to create a greater demand for groundbased data but a lower demand for conventional observing time, where the observer is actually present at the telescope. We already see this effect in solar astronomy, where groundbased data are needed to put space data in the context of the activity cycle and to characterize active regions on the Sun. We are likely to see a similar phenomenon in nighttime astronomy, where there will be a requirement for optical identifications, spectra (the optical region remains the one richest in spectral diagnostics), and photometry in order to interpret space observations. We are also likely to see a growing demand for simultaneous observations at multiple wavelengths and of variable objects (e.g., supernovae and MACHO events) and targets of opportunity (e.g. gamma-ray bursters). As noted earlier, we also see a growing requirement for targeted surveys to define well chosen and unbiased samples of objects for detailed study.

This changing environment mandates that NOAO support new ways of acquiring and delivering data. NSO plans to experiment with providing "pre-packaged" suites of data focused on targeted areas at specific times, such as a potential flaring active region, using multiple instruments and facilities. KPNO and CTIO will move toward greater diversity in observing options with the goal of providing more support for larger survey programs and also for shorter "snapshot" observations of specific fields, variable objects, and targets of opportunity. An opportunity to conduct surveys, with the condition that the data be made publicly available, has already been announced, and NOAO is taking the lead in conducting a very deep IR/optical imaging survey that will identify distant galaxies at the spectroscopic limit of Gemini-class telescopes. We will explore the feasibility of extending the WIYN queue observing mode as well as service observing to additional telescopes; it may be a reasonable goal to have the capability for quick response imaging available at all times on at least one telescope in each hemisphere. We will develop the procedures necessary to treat the NOAO telescopes as a true observing system, with observers able to submit a single proposal for a scientific program involving any combination of the telescopes accessed through NOAO—including CTIO, KPNO, Gemini, and the independent observatories. We will also explore the desirability and feasibility of joint scheduling with spacecraft.



Star Formation in the 30 Doradus Nebula
An infrared image from the South Pole of the 30 Doradus Nebula. This giant ionized complex, filled with hot young stars, is located in the Large Magellanic Cloud. The long, dry, bitterly cold Antarctic night is uniquely suited for observations of newly formed stars, which are embedded in dust and observable only in the thermal infrared.

The table below shows, as one example, how ***space- and groundbased telescopes will combine to form an observing system*** to produce a complete picture of the formation of accretion disks and the subsequent transformation of these disks to planetary systems.

Observing System:
Star Formation, Evolution of Accretion Disks, and the Formation of Planets

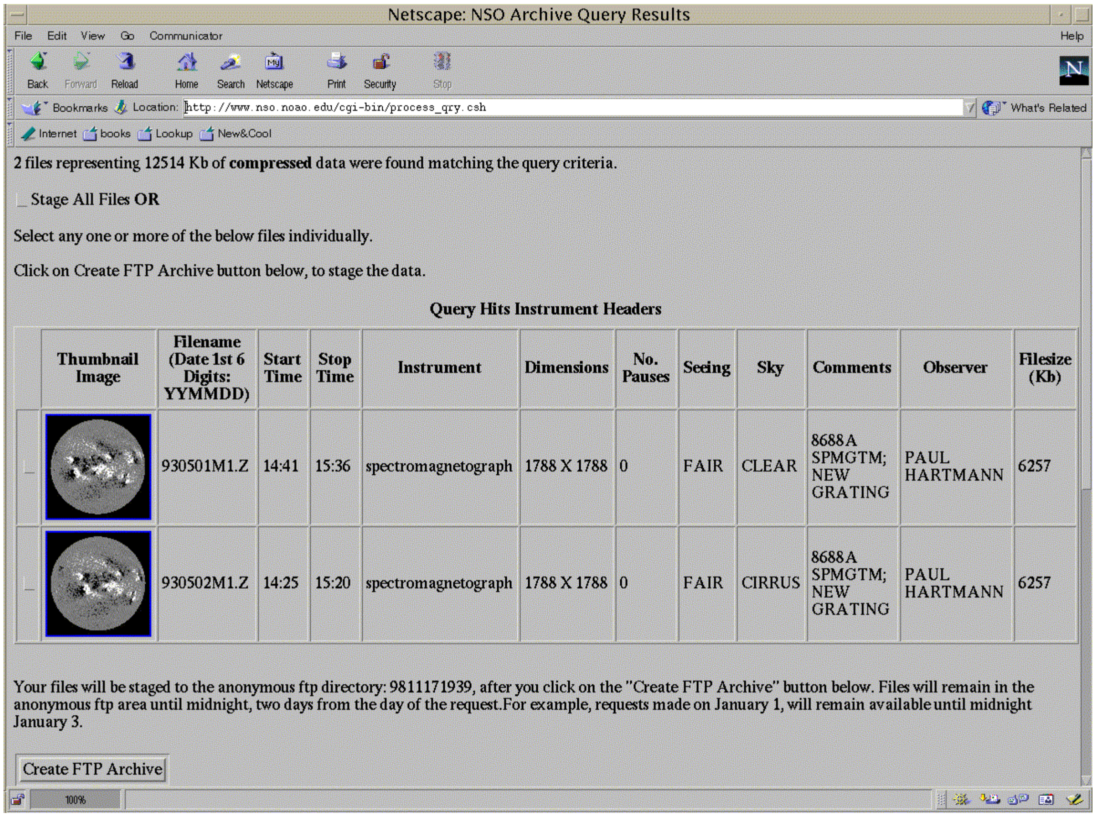
Facility/Instrumental Capability	*Goal of Observations*
Wide-Field 4-6.5 Meter Survey Telescopes	
Optical Imaging Near IR Imaging Optical Sp. (High Res.) Multi-Object OIR Sp.	Identify young stellar objects by OIR imaging and proper motions; characterize magnetospheres, estimate accretion rates, and understand time variations in accretion disks through high resolution spectroscopy
Gemini-Class Telescopes	
NIR AO Imaging NIR AO Sp. (R~1000) MIR AO Sp. (R~300) NIR AO Coronagraphy MIR Sp. (R>30000)	Search for silhouetted disks to quantify disk size as function of age; use spectral types to determine masses and ages; locate close companions; search for kinematic evidence of tidal gaps, which are indicative of when/where planet formation begins
Space-Based Facilities	
SIRTF	Locate candidates, search for inner holes in disks
SIM	Use wobbles in proper motion to infer asymmetric disks
NGST Imaging	Image disks via scattered light
NGST Sp. (Low Res.)	Characterize solid phase mineralogy
NGST Sp. (High Res.)	Determine when, where and how often planets form during accretion phase
Other Groundbased	
MMA	Characterize kinematics of cold outer portion of disk
Supporting Capabilities	
Pipelining, archiving, catalog inquiry	Provide community-accessible list of candidate objects with both optically thin and optically thick disks by combining ground- and space-based survey results to identify objects with IR excesses produced by accretion disks

Data Delivery for the Digital Age

The advent of the Internet is the key enabler of alternate modes of observing and data delivery. The Internet enables direct interaction between astronomers and queue or service observers and makes it possible to distribute the data obtained rapidly. It will also allow observers to schedule observations with SOLIS automatically. The Internet is currently being used to support remote eavesdropping, with one observer present at the telescope while collaborators participate from home. NOAO's WIYN partners have used the Internet to allow students to interact with the observing programs being conducted at the telescopes.

NSO has made its entire set of daily solar images from the Kitt Peak Vacuum Telescope, FTS spectra, and a growing portion of the Sacramento Peak spectroheliograms available on line.

The holdings of the NSO digital library are stored on robotic juke-boxes and are searchable via a web-based interface to a relational database. This system will grow. SOLIS will generate raw data at the prodigious rate of 100 Gb per day, with requirements for rapid reduction, archiving, and user access. A higher capacity storage system will be developed, probably based on either magneto-optical or DVD technology. The next generation of search tools for the Digital Library will contain context-based searches—data will be selectable using quantities computed directly from the data itself, rather than only from information contained in a supplementary header. Digitization of historical photographic solar data sets is in progress and will triple the time span covered by digital solar data.



2 files representing 12514 Kb of **compressed** data were found matching the query criteria.

☐ Stage All Files **OR**

Select any one or more of the below files individually.

Click on Create FTP Archive button below, to stage the data.

Query Hits Instrument Headers

	Thumbnail Image	Filename (Date 1st 6 Digits: YYMMDD)	Start Time	Stop Time	Instrument	Dimensions	No. Pauses	Seeing	Sky	Comments	Observer	Filesize (Kb)
☐		930501M1.Z	14:41	15:36	spectromagnetograph	1788 X 1788	0	FAIR	CLEAR	8688A SPMGTM; NEW GRATING	PAUL HARTMANN	6257
☐		930502M1.Z	14:25	15:20	spectromagnetograph	1788 X 1788	0	FAIR	CIRRUS	8688A SPMGTM; NEW GRATING	PAUL HARTMANN	6257

Your files will be staged to the anonymous ftp directory: 9811171939, after you click on the "Create FTP Archive" button below. Files will remain in the anonymous ftp area until midnight, two days from the day of the request.For example, requests made on January 1, will remain available until midnight January 3.

Create FTP Archive

The rate of expansion of the nighttime archive will depend on careful assessment of scientific and cost effectiveness. NOAO has already conducted a meeting to define the requirements for groundbased archiving. We are also currently exploring options for archiving selected data sets, including especially Gemini and survey data, and may contract with STScI or the Canadian data center for this service. Archiving other data sets will depend on how useful access proves to be.

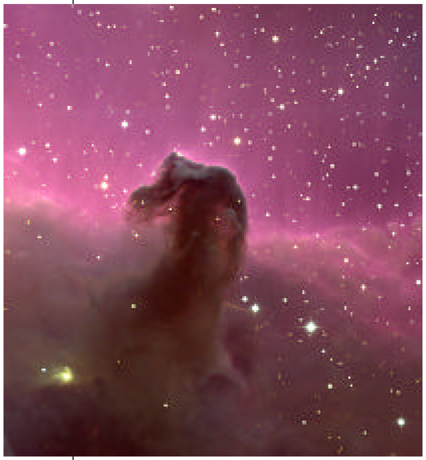
NOAO outreach programs are designed to use observations from the observatory to support science education at all levels—from pre-college through graduate school—and to increase public awareness of astronomical research.

NOAO outreach programs capitalize on the widespread public interest in astronomy to address the major issues of general scientific literacy and the enhancement of science education. NOAO provides a unique venue for the implementation of highly leveraged and focused outreach programs that make full use of the talent and facilities available only at a major national research center.

Pre-College Education

NOAO has developed a K-12 educational outreach program that integrates direct classroom involvement by NOAO staff, a national teacher training program, and the development of materials consistent with national science education standards. The NOAO Teacher Enhancement program, "The Use of Astronomy in Research-Based Science Education" (RBSE), has developed a paradigm and tools for implementing authentic research opportunities into middle and high school classrooms. We are exploring the feasibility of working with other groups, including Hands On Universe and SOFIA, toward the acquisition of data and the development of data analysis software of mutual interest. When RBSE funding expires in 2001, we anticipate moving RBSE away from its current in-residence summer workshop format to being an Internet-based "distance learning" program—possibly as a college course suitable for pre-service science teachers.

Since 1996, NOAO has been the lead institution for the expansion of the ASP's Project ASTRO in the Tucson area. A fourth training workshop will bring the number of teachers and astronomers trained through this expansion to over 150. We are exploring new partnerships and new methods of utilizing the experience gained through Project ASTRO. New efforts will likely focus on developing stronger educational ties with the Tohono O'Odham nation and building on the Project ASTRO-Tucson Coalition, a group which includes representatives from many Tucson-area science and educational organizations.

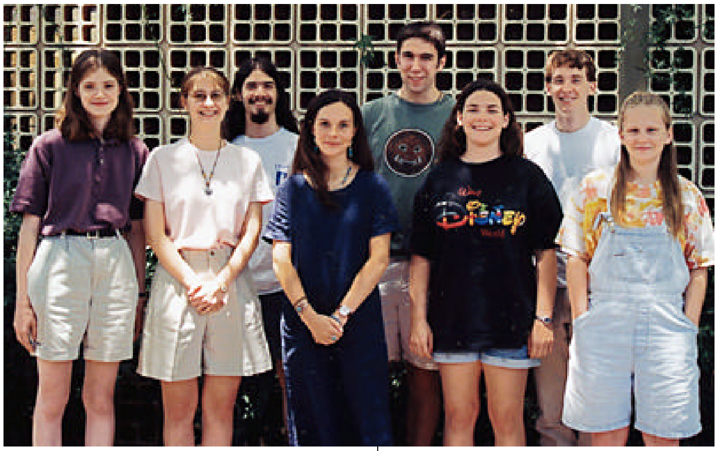


Greater visibility for NOAO programs

Much of the NOAO image collection is now on line and available to scientists, writers, and the general public. We will continue to improve the public Web pages in terms of both design and content. The next emphasis will be on developing both Web-based and printed materials that will include answers to frequently asked questions in astronomy, as well as referrals to information available elsewhere.

College and Graduate Education

NOAO will continue to host undergraduate students at all three of its sites through the very successful NSF Research Experiences for Undergraduates (REU) program. We will also continue our long established support of Ph.D. theses in observational astronomy. In a typical semester, about 25 thesis programs are assigned time through the competitive review process, and approximately 120 graduate students participate in observing runs. NOAO provides travel support for students conducting thesis research.



Visitor Center Programs

NOAO operates visitor centers at Kitt Peak (100,000 visitors annually) and Sacramento Peak (40,000 visitors annually), and has recently sponsored development of a public observatory in Vicuña, Chile, as part of the CTIO effort to control light pollution. These facilities provide a unique opportunity to increase public awareness and understanding of astronomy, the scientific method, and the research process. These facilities will be continually upgraded through the use of interactive displays, self-guided tours, and new display technologies. Kitt Peak also operates a fee-based program nightly to introduce participants to astronomy and basic telescope usage.

Media Relations and Web-Based Outreach

Over the period covered by this long range plan, NOAO will place major emphasis on enhancing the visibility of its programs through the World Wide Web and increased media coverage. We are streamlining procedures for producing press releases, images, and video materials requested by the media, and we intend to select a few stories each year with high scientific value and report them accurately. First light at Gemini and the subsequent images and other results from that facility offer an important opportunity to establish a stronger presence with the media. A primary issue is developing a closer partnership with our users, who rarely give credit to NOAO or the NSF for work done at the national facilities. It is our goal to bring the science of NOAO to the general public, educators, and the media in an accurate, timely, and usable manner.

Investing in the Future of Science

For over 10 years, NSF's REU Program has supported summer research internships for undergraduates to work directly on major research projects with NOAO astronomers. Beginning in 1999, a planned expansion of this program will permit K-12 teachers to work with scientists through the Research Experiences for Teachers (RET) program.