NOAO Long Range Plan

FY 2002 – 2006

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1 INTRODUCTION

A 21st CENTURY NATIONAL OBSERVATORY

1.1 The Endless Frontier

Astronomy is exploring the universe. A physics and engineering approach to the subject has revolutionized astronomy in the 20th century, in the same way that chemistry has revolutionized the life sciences. All of us now know something of the extraordinary Universe we live in, thanks to the untiring efforts of astronomers to build better observatories with larger telescopes, and to apply physical insight to understanding how the Universe works. Exploring the Universe is now in the national consciousness. Science has been called the "endless frontier" by Vannevar Bush, who fifty years ago made the case for the formation of the National Science Foundation. The most vivid expression of the endless frontier today must surely be astronomy. And we have only just begun. The 21st century holds the promise of completely re-writing what we know of our environment, both on the largest scales, and—since astronomy is our window into the first fraction of a second—on the smallest scales as well.

US astronomers have an established record in strategic planning, and the recently published report of the Astronomy and Astrophysics Survey Committee foresees unprecedented opportunities—many arising from recent advances in engineering and information technology—for dramatic advances in astronomical discovery over the next decade. The AASC also foresees new opportunities for astronomy to contribute to national social priorities, such as education for a life in which science and technology literacy are crucial to living standards and national leadership. Here the role of astronomy is to be a motivator for our young people to master a science-based approach to the world around us. Astronomy has never been more strongly coupled to NSF priorities.

1.2 Mission of the National Optical Astronomy Observatory

The mission of NOAO is to enable research and discovery in US ground-based astronomy and to promote public education, understanding, and support of astronomy and related sciences. Beginning with this long range plan, NOAO proposes to accomplish this mission over the coming decade with a bold plan to keep US astronomers at the frontier of astronomical discovery. Guided by the recommendations of the AASC report, NOAO has developed new objectives for an effective 21st century national observatory. The essential elements of NOAO's Long Range Plan are to:

- Support the use of state-of-the-art facilities, such as Gemini
- Undertake the next generation of forefront facilities
- Develop an integrated national observing system
- Work with the community to achieve a robust instrumentation capability
Foster an environment in which the integration of astronomical research with public outreach and education is a routine part of daily activities and staff responsibilities.

If we are to make the most of our opportunities, every element of the national astronomy enterprise must play its part. The resources at the disposal of US astronomy are no longer dominant by world standards, and yet the national expectation is that US astronomers will lead the exploration of the universe. In order to capitalize on strength in diversity—which is the cultural position from which we come—the AASC has called for the independent elements of the national observing “system” to work together in a complementary manner, with minimum redundancy and maximum access to the collective pool of research facilities. NOAO is the national organization made responsible for the flow down of that requirement into a set of workable arrangements in optical and infrared astronomy from the ground.

Three dominant themes run through this long range plan:

1. **Current investment in the facilities of the future.** NOAO believes that the LSST and GSMT project plans must be fully developed before consideration for major capital funding by NSF and other agencies—as was the case with the Gemini project. Preparation of these plans for the major initiatives of the decadal survey requires investment of funds from NOAO’s core budget now.

2. **Partnership with the entire research community.** AURA’s character as a representative organization of member universities with shared values—as well as the international scope of its operations—will support NOAO goals in an environment that requires the highest possible degree of inclusiveness.

3. **Broadening the impact of US astronomy** on the learning experiences of classroom students at all levels of the educational system and developing appealing outreach services, products, and media that make astronomical discoveries more accessible to the general public.
2 SCIENTIFIC PROGRAM PLAN

2.1 Where We Are Today

The past decade has witnessed dramatic discoveries, surprises, and advances in our understanding:

- Observation of large samples of supernovae in galaxies out to redshifts \( z \sim 1 \), which for the first time provide compelling evidence of a non-zero cosmological constant with a value consistent with that inferred from microwave background observations (Garnavich et al. 1998; Perlmutter et al. 1997).

- The first observations that quantify fluctuations in the microwave background over a wide range of angular scales (Netterfield, Ade, Bock, Bond et al. 2001). These observations provide both essential independent constraints on fundamental cosmological parameters, strong support for a non-zero cosmological constant, and empirical “initial conditions” for modeling the evolution of large-scale structure and the emergence of galaxies.

- Discovery of super-massive black holes hosted in a large number of galactic nuclei, the mass of which is tightly related to the galaxy stellar velocity dispersion (Gebhardt et al. 2000; Ferrarese and Merritt 2000). This result argues not only that black holes are a fundamental component of all galaxies including our own (Ghez, Klein, Morris, and Becklin, 1998), but that the formation of the black holes and the galaxies themselves are deeply intertwined.

- Discovery of gamma-ray bursters and their optical counterparts via observations with Compton Gamma Ray Observatory (CGRO) and ground-based telescopes, resulting in the unambiguous association of these incredibly energetic events with extragalactic systems (Bloom, Djorgovski, Kulkarni and Frail 1998).

- Discovery of dark matter in aggregates of size and mass comparable to galaxy clusters, but apparently not associated with visible clusters, via statistical studies of the effects of gravitational lensing on the isophotal contours of distant galaxies (Wittman, Tyson, Kirkman, Dell’Antonio, and Bernstein 2000).

Images of three high-redshift SN Ia discovered by the High-Z Supernova Search Team with the CTIO Blanco 4-m telescope. The “Epoch 1” and “Epoch 2” images were obtained with the Blanco in December 1997 and January 1998 with a separation of ~ 20 days. The “Diff” column shows the subtraction of these two epochs, revealing the presence of a SN in all three cases. The final column shows HST images of the SNe obtained only a few days after discovery.
• Detection of large numbers of forming and mature sub-stellar mass objects via photometric and spectroscopic studies of young stellar clusters, and deep optical and infrared imaging and astrometric studies of low luminosity stars in the solar neighborhood. These objects span masses from a few tens of Jupiter masses to the hydrogen-burning limit and are beginning to provide important insight into the chemical and physical processes that control the structure of planetary mass objects (Lucas and Roche 2000; Haisch, Lada, and Lada 2001).

• Detection of large numbers of Jovian mass extra-solar planets (now numbering more than 50), the vast majority located at distances within an astronomical unit of their parent star. This surprising result has led to a proliferation of new theories of planet formation and migration, and called into question whether Earth-like planets located in habitable zones are a common outcome of the solar-system formation process (Marcy and Butler 1998).

These advances represent not only the fruits of the collective efforts of teams of astronomers, but the culmination of investments in a wide variety of observational tools, ranging from ground-based imaging surveys with moderate-aperture telescopes (2MASS, SDSS, CCD mosaic cameras on 4-m class telescopes), through spectroscopy with the Keck telescopes, to a variety of space-based and balloon assets, including both Explorers (e.g., COBE) and great observatories (HST, CGRO). Ground-based O/IR astronomy played a paramount role in these discoveries. As we look ahead, NOAO must be prepared to support these advances by offering the facilities necessary to the US astronomical community.

2.2 The Next Decade

As we look ahead to the next decade, astronomers stand poised to research such fundamental questions as:

• How the largest structures of the universe take form and evolve, how they relate to the initial conditions imprinted at the time of the Big Bang, and how the cosmological system that governs the universe orchestrates these events.

• How galaxies form and evolve from local density fluctuations to pre-galactic entities, through mergers to mature galaxies, and how these processes are affected by environment.

Acoustic fluctuations on the surface of last scattering of Big Bang photons have finally been detected by BOOMERANG, a NASA-NSF-supported balloon precursor of the imminent MAP Explorer mission. From these density fluctuations groups of galaxies formed.
• How and when black holes form, and how galactic nuclei evolve

• How stars and planetary systems emerge from molecular clouds and pre-stellar cores; what physical, chemical, and environmental conditions determine the spectrum of stellar masses, how individual stars evolve, and whether the emergent distribution of planetary architectures favors formation of large numbers of habitable planets or whether Earth represents a cosmic accident.

Answering these questions will require combining results both from extant ground- and space-based facilities, which will provide enabling surveys and pathfinder observations, and from new facilities (e.g., NGST, MAP, SIRTF, FIRST, ALMA, LSST, and GSMT), which will provide the advances in sensitivity, angular resolution, and angular coverage crucial to enabling broad-scale progress.

LSST and GSMT, the ground-based O/IR facilities recommended by the AASC, will play a key role in addressing these questions. LSST is an unprecedented advance in opening the time domain; GSMT will be the driver of spectroscopic understanding for NGST and ALMA. The experimental approaches needed will in most cases demand large, often panchromatic databases—in some cases, petabytes in scale—from which samples spanning the requisite ranges of physical, chemical, and environmental conditions must be drawn and analyzed. The sheer scale of these databases will require qualitatively new approaches to data management and analysis, as well as extensive numerical modeling that exploits the full power of modern, parallel, teraflop computing. Moreover, the scale of the problems will require development of innovative ideas and approaches by individual scientists, and coordination of teams of researchers, each planning and carrying out large campaigns making use of a suite of ground- and space-based facilities, on scales unprecedented in astronomy.

The current telescopes of KPNO and CTIO also have a role to play in supporting the scientific themes articulated in the AASC decadal survey. "Red envelope" galaxies from O/IR surveys can trace the development of large-scale structure through intermediate to high redshifts. CCD Mosaic imagers can provide initial detection of distant supernovae, followed by light curves from Gemini and HST. Gravitational lens mass tomography and mapping of the Kuiper Belt will continue with systematic surveys. Candidates for the "Dawn of the Modern Universe" at $z > 5$ will be culled from R-band dropout surveys with the Mosaics and in the near-IR. The attack on star and planetary
system formation will be intense, with near-IR imaging and multi-object spectroscopy of star-forming regions, as a complement to SIRTF and radio studies. Wide-field CCD monitoring will be employed to investigate the census of planetary transits for large samples of stars. The aspects of depth and time domain highlight the ongoing need for systematic surveys that surpass the coverage of the 2MASS and Sloan Digital Sky surveys. Such surveys will also serve as critical precursors to the all-sky monitoring of LSST.

2.3 No End of the Boom in Sight

Technological change continues to favor O/IR astronomy. The new facilities advocated by the AASC lead us to anticipate with confidence that we can enter the redshift range 6-10 in the coming decade to learn more of the epoch of galaxy formation. Resolution and distance limits continue to be pressed back, as shown in Figure 1. Jupiter's detectability at increasing distance is a measure of this, as is the number of resolution elements per arcsecond offered by previous NOAO instruments and future ones. Productivity continues to grow in photometry and spectroscopy—although the next generation spectroscopic survey telescope was not identified by the AASC. And high resolution spectroscopy continues to make strides, as chemical composition analysis becomes possible for progressively fainter stars, and velocity precision homes in on its goal of detecting terrestrial planets. An essential element of NOAO's science plan is to exploit this Moore's-law-like behavior of ground-based O/IR astronomy by pursuing the science enabled by technological advances.

Figure 1. Four plots showing the increasing power of O/IR ground-based capabilities represented by NOAO instrumentation as measured by various performance metrics. The top left plot shows the increase in the largest redshift known for galaxies and QSOs with time. The top right plot shows the gain in spatial resolution of ground based observations. The bottom left plot demonstrates the increase in productivity through several measures. The bottom right plot shows the gain in precision and limiting magnitude of high resolution spectroscopic observations.
2.4 Scientific Staff

At the core of NOAO's scientific program plan are the individual research aspirations of its scientific staff. Under AURA policy, scientists are accorded half their time to pursue their own research. This policy equips NOAO with a science engine and a culture beyond that of a purely service organization. For example, Knut Olsen, Assistant Astronomer at CTIO is using CTIO's suite of telescopes to characterize the shapes of the Magellanic Clouds, to measure their chemical evolution histories, and to determine the types of star formation events that produce kiloparsec-sized holes in the interstellar medium. He uses the Mosaic 2 camera and Hydra at CTIO and finds that his involvement in supporting both instruments has a positive impact on his research projects. Generally, the science plan for NOAO is to align the research interests of the scientific staff as closely as possible to support of the observatory's instrumentation and programs.

The scientific staff will continue to be spread rather thinly across those programs, as the table on the following page demonstrates. However, as the new programs described in the next section commence, the guiding principle will remain: there is enormous synergy between the research ambitions of NOAO's scientific staff and the development of new facilities for the NOAO's user community. A dynamic NOAO scientific staff, vitally involved in research and driven by its own scientific curiosity, is therefore essential to success. The NOAO management plan in Section 5 returns to this matter in more detail.

2.5 NOAO and the Science of the Next Decade

The changing nature of astronomical research—wth its growing need to organize and orchestrate experiments of community and world-wide scale—has shaped NOAO's examination of the role of the national O/IR observatory in the coming decade. Clear guidance comes from the recommendations of the AASC, which proposed a forward-looking model that defines roles appropriate to the varied institutions comprising the US astronomical research enterprise: i.e., universities, independent observatories, and national observatories. The AASC recommends that US astronomy be envisioned as a "system" whose individual components carry out complementary roles in service of achieving shared scientific aspirations, and whose funding agencies develop investment strategies aimed at maximizing the potential to achieve scientific aspirations through support of both individual investigators and critical capabilities.
## Distribution of NOAO Scientific Staff Across NOAO Divisions and Programs

<table>
<thead>
<tr>
<th>Work Packages</th>
<th>KPNO</th>
<th>CTIO</th>
<th>NGSC</th>
<th>Tucson</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Director &amp; Deputy</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>7.0</td>
</tr>
<tr>
<td>Science Operations</td>
<td>1</td>
<td>0.5</td>
<td></td>
<td></td>
<td>1.5</td>
</tr>
<tr>
<td>Large Telescope Support</td>
<td>1.7</td>
<td>2.6</td>
<td>3.2</td>
<td></td>
<td>7.5</td>
</tr>
<tr>
<td>Other Telescopes</td>
<td>0.6</td>
<td>0.6</td>
<td></td>
<td></td>
<td>1.2</td>
</tr>
<tr>
<td>Instrument Upgrades</td>
<td>1.5</td>
<td>0.3</td>
<td></td>
<td></td>
<td>1.8</td>
</tr>
<tr>
<td>Data Products</td>
<td></td>
<td>0.5</td>
<td>2.5</td>
<td></td>
<td>3.0</td>
</tr>
<tr>
<td>LSST</td>
<td></td>
<td>0.5</td>
<td>1.5</td>
<td></td>
<td>2.0</td>
</tr>
<tr>
<td>NIO/GSMT</td>
<td></td>
<td></td>
<td>1.5</td>
<td></td>
<td>1.5</td>
</tr>
<tr>
<td>Major Instrumentation</td>
<td></td>
<td></td>
<td></td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Staff Research</td>
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<td>4.3</td>
<td>0.8</td>
<td>7.4</td>
<td>14.0</td>
</tr>
<tr>
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<td>7.3</td>
<td>11.3</td>
<td>6</td>
<td>18.4</td>
<td>43.0</td>
</tr>
</tbody>
</table>

In this context, the paramount role of NOAO in the coming decade will be to enable scientific research of scale and to assist in the creation of facilities and capabilities of scale. This new role requires that NOAO:

- Provide excellent facilities for the wide-field imaging and multi-object spectroscopic campaigns critical to solving large scientific problems or planning major programs with 8-m class telescopes
- Be the prime mover (or a strong partner) in building the new tools critical to ensuring continued US leadership—specifically, LSST and GSMT—along with the instrumentation and data management tools necessary for their success
- Build the supporting infrastructure—pipelines, archives, archive access tools, basic data mining tools—that enable large campaigns and surveys and provide access to these rich databases for analysis by broad communities of users
- Develop new observing modes that enable transient and synoptic observations in service of ground-based or coordinated ground and space programs
- Work with the community to develop a strategic plan within which the implicit system of public and independent observatories can evolve the suite of capabilities needed to achieve the scientific aspirations of the US community and to ensure the continued presence of the US community at the frontiers of astronomical research.

This new NOAO focus on enabling science of scale explicitly recognizes the paramount role of universities and independent observatories in leading innovative developments, fostering research by individual investigators and their students, and tackling, in an entrepreneurial manner, the funding and development of critical components of the larger system. From this science plan, with its strong emphasis on implementing the decadal survey, is derived the NOAO technical and facilities plan, and this is described and proposed in the following section.
NOAO’s responsibility to NSF in the international Gemini Project is to be the interface between the operational telescopes and the US research community. Models for this function include the Space Telescope Science Institute (more accurately, STScI before flight operations were transferred there from Goddard) and the SIRTF Science Center (SSC)—the SSC in particular seems the right-sized model for the US Gemini program. To mark the transition from project to operations, NOAO intends to re-launch the USGP as a science center with a staff complement of five to ten FTE astronomers, able to call on the full resources of NOAO for support as required. The new division is to be called the NOAO Gemini Science Center, and will be an integral part of the national observatory. NGSC will offer a light and flexible service delivery model because of its embedding in NOAO.

The new NOAO Gemini Science Center is the interface between the US community and the Gemini telescopes.

### 3.1 The NOAO Gemini Science Center (NGSC)

The twin 8-m Gemini telescopes form the apex of the facilities that NOAO offers to the US astronomical community. Gemini has particular competitive advantages in the infrared (an IR-optimized telescope) and in adaptive optics (its multi-conjugate adaptive optics team). The goals of the NGSC are to meet US community needs for 8-m aperture telescopes, to provide user support, including data reduction and analysis procedures, and to develop the input from the US partner perspective to the International Gemini Observatory (IGO) in science planning, instrument development, and operations support.

NOAO and the NGSC bring to the Gemini partnership a long history of broad community involvement in the scientific planning and operations of national observatory facilities, including, e.g., extensive community participation in the NOAO telescope allocation process. NOAO also offers a wide range of in-house scientific expertise that encompasses the Gemini science goals and instrumentation diversity. The NOAO instrumentation and detector programs offer valuable engineering resources to the international project. The joint presence of NOAO and Gemini on the Cerro Pachón site offers extensive opportunities for collaboration on telescope support and instrument sharing mediated by AURA.

#### 3.1.1 Science Direction

Within the structure of the International Gemini Observatory, each partner agency created a national project office to represent its participation in Gemini. The project offices form the nodes of communication between the IGO and each partner country, providing input and advice to IGO.
on partner perspectives, and communicating to the national communities the capabilities and science opportunities that IGO presents. NOAO is the home of the US national project office, and the director of the NGSC is the US project scientist for Gemini.

In order to access and represent US interests, the NGSC director is assisted by a science advisory committee (US SAC) that consists of eight to ten prominent members of the US community. This committee meets annually to advise on science direction, operations models, instrumentation concerns, and the full variety of Gemini matters. Frequent telephone conferences and e-mail updates and exchanges allow the perspectives of a broad range of science expertise and interests to form the consensus and advice to the NGSC director. Six members from the US SAC are selected to attend the annual international Gemini Science Committee meetings. Some US SAC members also participate in the NOAO Users’ Committee, so that the US SAC is informed about NOAO capabilities and can help ensure the full deployment of NOAO resources in support of Gemini science.

3.1.2 User Support

User support at the NGSC starts with a group of more than a dozen instrument scientists, ranging from quarter-time to full-time, whose areas of scientific and technical expertise are matched to the diversity of Gemini instrumentation. The instrument scientists assist US principal investigators in preparing observing proposals, which are then peer reviewed and ranked by the NOAO telescope allocation committee.

The complexity of the Gemini instruments and operations requires complex observing protocols and calibration observations. Observations with adaptive optics and the mid-IR are areas in which Gemini has the competitive edge; these will be specialist fields for the NGSC. NGSC staff will work closely with observers to develop and document observing procedures to assure that Gemini data are of the highest quality and that the data are both calibrated and documented to archival standards.
A remote operations center is currently being established in Tucson with high-speed internet connections to the Mauna Kea and Cerro Pachón sites. The remote operations center will serve community observers as well as NGSC staff, enabling staff to support US observers and US instrumentation efforts on Gemini. NGSC staff will also use this center for training and for conducting engineering programs to enhance the productivity of Gemini observing.

In order to attain Gemini science goals, data reduction, pipelining, and analysis tasks need to be developed for the Gemini data products. The NOAO Data Products Program will strengthen these efforts, providing system enhancements and data quality and error mapping specifically for Gemini data. The reduction and analysis of adaptive optics images and spectra, multiple-object and integral field spectroscopy, and mid-IR images and spectra all require extensive software support, which is linked to ongoing IRAF development.

3.1.3 Operations Support

NGSC staff will provide support for the commissioning and operations of US instrumentation efforts. NGSC staff are also responsible for the coordination of shared Gemini instrument packages from the US, currently FLAMINGOS (a University of Florida instrument shared between KPNO and Gemini South) and Phoenix (an NOAO instrument shared with SOAR and Gemini South). NGSC staff will work with the instrument teams in the testing, maintenance, and calibration of these shared instruments, and provide documentation on performance, operation modes, and calibration procedures for the Gemini community.

NGSC staff in Chile share many facilities with CTIO: a common base site in La Serena (the AURA compound), the mountain site (both Gemini South and SOAR are on Cerro Pachón), and shared network bandwidth and some computing facilities. Coordinated efforts by the AURA Observatories in Chile, with NSF support, will have increased the bandwidth to the southern sites by a factor of >20 over current capacity by early 2002. This expanded capacity (initially ~10Mbits/s) will permit IP video and data links, and some remote observing options (e.g., eavesdropping) for all the southern sites. AURA has long-range plans for additional bandwidth improvements. The AURA Observatory Support Services (AOSS) office in La Serena provides Gemini South with local expertise over a broad spectrum of activities ranging from importation services in Santiago/Valparaiso to water and power facilities on Cerro Pachón.

These joint operations in Chile also provide a natural path for the sharing of mountain support efforts, in particular a QuickStart queue (which will be run on Gemini South in semester 2001B) and US mini-queue programs. NGSC will also provide a US presence in Hilo to support observations at the Mauna Kea site. The exchange of effort between NGSC staff and the IGO will allow consolidation of critical personnel for the development of other long-range planning efforts within NOAO, including the GSMT project.
3.1.4 Instrumentation and Development

As the major partner in the IGO, the US contributes approximately half the major Gemini instrumentation. It is the role of NOAO and the NGSC to foster instrumentation development for the IGO in the US community. This effort is divided between projects undertaken directly by NOAO (e.g., GNIRS) and projects under development elsewhere in the US community (e.g., NIRI, T-ReCS, FLAMINGOS-II) in collaboration with university groups (currently U. Florida and U. Hawaii). The NGSC fulfills this role through a range of activities, such as:

- Encouraging responses to IGO instrument procurement opportunities by organizing workshops and facilitating collaborations where appropriate
- Facilitating contract negotiations between IGO and the prospective supplier
- Facilitating the instrument review process (conceptual, preliminary, and critical design reviews)
- Publicizing progress on the instrument development within the US community.

The current set of instrument specifications and science goals was elaborated in an international meeting (the “Abingdon Meeting”) in 1997. In 2002-2003, a second international meeting will be held to explore the next generation of instrumentation and to develop the strategic plan for the IGO in the coming decade, including the role of Gemini in the Next Generation Space Telescope (NGST) era. As was also done prior to the Abingdon meeting, the NGSC will conduct a community workshop in the US to prepare the science cases and instrumentation opportunities that best satisfy the needs and preferences of our community, and to coordinate the Gemini Observatory within the US system.

The need for an instrument simulator and integration and testing facility for major US instruments has become evident over the past several years. Such a facility would allow the simulation of the telescope control and software system, permit full flexure and environmental testing, and perform alignment and integration activities so as to minimize the amount of valuable telescope time that would otherwise be spent on these activities. NOAO is pursuing such a capability as part of its major instrumentation initiative; this facility would be available for all Gemini instrument builders in the US.

Integration of Research and Education in the NGSC

NGSC works closely with both the NOAO and IGO Outreach groups to identify important Gemini science discoveries and to highlight these science stories for the public via press releases, media outlets, and the NOAO and Gemini Web sites. The Tucson-based remote operations center currently under development will also be a locus for public education programs tied to Gemini, and will include a public viewing gallery with video, audio, and computer monitors, and Web-based tours of the Gemini facilities, instruments, and science programs. Over time, these Gemini outreach efforts will bring the operations of the distant Gemini observatories home to the general public as a tangible and accessible achievement of astronomical discovery. The image of GG Tauri A-B above, taken at Gemini North using the AO system Hokupa’a, is currently displayed on the home page of the NOAO Web site, and is a good example of how Gemini science is intelligently presented to the non-specialist public. (Photo: D. Potter/U. Hawaii/IGO/NSF)
3.1.5 Building the Gemini Community

NGSC will communicate with the user community by means of articles in the *NOAO Newsletter*, special brochures, "town meetings" and special sessions at AAS meetings, electronic announcements, and Web-based information. Currently under exploration is the use of Web casts to inform the users on specifics of Gemini instrumentation and to instruct them on the use of Gemini queue-scheduling tools.

The NGSC intends to organize and conduct science workshops, in collaboration with the IGO and partner countries, to highlight particular areas of Gemini science that are both timely and productive. Currently anticipated workshop topics are "Astrophysics in the Mid-IR" or "New Frontiers in Coronography." The NGSC will also sponsor technical workshops, like this year's Tucson workshop on AO data reduction, to assist the community in obtaining the highest scientific return from Gemini observations. Plans for an OSCIR/T-ReCS data reduction workshop for late 2001 are currently underway in collaboration with C. Telesco and the University of Florida group. Future workshops may focus on multiple object spectroscopy in the optical and near-IR (with GMOS and FLAMINGOS), on integral field spectroscopy, or on other specialized reduction and visualization tools and procedures.

To mark the launch of the NGSC, a new postdoctoral program has been created to encourage young astronomers to utilize the Gemini telescopes for innovative science. This program will complement AURA's Gemini Fellowships for graduate study.

3.2 Developing CTIO and KPNO

CTIO and KPNO serve as key elements in the system of US ground-based optical/infrared telescopes. The wide-field capabilities of the Blanco, Mayall, and WIYN telescopes provide essential support for the major portion of the US investment in large glass. This distribution is appropriate, as six out of the eight independent large-aperture telescopes are in the Northern Hemisphere. Observing programs and survey data sets from the Blanco and Mayall telescopes create a level playing field for effective utilization of Gemini. These NOAO telescopes greatly enhance the exploitation of national space assets by providing two-hemisphere programs of optical/near-IR source identification, reconnaissance spectroscopy, and synoptic monitoring. KPNO data are of particular value to those multi-wavelength programs that rely on VLA (and EVLA) observations. From 2003, the fourth 4-m telescope—the Southern Observatory for Astronomical Research (SOAR) telescope—will supplement Gemini South in exploiting Cerro Pachón's superb observing conditions.

In addition to the platform of 4-m telescopes required for the effective exploitation of Gemini, KPNO and CTIO will provide:
• Efficient infrastructure supporting Gemini South, GONG, Steward Observatory, MDM, and other tenant telescopes

• Continued support for an estimated 25% of US astronomy doctoral thesis students

• A strong base of scientific and technical expertise for effective participation in upcoming major projects, such as GSMT, LSST, ALMA, and OWL

• Experience and leadership in the protection, location, and characterization of present and future sites

• Integrated programs with Gemini, other telescopes in the O/IR system, and ALMA,

• Space mission follow-up and calibration support for HST, and eventually for NGST.

3.2.1 Instrumentation

At KPNO the instrument complement will evolve from versatile multipurpose capability toward dedicated support for surveys, particularly on the 4-m telescopes. Initially, the Mayall will be equipped with the Prime Focus CCD Mosaic Imager with 8K x 8K format covering 37' square; the FLAMINGOS wide-field near-IR imager and cooled multi-slit spectrograph, developed in partnership with Richard Elston at the University of Florida and shared with Gemini South; the Simultaneous Quad Infrared Imaging Device (SQIID), the 4-color near-IR imager; and optical spectroscopic capability with emphasis on high efficiency in the far red. WIYN provides the Hydra multi-fiber positioner plus bench spectrograph covering 1 degree; the direct imager, Mini-Mosaic; and the Tip/ATilt imager with rapid guiding correction, all mounted simultaneously and addressable with the rotatable tertiary. Because it can accommodate the 4-m near-IR instrumentation, the 2.1-m will continue to be operated, but with minimal technical support. The combination of the 2.1-m plus FLAMINGOS does provide a 20' field of view in the near-IR, making it a powerful survey capability in the near term, and the most oversubscribed resource for Semester 2001 A.

Three major new instruments are planned. NEWFIRM will be a wide-field near-IR imager with a 4K x 4K mosaic array detector, covering a 30' square field of view on the 4-m. Goddard Space Flight Center and the Space Telescope Science Institute are building an NGST prototype multi-object near-IR spectrograph with a micro-mirror array as a programmable slit mask. When NEWFIRM and the Goddard IRMOS are fully commissioned, SQIID will be retired and the 2.1-m privatized, fully or partially, with the goal of continuing operations in a single optimized configuration. The WIYN consortium is pursuing the development of a one-degree CCD imager with orthogonal-transfer integrated CCD arrays for local fast guiding.

At CTIO, the scientific priorities flow down to an integrated “mini-system” of complementary telescopes and fixed instruments comprising:
- Blanco 4-m with wide-field optical and IR imaging, and wide-field spectroscopy
- SOAR 4-m with IR and optical spectroscopy, and high-resolution imaging
- 1.3-m (ex-2MASS) with optical imager
- 1.5-m with queue-scheduled and target-of-opportunity dual IR and optical imager.

Implementation of this mini-system is already well developed, with recent new Blanco instrumentation (Mosaic 8K CCD imager, Hydra multi-object wide-field spectrograph), plus the ISPI 2K IR imager (due late 2001) and the SOAR telescope, which is expected to reach first light in late 2002. During the period 2002–2003, the major activity of the CTIO Engineering and Technical Services (ETS) group will be integrating and commissioning SOAR under an “early operations” agreement between SOAR and NOAO. Both instrumentation and telescope subsystems are being built for SOAR by ETS at CTIO. One of the most significant contributions is in the area of detectors and controllers, an area where CTIO has long had special expertise.

In the longer term, the direction of evolution is dependent on siting of new facilities such as LSST or a spectroscopic survey telescope, and on the instrument complements available on the southern large telescopes (Gemini, Magellan, SALT). A desirable post-2006 complementary configuration for the 4-m telescopes is for the Blanco to be equipped with a single instrument, a wide-field 8K IR imager at prime focus, while SOAR could be exploiting the R through J bands with a laser-guide-star AO system.

3.2.2 Telescope Operations

To support the survey and synoptic capabilities that characterize its unique role in the national system, NOAO must provide a powerful suite of wide-field instruments, operated at low cost, with scheduling and operational modes enabling the production of large, uniform data sets accessible to the astronomy community. The strongest science can emerge from a mix of surveying and some traditional PI observing. The latter allows multiple approaches to current key problems and innovative work on the variety of phenomena leading to the next decade’s major investigations. Such access enfranchises the estimated 50% of US astronomers without guaranteed arrangements for telescope time and particularly benefits graduate students in training and thesis research. Scheduling is evolving rapidly to this model. Major surveys currently receive 20% of the time awarded through open competition. In addition, when the SIRTF Legacy program offered ground-based time on NOAO telescopes to enhance the value of the publicly available space survey data, four out of six of the successful Legacy proposals requested KPNO time. Similar modes of supporting major programs on HST and Chandra are also in progress.
Under the current proposal, KPNO will continue to offer the wide-field Mayall 4-m and WIYN 3.5-m telescopes on a very good continental site. The modern design of WIYN allows it to deliver a median FWHM < 0.8", consistent with the recent site test value of <0.7" in the visible. WIYN image quality monitoring records FWHM < 0.5" for 10% of the time.

The program of refurbishment of the Mayall 4-meter is near completion. This included dome ventilation, mirror chilling and air flow control, active support of the primary mirror, wavefront sensing, and secondary focus and tilt control. CCD Mosaic users report stacking hours of integrations and maintaining 0.8" image quality. Massey and Foltz (2000) reported zenith sky brightness measurement of B = 22.63 mag arcsec², the same as that of Palomar Observatory in the early 1970s, considered at the time to be a premier dark site.

The operations model for CTIO is also rapidly evolving. CTIO has long been justifiably lauded for providing superb scientific and technical support to its users, complementing its state-of-the-art facilities. The advent of a wider role for NOAO, and the need to provide support for a distributed system of facilities, have led to a more focused role for the CTIO telescopes, one where the two 4-m telescopes operate with fixed instrumentation and the smaller telescopes require minimal support. CTIO is already well on the way to implementing this concept. At the same time, the impending arrival of wide-bandwidth connections to US users via Internet2 will allow CTIO to extend its exploration of creative ways to operate its telescopes. Two US groups have been successfully operating small, low-bandwidth robotic systems on Cerro Tololo for several years. The YALO consortium, now using the 1.0-m telescope but planning to transfer to the 1.5-m, already schedules its telescope in queue mode with the queue operated by Yale University, allowing rapid response to scientific opportunities and changing observing conditions. The SOAR partners (Brazil, U. North Carolina, Michigan State U.) will provide significant support to the basic operations supplied by CTIO. In particular, the universities will complement the CTIO efforts by contributing scientific staff on site and through development of remote observing tools; much of this is driven by the plan to use SOAR as an educational facility. Efficient queue observing in a multi-instrument environment is also a goal of the SOAR consortium.

3.2.3 Graduate Training and Education

In a typical year, US graduate students awarded observing time on CTIO telescopes—whether as designated PI's working on a thesis, or as Co-I's who may or may not be working on a thesis—account for almost 20% of awarded proposals. Overall, in the last five years, NOAO has supported the observing programs of 281 graduate (thesis) students in astronomy. CTIO and KPNO both offer superb opportunities for visiting graduate students to profit from the networking and learning relationships with visiting observers and scientists associated with the tenant facilities. CTIO, in particular, is a crossroad of international scientific, engineering, and technical
Number of Graduate (Thesis) Students Receiving Observing Support at CTIO and KPNO (1996 - 2000)

In addition to its appeal to undergraduates interested in a science work/study program over the US winter semester, the CTIO REU program is attractive to Hispanic-American students as an enriching, ethnically relevant experience in South American culture. CTIO also sponsors an REU-like internship for two Chilean astronomy students at the same time that the American students are in La Serena (January - March).

collaboration, permitting student visitors the opportunity to witness the collaborations of US and international astronomy inherent in the inter-American nature of the Cerro Tololo observatory and the broader Gemini partnership. Such exposure to projects of scale and their management and engineering structures can also be of significant value in broadening the experience base of graduate students—one of the salient findings of the AAS Education Policy Board (Strom, Edwards, Filippenko, Fraknoi, et al. 1997).

3.2.4 Integration of Research and Education

NOAO facilities also provide broader benefit to the educational and public community. Observing on KPNO telescopes is a significant attraction of several NOAO educational programs. The hands-on experience of designing and conducting an observing program on KPNO telescopes provides a direct link between scientific research and education. Summer students in the KPNO Research Experiences for Undergraduates (REU) and high school teachers in the Research-Based Science Education (RBSE) programs typically cite their observing time on Kitt Peak as one of the major highlights of their programs.

At Cerro Tololo, participants in the REU program benefit from the international scientific and cultural environment at the observatory. The NSF has just funded a new research fellow at CTIO whose activities will include a 25% public outreach component—at the same time as the Gemini outreach program in Chile has begun to ramp up sharply. As an aid to alerting Chilean authorities and the general public of the need to control light pollution, substantial local outreach has been conducted through strong support of a local municipal observatory and a new schools outreach program "RED-
LASER,” which has already reached teachers in 60 local schools and over 7,000 local children. This provides a strong foundation for extending the environmental message to include the concept of radio interference—a message that must be introduced soon in order to ensure protection of the ALMA site in northern Chile.

3.2.5 Proposed Cost Reductions

To enable progress on the major new initiatives, the current investment in operations costs on Kitt Peak and Cerro Tololo must be significantly reduced from FY 2001 levels. At KPNO, that phased reduction will consist of three major elements:

1. Telescope imaging performance will be maintained, but trouble response time may be lengthened and no further major performance upgrades will be undertaken. The development efforts of the current engineering group will be redirected toward other NOAO technical priorities, such as the Major Instrumentation program.

2. The instrument complement will be reduced and observing run lengths significantly expanded, easing support requirements. Scientific staff effort will be shifted away from instrument and start-up, which will re-allocate the effort of two FTE scientific staff.

3. The 2.1-m will be privatized when NEWFIRM becomes operational.

Establishing an operating partnership maintains significant proposal-driven access to a key set of capabilities, while recognizing the financial challenges of supporting a complex mission.

As instrumentation partner for ~10% of the Blanco telescope will also be sought. Like the SOAR project, the partnership should enhance the inter-American character of the observatory. At CTIO, the Telescope Operations (TELOPS) group is at present only concerned with operating facilities on Cerro Tololo. The group supports classical observing on the Tololo telescopes, with the 4-m and 1.5-m operating with a diverse set of instruments, and queue-scheduled observing at YALO. This group also provides contract support for other projects on Tololo. With the advent of SOAR, TELOPS will need to support operations on two mountains. The simplification of operations on the Blanco and 1.5-m, plus the retirement of the older telescopes and their functional replacement with the 1.3-m (ex-2MASS) telescope, should allow TELOPS to continue to provide similar service to that at present. This operational model provides strong support to classical observing and results in low downtime. However, when everything works well, it is an inefficient use of manpower, and has greater cost than “minimal support” models.

A “Cheap Ops” model for CTIO has also been developed and is phased to cut in when SOAR is in stable operations mode in 2004. The three main features of this model are:

- The ETS and TELOPS groups are to be merged and based in La Serena
- Technical support will be provided from La Serena, on an as-needed basis
- Telescope operators will be present only at nighttime.

At CTIO, the advantages of “Cheap Ops” are lower manpower costs, more efficient use of the workforce—provided that systems are reliable—and lower AOSS charges. The challenges are achieving reliability and management of a multi-functioned technical group.
3.3 The NOAO Data Products Program

A principal advantage of AURA’s management of a constellation of national centers is the opportunity to transfer successes in one center to another. The Space Telescope Science Institute has pioneered a global trend in data management, with the aim of adding value to the client observer’s creativity through provision of calibration, pipeline, and archive databases. It is now time to transplant this culture and its benefits to NOAO and its ground-based O/IR community. NOAO’s programmatic aim is to gain the full value of the NSF investment in observing facilities by ensuring that data taken with these facilities become available to the community after an appropriate data rights proprietary period. These goals will be realized at NOAO in the Data Products program. Through this new program, the cost savings described above in section 3.2.5 will in part be redirected into the observatories’ science programs, raising their productivity while simultaneously increasing their efficiency.

3.3.1 Scientific and Technical Drivers

The past decade has witnessed the advent of a number of ambitious astronomical surveys (Sloan Digital Sky Survey; 2MASS) that have just begun to exploit the parallel revolutions in digital detectors and computational power. The initial returns from these first generation digital surveys are already impressive—ranging from the discovery of galaxies at $z > 5$, to gravitational microlensing events, to methane-dominated T dwarfs. As we look ahead, the astronomical community stands poised to take advantage of the continuing breathtaking advances (factor of 2 increases every 18 months) in computational speed, storage media, and detector technology in two ways: (1) by carrying out new-generation surveys, and (2) by developing the software tools to enable discovery of new patterns and new phenomena in the multi-terabyte (and later petabyte) data sets that represent their legacies. In combination, new generation surveys and software tools can provide the basis for enabling science of a qualitatively different nature. Whereas in the past, astronomical experiments were constrained by the need to carefully select small samples (often limited by a priori assumptions), we can now plan objective approaches based on deep images of wide areas of the sky or spectra of millions of stars or galaxies. Furthermore, the archiving of surveys and other coherent data sets enables access by the entire community for defining samples, preparing observing proposals, and additional mining of the information. These archives are becoming a critical element of the national O/IR system and address the needs of researchers, educators, and students who have limited access to telescope facilities and other opportunities. The potential of these revolutionary developments was recognized by the AASC, which recommended (1) the development of a “national virtual observatory” (NVO) aimed at federating astronomical databases spanning the electromagnetic spectrum (the highest ranking initiative among AASC “small” projects), and (2) the construction of a Large-aperture Synoptic Survey Telescope (LSST) capable of mapping the entire visible sky once per week, thus enabling detection of variable/transient or moving objects, and by summing frames acquired over a decade, providing images of unprecedented depth.

3.3.2 NOAO Interface to the National Virtual Observatory (NVO)

Both these efforts—an NVO and the LSST—are undertakings of national scale, each requiring partnerships among existing NASA data centers, national observatories, astronomers and computer scientists at universities, and the private sector. Owing to the need for broad community participation in planning and implementing the NVO and LSST, NOAO believes that the US national observatory is a natural focal point for assembling the core scientific, technical, and management skills critical to the following activities:
• Playing an active role in the development of the NVO
• Serving as an O/IR node of the NVO, thereby providing wide public access to coherent O/IR survey data sets (starting with the NOAO Deep Wide-Field Survey (NDWFS), evolving to include data sets resulting from the efforts of survey teams supported by NOAO, and eventually to include data sets produced by teams of astronomers making use of other facilities in the US system)
• Leading the development of the data management system for the LSST

Embracing these new roles will require building on NOAO's heritage of strong investment in data systems—beginning with the first widely available astronomical image processing center in the late 1970s, leading next to a systems approach to data acquisition and data analysis introduced in the early 1980s, and culminating in the widely distributed IRAF system and associated packages—which have become critical to the ability of astronomers working on both space- and ground-based data to reduce data efficiently.

NOAO will also draw on the expertise at other AURA centers. STScI, which pioneered data archiving in astronomy, will also play a key role in developing the NVO. NOAO and STScI have been sharing their experience; together they form a unique partnership, representing the needs of O/IR astronomers in the NVO.

Success in meeting the challenges and opportunities of the coming decade will require new investments in scientists and software specialists capable of working with the community to exploit the opportunities of the data revolution, as well as new partnerships with universities and the private sector. The Data Products program will become a new priority within NOAO.

3.3.3 Elements of the Data Products Program

The key components—current and planned—of NOAO software and data management efforts comprise the following activities (listed in chronological order):

• IRAF system maintenance and development
• Software development for data reduction and analysis (including NGSC)
• Archiving extant and planned survey data: i.e., NDWFS, NOAO survey data, other coherent data sets
• Design or adoption of pipeline architecture extensible to LSST
• Development of a ground-based NVO node and NVO interface for archived data, meta-data, data access layer, and a management interface
• LSST data management: e.g., support of precursor activities, scheduling, pipeline processing (real-time and post-), archive, access tools.
3.3.4 **Balancing Present and Future Needs**

The proposed investment strategy and staffing model for the Data Products program at NOAO are predicated on the belief that the challenges of the next decade—i.e., fully exploiting tera- and petabyte data sets and opening the time domain—promise immense scientific payoff to a broad community of US scientists, and therefore require a major national effort. We thus intend to evolve our current software and data management efforts to focus on the dual needs of:

1. Producing data that are "NVO compliant" and available to the entire community.
2. Leading the development of the LSST data management system.

![Deep Lens Survey](image)

*The Deep Lens Survey is an ultra-deep multi-band optical survey of seven 4 square degree fields. Using Mosaic CCD imagers at NOAO’s Blanco and Mayall telescopes, the survey will support a variety of galactic and extragalactic studies through the NOAO Data Products program.*

1. Producing data that are "NVO compliant" and available to the entire community.
2. Leading the development of the LSST data management system.

In these efforts, NOAO will be guided philosophically by the following principles:

- NOAO will seek to assemble core groups—limited to a size necessary to guide planning and development efforts—to establish and manage collaborations or partnerships. Where existing entities provide the required infrastructure and experience base, NOAO will forge partnerships (for example, with STScI) rather than reproducing those capabilities.
In developing software and data management plans, NOAO will carefully examine existing software approaches and solutions and will make far more extensive use of commercially available packages and approaches where applicable, and adopting or adapting community-developed software approaches where appropriate. For instance, continued work on "Open IRAF" and incorporating Python into the IRAF environment will better leverage community software efforts. NOAO expertise will be focused on developments that take advantage of the unique strengths of its staff and community.

By making use of extant expertise and software, it is expected that over time total costs to the federal government and the community will be reduced and NOAO will deliver the data products it is uniquely positioned to provide. The choice of archive provider needs to be made with care. For example, it is noteworthy that Fermi Lab, recognizing that a qualified astronomical supplier had the edge over its own in-house expertise, awarded the contract to service its Sloan Digital Sky Survey (SDSS) archive to AURA's Space Telescope Science Institute.

3.3.5 Near-Term Milestones and Priorities for the Data Products Program

At the beginning of the period of this cooperative agreement, NOAO will focus on the following specific activities and accomplishments:

- By mid-2003, complete reduction and archiving of the NDWFS in a manner that will be extensible to other NOAO survey data sets

- By the end of 2002, develop a science-to-requirements flow down for LSST data management and include this in an NOAO-led, community-based, LSST proposal founded on input from a community-based science working group and refined from experience with an experiment designed to duplicate some of the challenges of data management for LSST—in effect, an LSST precursor

By mid-2003, the archive and basic archive access tools for the NDWFS are to be completed and capabilities extended to archiving and serving other NOAO data sets.
• Continue to develop reduction and analysis software for NOAO and Gemini instruments

• Either design or adopt a pipeline architecture, and begin to populate it with modules for processing data from NOAO instruments

• At a lower priority, maintain and upgrade the IRAF system. Development of new applications will be focused on providing tools for the data products activities listed above. Improvements to the IRAF system will concentrate on making the community more self-sufficient in areas of applications development and support.

3.3.6 Long-Term Direction of the Data Products Program

The result of these priority choices will have the effect of shifting the balance of NOAO support for software development, from its current concentration on IRAF maintenance and instrument support to developing archives and archive access tools, serving as the O/IR NVO node, and toward the end of the decade, serving as the data management lead for the LSST.

3.3.7 Resources for the Data Products Program

The investments needed to develop NOAO's Data Products program and to lead the development of the LSST data management effort include the following:

• A local archive from which to serve the NDWFS and later, other coherent O/IR datasets. Initially, this will be a 10 terabyte archive; ultimately NOAO will need to invest in a larger archive or partner with an extant archive center. This decision falls in the FY 2003 time frame.

• A core group comprising a lead scientist and four programmers/support scientists to coordinate development of the Data Products program, including archive access and data mining/visualization tools to design and carry out a precursor experiment to guide an LSST science requirements document and to design the data management system for LSST.

Some of these resources can be provided via reallocation of extant resources from current tasks (e.g., IRAF maintenance and development). To meet the full needs of the program, however, a net annual increase in resources is budgeted for hardware and planning. (See below Section 5.6.1 for the management of the Data Products program under the NOAO Deputy Director.)
3.4 Large-aperture Synoptic Survey Telescope (LSST)

The Large-aperture Synoptic Survey Telescope (LSST) is one of three major new ground-based facilities recommended for construction during the coming decade by the AASC. With the capability of providing a digital survey of the entire visible sky every week or so to a deep limiting magnitude (~ 24 in a single optical band), the LSST will take advantage of developments in telescope and detector technology and computational hardware and software to open up new domains of astrophysical research. It would, for example, be possible to detect within a decade about 90 percent of all the Near-Earth Objects (NEOs) with diameters greater than 300 m, i.e., nearly all of the objects that would inflict significant damage should they impact Earth, the data would also make it possible to derive orbital parameters and thus assess the threat. It would be possible to detect supernovae at redshifts well beyond z =1, thereby breaking the degeneracy between acceleration and other potential causes, such as reddening and evolution, of the observed dimming with redshift. Observations of gravitational lensing would enable mass tomography—the mapping of the distribution of total matter, bright plus dark, out to z =1, thereby constraining models of the Universe. Scanning the sky with repeated short exposures, as is required for discovery of NEOs, would also open up studies of time-variable objects: topics as diverse as the characterization of the galactic halo through light curves of distant RR Lyrae variables, to the detection of gamma-ray afterglows, could be tackled in a systematic way.

The LSST is necessarily a national project. The resulting database is likely to be one of the largest non-proprietary data sets in the world and will enable a rich range of scientific explorations that no single institution could begin to undertake. The success of the project depends on a range of new technologies—optical components, advanced CCD development, and especially the acquisition, archiving, and mining of large data sets—and will therefore require the active engagement of scientists and engineers from many different fields and different institutions. As stated in the AASC report: “The construction and operation of LSST, together with the processing and distribution of the data, provide critical community service opportunities for an effective national organization for ground-based OIR astronomy.”

3.4.1 Four Phases of LSST Development

NOAO proposes to lead the community-based effort to construct the LSST. The project will proceed in four phases. The first, which is estimated to take two to three years, will result in a proposal for construction; the goal of this pre-proposal phase is to establish the existence of affordable solutions to the major technical challenges posed by this project and to bound the total construction and operations cost. During the second phase, while the proposal is being evaluated and funding sought, NOAO will continue to develop the project plan, ensuring that necessary technical development efforts are continued, especially in terms of evaluating detector design and undertaking precursor experiments that will drive the development of the necessary data management tools. Data management is the primary challenge of the LSST project. We can expect to generate up to five terabytes of data per night; certain information, particularly about variable, transient, and moving objects, must be extracted and made available in near real time; and the cost curve inferred from such projects as
2MASS and Sloan must be reduced by a factor of the order of five for the LSST project overall to be affordable. NOAO’s existing expertise and current efforts to advance the NVO program—including the potential synergy with STScI—are good preparation for meeting the data management challenges of LSST. The third phase is construction, and the fourth is operation and distribution of the data.

NOAO’s current plan is to establish an independent corporation for the LSST project, following the model of WIYN and SOAR, with a well-defined mission and time scale for operation. Steward Observatory, NOAO, and a Bell Labs group are working together as a nucleus of the project. Other institutions will join as the project develops. Committees have already been established to define the science requirements for three areas where the LSST will lead to qualitative breakthroughs: (1) the characterization of small bodies in the solar system, (2) the study of variable objects, and (3) ultra-deep imaging. The baseline design that these groups will work with initially has a 3-degree field with an 8.4-m primary telescope as devised by Roger Angel at Steward and his collaborators. The option for modification of the baseline after the science requirements are established remains open.

Once the project has the initial round of science requirements, technical working groups will be constituted to develop conceptual designs, technical proofs of concepts, and costs for the optics, mount, enclosure, controls, instrument, and especially for data management. The goal is preparation of a technically sound and well-costed proposal. The work packages and costing for this first phase of the project are shown below in Section 5.6.2.

The second phase will require a project manager, continuing investment in hardware development, and support of both the observing programs and the software required to support precursor experiments. These will establish the feasibility of achieving certain performance goals and of making it possible for the community to mine the data. The estimated costs for this phase have been projected in an NOAO study.

3.4.2 Estimated Costs for Phases 1-4

**Phase 1: Proposal Development**
- Involvement of science community in developing requirements: $200K
- Solutions to key technical challenges for instrument and telescope: $3M
- Development of plan for data handling: $400K

**Phase 2: Project Development**
- Two scientists, two post-docs, one data aide, two programmers, one half-time project manager: $700K/year

**Phases 3 and 4: Construction, Operation, and Data Distribution**

To be supported by NOAO when the proposal is funded. Provision has been made in the FY 2005-07 budgets at the level of $1.1M/year. Information technology investments are best made as late as possible in any project. Therefore, most of this sum would be carried over into succeeding years if capital funding for the LSST were delayed, with a decision in FY 2007 about appropriate alternative strategies.

If LSST passes its reviews successfully, the total investment proposed by AURA over the performance period can be as large as $13.6M. A significant share of the total Data Products Program ($6.6M) can also be considered as related investment tending to decrease the total LSST cost.
3.5 NOAO Major Instrumentation Program

Over the past decade there has been an unprecedented investment in new telescopes in the 8-m to 10-m class. The challenge in the next decade will be to take full advantage of these facilities by equipping them with advanced technology instruments. Experience with the first generation of 8-m telescope instrumentation shows that these instruments will typically each cost several million dollars, and their successful deployment will require effective partnerships between astronomers and professional engineers and a systems approach with strong project management. In addition, coordination among the major astronomical observatories will be necessary, in order to maximize the range of available capabilities and optimize the expenditures on the infrastructure required to support the building of complex instruments.

3.5.1 Program Goals

The primary goals of the NOAO instrumentation program are: (1) in partnership with other major instrumentation providers, to establish a robust pipeline for the delivery to the Gemini telescopes of instruments that simultaneously meet performance, cost, and schedule requirements, and (2) to supply key instrumentation technologies, such as infrared arrays, to the developers of instrumentation for other large telescopes in return for community access.

- A secondary goal of the program is to develop the broad range of capabilities that will be needed to serve as the prime contractor for the still larger and more complex instruments that will be required for GSMT and the LSST.

Decisions on where the major instrument program will invest will be based on the following principles:

- The NOAO program will focus on major instruments (est. $4M for the optical and mechanical housing plus $2M for detectors and controllers). Priority will be given to building instruments for large aperture (6.5-m and up) telescopes.

- The instruments must be integral to the strategic plan for the US ground-based system of telescopes or synergistic with it. The assessment of NOAO’s program in this context should be assigned to an external group with some vision about the evolution of the system.

- It would be reasonable to use the proposed System Committee for this evaluation; this possibility will be explored with that committee. Criteria for this assessment would include (1) the investment by US universities or astronomy research organizations; (2) the membership on the science team, which will be drawn from a number of US universities as well as from NOAO scientific staff; (3) plans, if any, for sharing or cloning instruments; and (4) program components geared toward educating future instrument builders.
Training Future Instrumentalists

While the overall proposed NOAO instrumentation program—including the direct involvement of the university community—will undoubtedly strengthen the collective US effort in ground-based astronomical instrumentation, the program will also provide important opportunities for instrumentally-oriented postdoctoral researchers to gain direct experience in building state-of-the-art instrumentation. In addition, NOAO is currently exploring (with our WIYN partners) the feasibility of establishing a special summer program of classes in instrumentation for graduate students, followed by a period of residency of a few months, so that these students can become broadly familiar with the opportunities and challenges in the field of instrumentation. In addition, NOAO is currently exploring (with our WIYN partners) the feasibility of establishing a special summer program of classes in instrumentation for graduate students, followed by a period of residency of a few months, so that these students can become broadly familiar with the opportunities and challenges in the field of instrumentation. If called on to do so, NOAO can also supplement the engineering and management skills of university groups so that they can undertake instruments on a scale that they otherwise might not attempt. By making it possible for university groups to build instruments for NOAO and Gemini telescopes, NOAO will influence the training of future instrumentalists in university programs which are not direct partners in a telescope project.

3.5.2 Program Components

- The program described below is sized in such a way that it can at most provide about half of the Gemini instruments that will be built in the US. With appropriate investment, NOAO expects that our track record at the forefront of infrared array technology and proven capability in CCD mosaics will encourage partnerships in other major system instruments, leveraging access to system telescopes in parallel with the Telescope System Instrumentation Program (TSIP).

- The only 4-m instruments that will be undertaken in-house are those major instruments that provide a capability that is seen as essential to the US ground-based system of telescopes, with wide-field IR imaging being the first, and possibly the last, example. The partners in WIYN and SOAR are expected to provide instruments for those telescopes in proportion to their shares of the observing time.

- Therefore, it is inherent in the overall instrument plan that about half of the instrumentation required for the Gemini telescopes, about two-thirds of the instruments for WIYN and SOAR, and instruments for the Mayall and Blanco telescopes be provided by the community. CTIO has a model for supporting the Blanco telescope in this way in its collaboration with Ohio State University to build and operate OSIRIS.

The following elements are key to achieving the goals of the NOAO instrumentation program:

- Strong in-house capability in project management as well as in the core engineering disciplines: systems, optical, mechanical, electronics, and software.

- A program to develop (when appropriate) and to test, characterize, and deploy detectors and controllers.

- Infrastructure adequate to support the integration and testing of large instruments, including a telescope simulator. This infrastructure will be made available to community instrumentation groups as well as to NOAO projects.

- A program to train postdoctoral associates in the skills required to provide scientific leadership in the building of large instruments and an intern program extended from the current undergraduates to graduate students.

- A program to develop and/or evaluate a limited number of key new technologies.
Project scientists must be an integral part of instrument teams, participating actively and essentially on a daily basis in the project definition, the trades that must be made through the design phase, and the integration and commissioning. For major instrument projects based at NOAO, science working groups will be established, including scientists from the community who make commitments to contribute to the project.

3.5.3 Project Phases and Resources

The phases in the construction of a major instrument are (1) the development of a concept design and proposal, (2) detailed design, fabrication, integration, and testing; and (3) commissioning at the telescope. The staffing through these stages is dynamic, with emphasis on scientists and engineers in the early and late stages, and with the addition of designers and instrument makers in the middle stages. A procurement expert with a strong technical background is an extremely cost-effective addition, facilitating outsourcing of fabrication work to help level manpower requirements. It typically takes a minimum of four years from the time an instrument is selected for funding to the time it is ready to be shipped to the telescope. From the standpoint of smoothing out the cash flow and manpower requirements, it therefore makes sense to undertake two instruments, staggered by two years, within a single instrumentation program—this is the model for the NOAO program. A Work Breakdown Structure (WBS) for the Major Instrumentation program is outlined below in Section 5 and illustrated in Section 5.8. It provides the workforce for an instrument for which the opto-mechanical components, excluding controllers and detectors, cost $4M and take four years to build.

In this concept, each of the two instruments under construction in house will require an engineering team with the core capabilities described above, and a third team that will be preparing proposals for future work. The availability of three project teams will provide continuity and eliminate one of the biggest sources of schedule delay, namely the loss of key personnel through turnover. The members of the proposal team could be reassigned to an instrument project to fill any temporary gaps in personnel. There would be sufficient redundancy to provide training and a smooth transition when new staff are hired. This third team will be made available to external groups proposing for Gemini instruments and will strengthen the quality and completeness of US proposals to the international Gemini program.

Each of these teams is potentially a partnership opportunity between NOAO and university instrumentation programs. There is clearly great merit in such collaborations, as evidenced in the development of the WIYN and especially SOAR projects; to take another example, ESO has managed to multiply its in-house efforts by collaboration with experienced research institutes. In the NOAO program, we assume that the core engineering staff will be continuing employees; we would expect designers and instrument makers, however, to be employed only when required. It is already NOAO’s practice to conduct “make-buy” reviews on all components of major instruments such as GNIRS, with the final decision being based on both internal and external bids and on cost and schedule requirements.

The total budget for the two-instrument model, including scientific as well as engineering staff, plus the supporting programs in detectors, technology, infrastructure, and postdoctoral training is $6.5 M. This design for the program assumes that one of the instruments, its supporting subprograms, and the preparation of proposals, will be provided for, to the level of $3.5M, by the NOAO core budget. The remaining instrument is to be funded by external sources, generally by Gemini. These staffing levels are adequate to produce an instrument that provides data to a system to be specified in collaboration with the Data Products program.

This program is modest relative to international investment in instrumentation and is internationally competitive only because of the planned involvement of the university community. As one
benchmark, we note that the Astronomy Technology Center in Edinburgh, which fills much the same role in the UK as that proposed here for the NOAO major instrumentation program, has a staff that is 30 percent larger, consisting of eight scientists, six engineering managers, and 53 engineers and technicians, with 21 of the latter for mechanical engineering and fabrication: nine in electronics, five in applied optics, and 18 in computing and software development. The NOAO Major Instrumentation program proposed here is the appropriate size for the US, given the more widespread instrumentation capabilities in our universities.

3.5.4 Proposed Instruments

In the course of the NOAO-sponsored community workshop on the proposed US observing “system” (Scottsdale, October 2000—see Section 3.7 below), two types of instrumentation were identified as priority capabilities needed over the next few years. These are (1) wide-field near-infrared imaging to support star formation and galaxy evolution studies with large telescopes, and (2) wide-field multi-object spectroscopy with 8-m class telescopes to understand large-scale structure and galactic halo formation.

In summary, the specific major instruments that NOAO proposes to build during the early years of the current plan are the following:

1. **A wide-field 4K x 4K near-IR imager (NEWFIRM)** for at least one 4-m telescope. Regardless of which of the 4-m telescopes is ultimately equipped with this instrument, NOAO could propose a time-trade with one of the independent observatories so as to provide community access to 4-m telescopes in both hemispheres. Failing that, there would be an option for NOAO to build a second 4K x 4K imager.

2. **The Multi-Conjugate Adaptive Optics (MCAO) 4K x 4K IR imager for Gemini.** Given experience with GNIRS and NEWFIRM, NOAO should be well positioned to submit a successful bid for this project.

3. **A wide-field high-throughput optical spectrograph that enables a very large number of spectra to be obtained simultaneously, or alternatively, a second Gemini instrument.** Which of the two instruments is to be built can be determined only after Gemini adopts a new long-range plan for instrumentation, probably within the next two years. If Gemini chooses a next-generation GMOS, these could be one and the same. (Section 3.7.2 below outlines other possibilities).

4. **The One-Degree Optical Imager (ODI) for the WIYN telescope (partial funding only).** As noted above, some or all of these instrument projects may be carried out in collaboration with instrument groups at universities or at the independent observatories.

After completing these projects, NOAO would be in an excellent position to undertake the role of prime contractor for the LSST imager and to define instrument concepts for the GSMT. The period 2003-2007 will therefore represent a steady strengthening of the national observatory’s contribution and credentials as a major instrumentation resource for the US system.
3.6 Planning a GSMT for the US Community

The past decade has witnessed the development of a new generation of large telescopes in the United States, Europe, and Japan. The potential of these telescopes to enable new discoveries and to advance and deepen understanding is already apparent from the pioneering observations carried out with the Keck 10-m telescopes: detection of galaxies with redshifts exceeding 5; the first comprehensive survey of galactic star-forming and intergalactic gas out to redshift 3; detailed spectroscopic study of the Hubble deep field. Full exploitation of their power will continue to excite the imaginations of the world’s astronomers for the next decade and beyond.

Nevertheless, astronomers can already perceive phenomena that lie beyond the horizons of sensitivity and angular resolution of today’s ground- and space-based telescopes: galaxies beginning to take form via mergers of smaller building blocks; webs of galaxies and gas beginning to emerge, their form determined from primordial fluctuations now visible from maps of the microwave background radiation; planets forming in circumstellar accretion disks. The drive to explore these new frontiers has led astronomers in the US to propose construction of a Next Generation Space Telescope (NGST) designed to explore the epochs when large-scale structure, galaxies, and stars take form. US astronomers have also recognized the need to build a ground-based telescope with collecting area and angular resolution required both to fully exploit the potential of NGST and ALMA, and to extend the horizons of today’s 8-m to 10-m telescopes: a 30-m diameter Giant Segmented-Mirror Telescope (GSMT). Fully recognizing the importance of a next generation, ultra-large OIR telescope, European astronomers have already initiated a serious planning effort to design and build a telescope of aperture ~100 m.

The importance of NGST and GSMT together to ensure continued US presence at the frontiers of astronomical research led the AASC to recommend these telescopes as the highest priority space- and ground-based initiatives. The AASC further urges that GSMT be designed, built, and operated as a partnership involving NOAO and either domestic institutions (preferred) or international partners. NOAO was charged with the essential roles of involving and representing the US community in all phases of GSMT development and operation, and of ensuring broad access to this critical research tool.

3.6.1 AURA New Initiatives Office (NIO)

In 1998 and 1999, AURA organized two broad community workshops aimed at understanding the key science to be enabled by a GSMT and the design and technology challenges inherent in the construction of the telescope and its instrumentation. As a result of these community discussions, AURA established a New Initiatives Office (NIO). Located in Tucson, and involving the activities of astronomers and engineers from both NOAO and Gemini, the primary goals of the NIO are (1) to build a strong basis for a public/private partnership to design, build, and operate a GSMT; and (2) to
develop a comprehensive understanding of key science drivers, instrumentation needs, and telescope design and technology issues. In the longer term, NIO aims to engage international partners in a constructive way that will achieve mutual aims.

Last year, the NIO science and engineering team initiated studies to:

- Identify key design, technology, and fabrication issues common to multiple design approaches (e.g., projects such as CELT, FELT, OWL)

- Understand key systems issues through analysis of a "point design," e.g., effects of wind buffeting, control system architecture, adaptive optics systems to enable diffraction-limited and wide-field native-seeing performance

- Understand site requirements and develop a plan for site testing and evaluation

- Understand the instrumentation challenges: e.g., native seeing-limited MOS spectroscopy, MCAO imaging and multi-object spectroscopy; narrow-field, high Strehl imaging and spectroscopy.

3.6.2 Current and Near-Term Activities

Prior to September 2000, these NIO efforts involved ten part-time Gemini and NOAO staff, and eight community-based task groups comprising ~80 individuals drawn from 19 US and four international academic institutions, plus five private sector companies and government laboratories. As of January 2001, NOAO and Gemini agreed, under the auspices of AURA, to fund a core NIO group comprising five full-time engineers and scientists charged with coordinating efforts to accelerate analysis of a point design concept, instrument concepts, and science requirements.

Near-term goals for the NIO are to produce:

- A summary of the key design issues for GSMT and its instruments and the studies needed to resolve these issues (completion in fourth quarter FY 2001)

- Initial trade studies aimed at understanding the cost and performance envelopes for realizable GSMT concepts (completion estimated in third quarter FY 2002)

- A proposal to carry out a preliminary GSMT design study in partnership with one or more US institutions or international partners (completion estimated in first quarter FY 2003).

3.6.3 GSMT Phase A Study FY 2003–2006

The largest single investment NOAO plans to make over the period of this long range plan is aimed at presenting NSF with the opportunity to confidently enter the AASC's planned public-private partnership—or alternatively, an international partnership—for this next flagship O/IR large ground-based telescope. NOAO will only propose a fully-costed, technically-prepared project to the relevant agencies; the work planned for the performance period is designed to reach that point in FY 2006. The principles and purposes governing NOAO's Phase A study are:
To concentrate NIO efforts on areas both complementary and relevant to those underway elsewhere (e.g., CELT, OWL, FELT, 20/20)

To exploit NOAO and Gemini expertise and strengths in such areas as adaptive optics, site evaluation, and system engineering

To involve the community broadly in developing the science case for GSMT, exploring design concepts and participating in the science-cost-performance trade studies

To design, construct, instrument, and operate GSMT in partnership with domestic or international institutions, and as recommended by the AASC, to make significant time on this frontier facility available broadly to the US astronomical community.

A proximate objective is to identify one or more partners to share in the funding of a preliminary design for GSMT starting in the second quarter 2003.

3.6.4 Resource Requirements

The NIO core group has produced program and management plans for the pre-Phase A calendar years 2001 and 2002, outlining the resources deployed to achieve the goals described in Section 3.6.3. During these two calendar years, NIO core activities, aimed primarily at analyzing the point design, are funded at $1.7M (the sum committed by NOAO and Gemini). External studies focusing on developing science requirements and instrument concepts, which will complement the engineering efforts of the NIO core group, call for investment of an additional $0.9M in FY 2002.

It is estimated that the Phase A design effort for GSMT will cost ~$30M (approximately 10% of GSMT construction costs) and span a four-year period. NOAO proposes to invest between $9.5M and $19M during fiscal years 2003–2007 as its share of funding for Phase A and possibly for Year 1 Phase B design work. The preliminary design will be led by a team of scientists, engineers, and managers drawn from the partnering institutions, and guided by science and technical working groups from the broader US community. A successful proposal in FY 2006 will carry the project into the detailed design phase in FY 2007, for which provision is also made in the proposed budget.

3.6.5 Infrastructure for Networks and Partnerships

The GSMT program will involve extensive partnerships and collaborations among NOAO, university groups, and multiple private sector firms during all stages of design, construction, and operation. Through the AURA New Initiatives Office (NIO), NOAO has already begun to involve scientists, engineers and program managers from 20 universities and five private sector/government laboratory groups in the GSMT program.
3.7 NOAO’s Role in the Observing System

The technical and facilities plan for NOAO in the period FY 2003-2007 can be read as a set of discrete pragmatic partnerships with research institutions in the astronomical community. As shown in the table below, NOAO has a proven track record of developing, supporting, managing, or participating in such cooperative arrangements with university research groups. Each of these partnerships has resulted in a major telescope, instrument, or observing collaboration that benefits the larger US community.

The partnership paradigm also clearly informs the NOAO approach to the Gemini telescopes (3.1), Kitt Peak and Cerro Tololo operations (3.2), the proposed LSST program (3.4), the proposed major instrumentation program (3.5), and the proposed activities that will lead to the GSMT (3.6). Some of these partnerships are existing, some incipient, others still theoretical. The right way to read this, however, is with the mind of the AASC, which saw a national observing system as the way in which US astronomers and their institutions could combine forces to compete, make the discoveries, and bring home the trophies in the opening decades of the new millennium. By taking this partnership approach, NOAO is helping to create the recommended observing system.

NOAO’s roles and responsibilities can be understood in the context of a coordinated system of ground-based O/IR capabilities, including both federally-funded and private/state facilities. Such a system will allow the US astronomical community to maintain its preeminent position with a federal investment guided by strategic consideration of private investments and the capabilities that they contribute. More importantly, it will allow us to exploit our space assets fully and to accomplish larger projects than could be considered otherwise. Within this paradigm, NOAO must nurture the system by (1) establishing and supporting mechanisms that guide its evolution and channel resources into it, (2) providing some of the capabilities that make it up—especially those that are appropriate to a national observatory, and (3) helping the community to use the elements of the system effectively.

Inherent in this model is the idea that NOAO represents the interests of the entire US community. NOAO has a special responsibility on behalf of (and involving) the community where the US participates in facilities developed as international collaborations.

### 3.7.1 Creating the Framework of the Observing System

The ground-based O/IR community currently has no strategic planning process other than its piece of the decadal survey. An important element of the framework of the proposed system is the creation of a mechanism by which the community can develop an evolving plan that identifies needed capabilities and

<table>
<thead>
<tr>
<th>Telescope/Instrument</th>
<th>NOAO Partners</th>
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<tbody>
<tr>
<td>WIYN</td>
<td>U. of Wisconsin, Yale U., Indiana U.</td>
</tr>
<tr>
<td>SOAR</td>
<td>U. of North Carolina, Michigan State U., Brazil</td>
</tr>
<tr>
<td>CHARA Interferometer</td>
<td>Georgia State U.</td>
</tr>
<tr>
<td>MMT observing</td>
<td>U. of Arizona, Harvard-Smithsonian Center for Astrophysics</td>
</tr>
<tr>
<td>YALO</td>
<td>Yale, Ohio State U., U. Lisbon</td>
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<tr>
<td>Abu</td>
<td>U. of Chicago, Rochester Inst. of Technology</td>
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<tr>
<td>HET observing</td>
<td>U. of Texas, Pennsylvania State U.</td>
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<tr>
<td>FLAMINGOS</td>
<td>U. of Florida</td>
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<tr>
<td>NIRI</td>
<td>U. of Hawaii</td>
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<td>T-ReCS</td>
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<td>NICI</td>
<td>Mauna Kea IR</td>
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<tr>
<td>OSIRIS</td>
<td>Ohio State U.</td>
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provides ideas for making them available. This plan should be motivated by the scientific aspirations of the community, and also must consider the larger context of using our space-based assets most effectively. The strategic plan for the system should guide federal investment, identify contributions that NOAO should make to the system, and create opportunities for the independent observatories.

NOAO has already begun organizing community discussion of these issues. This was the goal of the “First Workshop on the Ground-based O/IR System” held in Scottsdale, Arizona in October, 2000 (http://www.noao.edu/gateway/oir_workshop/). This workshop brought together a broad segment of the community with the goal of formulating a list of science-driven needs that could guide future investment in the system. NOAO will continue to organize workshops, presentations, and outreach efforts aimed at informing the broad community and involving them in discussions that lead to a system strategic plan. In addition, an O/IR System Web site has been created (http://www.noao.edu/system/) with the goal of providing current information to the community on the capabilities that are available within the system, how to access them, and how they are expected to evolve.

A second piece of the framework is the channeling of new resources to providers of the needed capabilities. The most obvious and critical example of this is the Telescope System Instrumentation Program (TSIP). As proposed in the AASC report, TSIP will be a $5 million per year program that funds the development of facility-class instruments for the telescopes of the independent observatories and provides time on these telescopes to the community, thus simultaneously improving the capabilities within the system and broadening the access to its elements. NOAO will assist the NSF in the development and operation of TSIP, providing appropriate management and administrative support. This could include managing the selection process (through peer review) itself, as well as contract management to ensure that the federal funds are used effectively and efficiently to provide the capabilities that the community has identified.

In undertaking these system framework activities, NOAO must depend on various mechanisms to assemble input from the community and integrate that input into a coherent strategic plan. This should be effected by a group that (1) maintains an overview of the ground-based O/IR system, its needs, and constraints, and (2) is as free from conflict of interest as possible. To fill that role, we envision a “System Committee” that will assist with the planning and organization of the community meetings, help formulate the discussion into a strategic plan, and advocate that plan to the funding agencies. NOAO has begun the process of establishing the System Committee, using the group that organized the Scottsdale workshop. NOAO will organize and support the activities of this committee, but it will report directly to the AURA president to preclude the perception of any conflict of interest with NOAO.

3.7.2 Implementing the Plan for the O/IR System

Through TSIP and other programs, the system will evolve as new capabilities are developed. Some of the new capabilities will naturally be provided by the independent observatories, and the effectiveness of the system will be enhanced through broad competitive access. Others will be appropriately provided by NOAO. These will include those facilities that are too large, complex, or expensive to fit within the resources of an individual institution; those that are unique or complementary; or those that demand national coordination. This distinction provides the context for the recommendations of the ground-based O/IR panel of the AASC, who envisioned one program, TSIP, aimed at involving the independent observatories in the system; one program, LSST, aimed at providing a nationally-accessible data set and therefore a program appropriate for NOAO; and a third program, GSMT, that could be accomplished only if public and private organizations work together.
At a lower level, the ongoing discussions about the system, such as that conducted at the Scottsdale workshop, provide impetus for decisions about which projects to pursue. Wide-field imaging, particularly in the near-IR, was noted as a high priority in the Scottsdale report. This is clearly an enabling capability—observations of this type will provide samples for more detailed study with current and future generations of large telescopes. The high priority of NEWFIRM within NOAO’s major instrumentation program recognizes the importance to the community of this capability.

In addition to deep infrared surveys, the Scottsdale workshop articulated the need for an order of magnitude advance in multi-object spectroscopy. In the era of DEIMOS (Deep Extragalactic Imaging MultiObject Spectrograph), VIMOS (Visible MultiObject Spectrograph) (http://www.eso.org/instruments/vimos/index.html) and AAOmega (http://www.aao.gov.au/local/www/aaomega/overview.html), it is clearly possible to step up by a factor of ten to thirty in performance on Hydra seen in Figure 1 above. Consistent with the systemic approach recommended in the decadal survey, NOAO will attempt to broker a partnership of universities to provide an 8-m class platform on which to place such a facility. An initial community workshop is currently being planned in Tucson (http://www.noao.edu/meetings/wfmos/). Science cases for 6.5-meter, Gemini, and GSMT implementations will then be compared in order to provide design constraints for the instrument in the discussion of the NOAO major instrumentation program (Section 3.5.4).

The Scottsdale workshop called for the coordination of small- and medium-sized telescopes. NOAO will explore the coordination of instrumenting and operating these telescopes and will help to establish a national network of such telescopes with some time available to the general community. This will be undertaken through regular meetings of groups operating telescopes between 1-m and 4-m in order to provide a forum for initiating partnerships.

3.7.3 Supporting Effective Use of the O/IR System

One of the fundamental steps that has already been taken toward the implementation of a national system of facilities is the incorporation of telescope time at independent observatories into the NOAO proposal submission and evaluation process. This step is important both in that it is a strong link between science and capabilities and because it presents the total suite of available capabilities in an integrated way. This activity includes the development and maintenance of the proposal process (including a unified, extensible proposal form linked to proposal preparation tools) and the sequence of peer-review meetings that result in time assigned on all the participating facilities.

Whatever type of broad access is negotiated with the independent observatories through TSIP, few will be prepared to provide the support needed for scientists outside their customary base to use the facilities effectively. Such access should be supported through documentation, availability of staff to answer technical questions, assistance in preparing and carrying out observing programs, and software and support for data reduction. NOAO can provide support in a manner that makes the most sense to each independent observatory. An approach that considers an investment proportional to the value of the telescope time being provided will ensure that the investment does not outweigh the return.

3.7.4 Resource Requirements

The system will only evolve to a more structured form with NOAO’s involvement. NOAO intends to strengthen its role as a “fair broker,” a representative of the whole community, an engine for turning scientific aspirations into real capabilities, and a creator of incentives for
cooperative approaches. The resources needed to accomplish this are not extensive, but AURA will commit the attention of upper scientific management of NOAO. The resources deployed should be proportionate to the task, which in turn is proportional to the observing nights created by the TSIP program. Until NSF funding for that is provided, the planning and coordination elements of the system framework can be undertaken at a cost of approximately $200K per year. As the system develops, NOAO will attend to setting and assisting with maintenance of standards for post-observing support of the systems users. This set of activities would be more resource intensive.

3.8 Responding to Opportunities and Changing Needs

The foregoing plan provides the best balance among the competing priorities as they exist today. However, there are several potential changes in the landscape which may trigger a shift in resources or emphasis in order to be more responsive to external developments in federal and partner funding.

1. The trigger for growth in the NIO/GSMT program will be an invitation from CELT (or other equally substantially funded 30-m telescope project) for partnership. Until then, the NIO program will continue at the FY 2002 level (plus any external funding it can raise), carrying out studies of technical issues in AO, optical design, and instrumentation. AURA’s NIO Advisory Committee will continue to ensure complete US community participation. One viable structure which may enable the public/private partnership envisioned by the Decadal Survey is one in which NOAO participates and engages the community in participating in the design and development of the GSMT during the development period and takes on the major burden of operations at some future time. This maximizes calls on federal funding in the near term.

2. The trigger for the proposed 4-m and 2.1-meter operations partnerships will be the decline in oversubscription to a factor of 3. This factor is chosen to bear some relation to a desirable value for NSF’s grant success ratio. The funds to maintain NOAO’s 100% share in these facilities, as long as is necessary, or until LSST is within sight of operations, will be found in the modified funding wedge for NIO.

3. As recommended by NOAO’s May 2001 Balancing Review, additional funding will be provided for the “System” program (WBS line 17) to enable TSIP to be supported at a level appropriate to the new funding.

4. The trigger for major investment in LSST will be completion of the FY 2002 “tall poles” study and a successful Concept Design Review at the standard of similar reviews conducted by the Gemini Project. Major investment could be the full extent of the funding wedge modified as described in (1), (2), and (3) above. Externally-led science working groups will be established at the November 5–6 workshop in Tucson.

These potential changes maximize the likelihood that some new facility of a world-leading standard will be realized for the US community in the years immediately following the 2003-2007 performance period, even in a lean near-term funding environment. They also support the opportunity for wider participation in the system opened up by TSIP.
3.9 Longer Term Plans Beyond FY 2007

Although the critical work on the top level objectives presented here will be undertaken in the course of this long range plan period, full realization of the new facilities will only be accomplished after FY 2007. After assisting the commissioning of the LSST in FY 2009, NOAO will be ready to manage either the operations of the telescope or dissemination of the data, or both. The LSST is a long-lived facility with a lifetime of at least a decade and a likely upgrade path to more rapid survey cadence. On the timescale FY 2011-2020, the survey roles of the Mayall and Blanco telescopes are projected to diminish, and closure or transfer of these telescopes is anticipated once a deep all-sky infrared survey is complete. However, there is one caveat. If LSST and GSMT are placed in opposite hemispheres, the system will need to provide, in some other form than LSST, a survey support facility for GSMT. Since the GSMT is planned to become operational with NGST, NOAO will need to be prepared for either contractual or direct operation of that telescope by 2011. At that time, NOAO projects a distribution of resources to the primary NOAO programs as depicted in the following chart.
4 PUBLIC AFFAIRS AND EDUCATIONAL OUTREACH

Modern astronomy is a potent mixture of physics, mathematics, chemistry, history and sociology, infused with ancient human wonderment about the nighttime sky. When combined with the constant tug-of-war between awesome theoretical cosmology and rigorous measurements of the Universe, the multidisciplinary nature of astronomy makes it an excellent vehicle through which the achievements and value of US scientific discovery are communicated to people of all ages.

4.1 Mission and Objectives

The mission of the NOAO Office of Public Affairs and Educational Outreach (PAEO) is to advance the cause of science education and analytical inquiry in all sectors of American life. Our ultimate goal, consonant with NSF Education and Human Resources priorities, is to further the development of a scientifically literate citizenry capable of meeting the science, engineering, and technology (SET) challenges of 21st century society (Mendoza and Johnson 2000).

Undergraduate Research Program in Astronomy (URPA) students present results of summer research project at NOAO Tucson, July 2001. (Image courtesy: K. Mighell)

NOAO believes that the primacy and productivity that US science currently enjoys cannot be sustained without concerted outreach strategies that (1) foster higher standards of science teaching and science-based learning in K-12 classrooms; (2) broaden the participation of women, underrepresented minorities, and the disabled in the SET work force, while increasing the access of these groups to quality science education at all levels of the educational system; and (3) develop and implement the learning and communications modes that make the basic research results of US science accessible and meaningful to the public at large. As the national center specifically founded on broad access to the facilities that make advances in scientific discovery possible, NOAO is in an ideal position to achieve these goals.

Although high quality personnel with experience in both astronomy and education are exceedingly rare, NOAO has been able to provide a first rate staff to manage this important function. (See NOAO Public Affairs and Educational Outreach organizational chart below.)
Following receipt of a Ph.D. in astronomy from the University of Arizona, NOAO Senior Education Program Coordinator Connie Walker has coordinated instructional resources for the UA’s introductory astronomy course, and served as a lecturer in the UA Department of Astronomy. She has also developed curricula and served on the instructional faculty at Pima Community College.

Walker’s supervisor, NOAO Education Office Suzanne Jacoby, built NOAO’s active educational outreach program from the ground up, beginning in 1995. She has been the lead author on several educational outreach papers published through the AAS and ASP, and serves as the Principal Investigator on NOAO’s $1.8 million grant from NSF EHR to conduct the Teachers Leaders in Research Based Science Education (TLRBSE) program. (Jeff Lockwood of TERC, Cambridge, MA, is a co-investigator on TLRBSE; the program was developed with input from an advisory board of middle school and high school teachers.) Jacoby has served on three NSF/EHR proposal review panels (for both teacher enhancement and instructional materials development), and was a reviewer for NASA IDEA grant proposals. Jacoby has an M.S. degree in astronomy from New Mexico State University.

NOAO also intends to hire a dedicated Education Specialist to organize the day-to-day operations of TLRBSE, with advertised qualifications to include five-years experience teaching at a middle or high school level, and evidence of leadership in their local school district or community. NOAO benefits, and will continue to benefit, from the availability of a synergistic astronomy education program at the University of Arizona.

As described in NOAO’s successfully funded TLRBSE proposal, the NSF AST Division is expected to help support the education program in FY 2004 and FY 2005 through augmented funding for AURA/NOAO educational outreach, as proposal-related NSF EHR funds decline.
If absolutely necessary budgetarily, we can transition to partial support from participating teachers and their institutions, as is commonly done in other teacher training programs, via Eisenhower grants and other professional development funds. A unique, high-quality program merits such a partially offsetting fee.

4.1.1 Integration of Research and Education

The NOAO educational programs planned for the next five years are derived from a single overarching strategy: the use of the forefront astronomical research activities of the national O/IR observatory to support efforts to raise national standards in science education and technical training. The use of NOAO science and its unique facilities as the framework for promoting public understanding, awareness, and support of US science also underscores NOAO outreach activities to the non-specialist public. Whether via NOAO's newly revamped Newsletter, its new “public-friendly” Web site (http://www.noao.edu), the popular exhibits and guided tours at the Visitor's Center on Kitt Peak, or the stream of press releases and scientific news items produced by the Public Information and Media Outreach group—NOAO regularly communicates the excitement and significance of astronomical research to a wide range of audiences.

4.1.2 Astronomy Education Review

A new EO-related project, still in the planning stages and as yet unfunded, aims specifically to bridge the gap between current astronomical research and science teaching, science learning, and broad science communications to the public. Astronomy Education Review, conceived by S. Wolff as a “lively compendium of research, news, and opinion,” is designed to fill a long-recognized need for a forum in which non-specialist educators and other science professionals are informed on current research knowledge and successful approaches in science teaching and public outreach. Though educators doing specialized research in science pedagogy are likely to be interested in these topics, the journal is broadly aimed at a core audience of non-specialists from all corners of the scientifically-literate universe: K-12 science teachers and student teachers, college and university instructors in introductory astronomy and physics courses, graduate students with career interests in astronomy education, science journalists and authors, and non-academic outreach staff in museums, planetaria, non-profit science societies, research institutions, and even corporations. This vast, diverse group of science professionals could benefit enormously from peer-reviewed, high-quality information on successful teaching models, learning formats, and communications strategies that can be adapted to energize their presentation of the world of astronomy to their particular audiences.

The new journal is projected to be published electronically on the Web, possibly in combination with a paper version in the beginning. External funding will be sought for start-up funds for the design and implementation of the Web-based services. NOAO will provide limited administrative assistance and support in the early stages, and NOAO PAEO professionals will also contribute time and skills to the project. S. Wolff will contribute startup strategic and editorial planning, and will be associated with the editorial content when the project is realized.

4.2 K–12 Educational Outreach (EO)

From modest beginnings in 1995 in the person of a single half-time Education Officer and a budget of $20K, EO has grown into an entrepreneurial and nearly-self-supporting unit within NOAO that
delivers exemplary astronomy-based learning and teaching tools to classroom students, teachers, and scientists across the country. Thanks to the commitment of its small staff—coupled with impressive successes in securing most of its program funding from sources outside the NSF Astronomical Sciences division—NOAO EO programs are directly addressing national reform priorities in the teaching of science and math in the K-12 educational system.

4.2.1 Professional Development for Teachers through TLRBSE

The NSF-funded “Use of Astronomy in Research-Based Science Education” (RBSE) has been one of the key programs in EO efforts to integrate scientific research as conducted by professional astronomers with the teaching of science as practiced by teachers in the classroom. RBSE is an exemplary teacher enhancement program that links the processes and results of current astronomical research with the creation of science-based curriculum models and teaching strategies. With the participation of NOAO and other astronomers who act as mentors to the teacher-participants, this highly successful program engages classroom teachers in cutting-edge astronomical research projects that enhance their pedagogical skills, content knowledge in astronomy and physics, and grasp of computer-based tools such as data and image processing.

Over the course of the current proposal period, the RBSE program is slated to grow in two directions. First, the range of astronomical research projects that form the basis of the program will be expanded beyond the initial three (solar variability, novae search in local group galaxies, and AGN classification) to include more areas of current astronomical inquiry. Collaborations with research astronomers outside NOAO are part of this effort. Discussions are underway with astronomers from the University of Arizona, the Planetary Science Institute, and an NSF-funded post-doc associated with the Deep Lens Survey at CTIO (A. Tyson, PI) to develop RBSE modules for their respective research programs.

Second, the focus of the original RBSE program has been expanded and re-structured in a new five-year program, “Teacher Leaders in Research-Based Science Education” (TLRBSE), in which experienced middle and high school “teacher leaders” are mentored and trained in RBSE teaching models and approaches. These “master” teachers in turn are prepared to train and mentor novice teachers in the exemplary science-based tools that will eventually help transform student learning in science and mathematics in our schools. A primary goal of TLRBSE is to develop an Internet-based, moderated distance-learning course encompassing pedagogy, leadership and astronomy content.

Funded through the NSF Education and Human Resources Directorate, the new program is expected to involve 360 secondary teachers (of which approximately 100 will be trained as master teachers).
over the next five years. Beginning in the summer of 2001, each participant will be involved in the program for two years—either as master teachers, novice teachers, or participating astronomers and mentors—in a variety of programmatic activities, including the on-going course on the Web. The TLRBSE program will eventually evolve into a free-standing, fee-based, teacher enhancement program within the NOAO core program, requiring no additional funds from the NSF Education and Human Resources Directorate beyond the initial period.

4.2.2 Project ASTRO

Project ASTRO teams professional astronomers with 4th to 9th grade science teachers and community educators in order to enrich science education in ways that engage children’s interest in the excitement of astronomical events and scientific discovery. The on-site workshops emphasize a hands-on approach to science learning and are based on classroom activities through which children learn about the processes, methods, and content of science. Began by the Astronomical Society of the Pacific, Project ASTRO was established in Tucson in 1996 with NOAO as the lead institution. Since that time, more than 250 teacher-astronomer partners have attended the two-day training workshop, reaching more than 12,000 students in the Tucson area. Project ASTRO has expanded to ten regional sites, forming the Project ASTRO National Network. NOAO served as the first Chair of this network in 2000, and will return to this leadership role in 2003.

4.3 Undergraduate Education

NOAO has a long-standing commitment to undergraduate education, beginning with the pioneering summer program for Native American, Hispanic, and Black Undergraduates (NAHB)(1980–1984), and since 1989, with the NSF-funded Research Experiences for Undergraduates (REU) program. The REU program was created to encourage undergraduates—especially women, underrepresented minorities, and students from institutions lacking access to first-rate research staff and facilities—to pursue careers in science. REU site programs at KPNO and CTIO provide a real-world context in which college students work as research assistants to NOAO astronomers on some of the major questions in current astronomical research. Both site programs were revamped in 1998 to involve REU students in more substantive research topics likely to lead to publishable results and to subsidize the attendance of all REU students at a major astronomical meeting. As a result, virtually all REU participants now publish some aspect of their research findings within 12 months of leaving the program—typically in a collaborative poster paper at a later AAS meeting. Thanks to NSF funding, NOAO plays a direct role in preparing the future professionals who will sustain US preeminence in science, engineering, and technology.

The impact of NOAO REU programs on the SET work force is clear. In a recent follow-up survey of 68 alumni who attended the program between 1991 and 2000, all but one are currently active in an occupation related to physics, astronomy, or computer science. Twelve have become career scientists, and 3/4 of the former REUs have attended, are currently attending, or have expressed their intention to attend graduate school in science. Minority representation, largely Asian-Americans and Hispanic-Americans, is estimated at 20% over this period. The representation of women in all REU programs
over the past ten years is about 50%. In the current KPNO and CTIO REU programs, women constitute the majority.

On any given weekday between June and August, no fewer than 25 undergraduate students from colleges and universities all over the US can be found in the corridors and offices of NOAO and NSO in Tucson. Whether engaged in working, studying, attending meetings, or networking informally with any number of NOAO/NSO scientific, engineering, or technical staff members, the mentoring relationships that result are as enriching for scientists as they are for the students.

In addition to the REU program, NOAO participates in the NASA-funded Arizona Space Grant Consortium, which sponsors an undergraduate intern at NOAO in space science, and NASA has also provided funding for two African-American undergraduates from South Carolina University to work as summer research assistants in the Summer 2001 REU program under the new Undergraduate Research Program in Astronomy (URPA) program. The GNIRS project has initiated a summer internship for four University of Arizona undergraduates interested in instrumentation to work in the NOAO Engineering and Technical Services department, and NOAO's WIYN partners have two undergraduate assistants working on the Tip/Tilt imager project in Tucson this summer. Finally, an REU-like instrumentation internship for two Chilean university students is supported by CTIO and runs concurrently with REU program in La Serena.

4.3.1 Recruitment of Underrepresented Minorities to the REU Program

In a continuing effort to increase participation of underrepresented groups in all NOAO educational outreach programs, NOAO’s mailing list for REU recruitment has grown by more than 30% over the past few years, including multiple mailings targeting Historically Black Colleges, the Hispanic Association of Colleges and Universities, and the American Indian Science and Engineering Society. Notwithstanding these and other outreach efforts, NOAO has not been as successful as might be hoped in encouraging underrepresented minority students, notably African-Americans, to apply to its REU program. While there may be various reasons why relatively few African-American undergraduates are selecting the NOAO program as their first choice for a summer research job—and it is unrealistic to suppose that NOAO is not in competition with other REU programs for a diminishing pool of science students in all demographic categories—it seems that NOAO recruitment methods are not reaching the underrepresented minority students we want to apply to our REU programs.

This problem has been squarely confronted by the NOAO director and a new recruitment strategy has been formulated. Beginning with next recruitment season, volunteer NOAO astronomers will conduct in-person site recruitment activities at selected Historically Black Colleges. These recruitment visits will consist of science seminars or other informal meetings in which the NOAO REU program will be described, discussed, and promoted as the first choice for any science undergraduate interested in getting research experience in the nation’s premier O/IR observatory.

Given the lack of spare funds in the REU program budget to support such direct interventions in minority recruitment, most on-site visits can take place only in the course of the NOAO scientist’s regular travel to scientific meetings or workshops; thus the location of the college and the timing of the visits will depend on the recruiting scientist’s travel plans over the course of a given year. The incremental travel costs and associated expenses of the one-day site visits are therefore expected to be...
manageable within the already strained travel budget for NOAO scientific staff. The most significant
cost is the recruiting scientist’s time and the incalculable value of his/her commitment to the REU
program.

4.4 Public Outreach

NOAO’s Public Outreach group manages all activities at the Kitt Peak Visitor Center, including the
center’s educational exhibits and retail operations, three daily tours of Kitt Peak observatories, the
Kitt Peak docent program, and the increasingly popular fee-based nighttime observing experiences
for both the general public and advanced amateurs.

4.4.1 Kitt Peak Visitor Center

Kitt Peak attracts more than 50,000 tourists annually. The Visitor Center serves as the hub for all
these visitors, providing information, services, and educational activities on the mountain, NOAO
facilities, and astronomy in general. NOAO is planning a series of significant upgrades to the Visitor
Center facility, with new audiovisual hardware and updates to its colorful display posters, more
hands-on displays, a new educational exhibit on the International Gemini Program and related NOAO
science, and a new display for the Center’s important and unique collection of historic Native
American baskets.

The Visitor Center gift shop generates much needed revenue through sales of popular-level
astronomy books and related clothing, Tohono O’odham crafts, and various astronomical items, as
well as a line of products directly related to Kitt Peak. As part of its educational and training
outreach to underrepresented minorities, the Kitt Peak Visitor Center continues to support the Tohono
O’odham Summer Youth Program by having a Native American student assist Visitor Center staff in
daily operations. The Kitt Peak docent program, including three daily tours of the Mayall 4-m, the
2.1-m, and the McMath-Pierce solar facility, not only constitutes a rewarding volunteer experience for
the 30 docents themselves, but also provides invaluable support to the public education mission of the
Visitor Center. A new and more in-depth educational training program for Kitt Peak docents has been
designed and is slated to begin in the Fall of 2001.

4.4.2 Public Observing Programs

The Kitt Peak Nightly Observing Program (NOP) is a fee-based program aimed at introducing the
general public to the wonders of astronomy. Limited to a maximum of 20 participants, NOP sessions
feature an in-depth, three-hour observing experience using star charts, binoculars, and the Visitor
Center’s 0.4-m telescope. With an annual growth rate of 10%, the NOP is one of the most popular
educational attractions at Kitt Peak, with more than 16,000 participants since its inception in 1996.

The Advanced Observing Program (AOP) is also a revenue-generating program targeted to amateur
astronomers interested in observing with a large telescope and state-of-the-art instrumentation. The
AOP is an all-night observing session (with no more than two participants per session) using the
Visitor Center telescope outfitted with a CCD camera operated with the help of an NOAO Public
Outreach telescope observer. This unique and popular program attracts participants from around the
world and receives positive publicity in both tourism and amateur astronomy publications, such as
the July 2001 issue of Scientific American and the October 2000 issue of Astronomy magazine,
which featured a six-page article and many astronomical images taken by participants.
In addition to the regularly scheduled NOP/AOP programs, the Visitor Center conducts special observing events throughout the year, such as public sessions for astronomical events like meteor showers and lunar eclipses. The Visitor Center staff and 0.4-m telescope are also an integral part of the RBSE Teacher Enhancement Program on Kitt Peak. Last summer, for example, a group of 16 teachers used the Visitor Center telescope for eight nights to obtain imaging data for use in the classroom. Special activities for visiting school classrooms, funded partially from monies donated for this purpose but not fully utilized, are a near-term priority under development.

The daily revenues generated by the Visitor Center attendees and programs help to offset much of the costs of NOAO's Public Outreach activities, including much-needed capital improvements to the Visitor Center building itself and equipment upgrades for the Center’s telescope. These revenues will also permit the creation of new interactive exhibits in the Visitor Center, as well as some planned improvements to the front patio area for purposes of safety, functionality, and aesthetics.

4.4.3 Public Outreach Partnerships

Over the course of the proposal period, the NOAO Public Outreach group will continue to work with the Southwestern Consortium of Observatories for Public Education (SCOPE), a cooperative of research institution-based visitor centers in the Southwest that promotes public awareness of astronomy through access and education. The consortium includes Kitt Peak National Observatory, the National Solar Observatory, Apache Point Observatory, McDonald Observatory, the National Radio Astronomy Observatory/Very Large Array and Whipple Observatory.

Educational posters, brochures, and lesson plans that focus on specific astronomical topics are regularly produced for dissemination by SCOPE members. NOAO also plans to build on the skills and experience of its newly hired Public Outreach manager to expand professional networking and cooperative publicity more effectively into the mainstream tourist environment across Tucson and in the surrounding region. The new manager, R. Fedele, will also develop a marketing program to increase sales of posters and related products based on NOAO imagery and scientific results.

4.5 Media Outreach and Public Information

More frequently than any other scientific field, astronomy and related topics such as planetary science are the subject of regular front-page newspaper coverage and analogous interest from major
television and radio news outlets. In combination with material posted simultaneously on the Internet, these media stories provide an extreme "multiplier effect" that can bring the latest exciting scientific results to the attention of millions of people around the world.

In the year ahead, NOAO plans to expand its media outreach into the growing world of Internet web casting by offering Real Video press conferences based on newsworthy results as they are published, in the same general style as the more costly and more labor-intensive Space Science Updates televised by NASA. (This web casting equipment will also be utilized for distance learning-based educational outreach programs and by project offices within NOAO to communicate with their users and advisory groups.)

PAEO has also completed a total re-design of the NOAO Home Page on the World Wide Web, streamlining its appearance by vastly reducing the number of links on the main entry page and increasing its visual appeal by focusing on a highlighted astronomical image that is updated regularly. Although the page retains its fundamental usability for the professional community (including a primary link to the latest materials related to the AASC decadal survey, titled "Developing The Future"), the NOAO Home Page is organized around the central principle of presenting a clear and interesting site for a Web surfer from the general public.

Related efforts include a major exhibit presence at each biannual meeting of the American Astronomical Society, based on the latest imagery and scientific results being presented at the meeting by NOAO, such as the Deep Wide-Field Survey (subject of a new exhibit produced in-house for the January 2001 meeting) and the US Gemini Program (featured at the June 2001 meeting.) By working closely with the AAS Press Officer and by pro-active networking with the astronomy-oriented news reporters who attend each meeting, NOAO will continue to produce significant science news coverage in major media outlets, as evidenced by recent stories published by ABC-TV, USA TODAY, and Reuters, including one of the first mainstream wire stories on the National Virtual Observatory.

The NOAO Image Gallery (http://www.noao.edu/image_gallery/) is accessed regularly by textbook writers, museum researchers, the media, and the public, as evidenced by a daily stream of requests for image use permission and frequent use of NOAO imagery by the popular Web site "Astronomy Picture of The Day." NOAO intends to expand this archive by increasing its interaction with researchers at CTIO and with the users of the Gemini telescopes, and by taking better advantage of the excellent images produced by the Kitt Peak Advanced Observing Program. This program for advanced amateur astronomers recently produced an image that was used as context for a press release from the European Space Agency's news office for the Hubble Galactic Flareworks. The colors within this image of a portion of a giant star-forming region in the southern sky known as the Carina Nebula (NGC 3372) trace the temperature of ionized gas in the region (blue is relatively hot and red is cooler), as radiation from the bright massive star Eta Carinae pushes apart nearby molecular clouds. NOAO Image Gallery.

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Space Telescope. Numerous other NOAO images have been used with more frequency to help illustrate releases from the Space Telescope Science Institute and its Hubble Heritage Team.

Future media and public information-related thrusts include more active cooperation with NASA on space-based astronomy missions such as SIRTF, highlighting the synergistic relationship between ground-based and space-based infrared astronomy (and, in the process, the connectivity between NSF and NASA.) An integrated media and outreach effort with the International Gemini Program has been given a “kick start” by a productive series of meetings between the NOAO manager of public affairs and his counterpart at Gemini; a full joint meeting of outreach staff from all seven partners is planned for Spring 2002.

Proposed major program initiatives, such as GSMT and LSST, will be highlighted by new information products on the Web, and related displays and exhibits at the meetings of the American Astronomical Society and other external organizations such as the International Dark-Sky Association.

The future goals of NOAO, and the observatory’s emerging roles in the larger astronomical community, will also become a more integral part of the quarterly NOAO Newsletter. Editorial guidance of the newsletter has been re-assigned to the Office of Public Affairs and Educational Outreach in order to emphasize the newsletter’s sharper focus on fostering regular and responsive communication with NOAO’s many and disparate customers, partners, and public stakeholders.
5 NOAO MANAGEMENT PLAN

The qualifications we look for in a good manager are track record, human relations skills in staffing, an understanding of the customer, a business and organization plan, and a performance assessment regime. In this section, we deal with each of these in turn.

5.1 NOAO's Track Record: Major Contributions of the National Observatory

Over the forty years in which AURA has been operating and developing the National Optical Astronomy Observatory, astronomy has moved from being a remote science of interest to specialists to a national and international enterprise engaging the best analytical minds, cutting-edge technology, the media, and the national infrastructure for science education, to realize a variety of aspirations related to the advancement of knowledge. Throughout this time, the national observatory has been intimately involved with every aspect of this extraordinary growth, remaining responsive at all times to the nation's science community it serves. A list of scientific highlights in extragalactic astronomy speaks for itself:

<table>
<thead>
<tr>
<th>Date</th>
<th>Science</th>
<th>NOAO Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1971:</td>
<td>Entry into the Lyman $\alpha$ Forest:</td>
<td>KPNO 2.1-m spectroscopy (Lynds 1971)</td>
</tr>
<tr>
<td>1978:</td>
<td>Flat rotation curves and non-rotating ellipticals:</td>
<td>CITO and KPNO 4-m spectroscopy (Rubin, Ford, and Thonnard 1978; Illingworth 1977)</td>
</tr>
<tr>
<td>1982:</td>
<td>Density of QSOs with $z &gt; 3.5$:</td>
<td>CITO 4-m spectroscopy (Osmer 1982)</td>
</tr>
<tr>
<td>1989:</td>
<td>First lensed arcs:</td>
<td>KPNO 4-m imaging (Lynds and Petrosian 1989)</td>
</tr>
<tr>
<td>1990:</td>
<td>The Great Attractor:</td>
<td>CITO 0.9-m, KPNO 1.3-m, 0.9-m photometry (Burstein, Faber, and Dressler 1990)</td>
</tr>
<tr>
<td>1992:</td>
<td>IRAS redshift surveys:</td>
<td>CITO spectroscopy (Strauss et al 1992)</td>
</tr>
<tr>
<td>1993:</td>
<td>The SNe Ia peak luminosity-decline rate relation:</td>
<td>CITO, KPNO imaging (Phillips 1993)</td>
</tr>
<tr>
<td>1997:</td>
<td>Optical counterpart of Gamma Ray Burster 970508:</td>
<td>KPNO 0.9-m (Sahu et al, 1997)</td>
</tr>
<tr>
<td>1998:</td>
<td>Observational evidence for the cosmological constant and an accelerating Universe:</td>
<td>Blanco telescope imaging (Riess et al. 1998; Perlmutter et al. 1997)</td>
</tr>
</tbody>
</table>

In astronomy, discoveries do not come from pure research, they come from the development of new technology to observe at different wavelengths, to look deeper into the Universe, to make more accurate observations, and so forth. To advance astronomy, the national observatory has been in the forefront of technological change. Some illustrative examples:
• Development of InSb IR arrays culminating in the Aladdin 1K array, and continuing with the present Orion 2K development.

• Early support of the University of Arizona Mirror Lab and the technology for off-axis parabolic segments for large primary mirrors.

• Telescope support of state-of-the-art university instrumentation, e.g., Fabry-Perot Interferometer (T. Williams, Rutgers U.), OSIRIS and ONIS (D. Depoy, OSU), Big Throughput Camera (A. Tyson, Bell Labs, and G. Bernstein, U. Michigan), OSCIR (C. Telesco, U. Florida), Flamingos (R. Elston, U. Florida), Fiber-Optic Echelle (L. Ramsey, Penn State); Goddard Fabry-Perot Imager (B. Woodgate, GSFC).

The central importance of technological breakthrough is a characteristic of astronomy that it shares with physics. A distinguishing characteristic, however, is the richness of the phenomenology of astronomy, which allows a large community (including especially students) to be profitably employed in discovery and exploration. This contrasts with fields such as high-energy physics, where the science is concentrated in a few key threshold experiments. The national observatory has been a good fit to the shape of the discipline in this respect, too, as illustrated by the following highlights of NOAO strategic leadership in the community.

• Development of the NOAO proposal for Gemini.

• Major initiatives subsequently ranked highly by the AASC decadal survey committee, identified as early as 1999 ([http://www.noao.edu/dir/lrplan/2000/](http://www.noao.edu/dir/lrplan/2000/))

• Autonomous Southern-hemisphere facilities located at CTIO: e.g., 2-Micron All-Sky Survey (2MASS), Swarthmore, GONG, USNO.

• Partners at Kitt Peak, including NRAO, Steward, MDM, Case Western, SARA, Calypso, NASA-MIT, and the RCT Consortium.

• Consortium-based facilities (YALO, WIYN, SOAR) have been developed as both national and international partnerships. These partnerships demonstrate a maturing of the relationship between NOAO and the community.

Finally, the published research productivity of the NOAO scientific staff, when last evaluated by Abt (1993), was the equal or better of the three large national astronomy centers (NOAO, STScI, and NRAO) in terms of publication rate per AAS member. An analogous count of University of Chicago Press publications for the year 2000 showed that both NOAO and STScI staff had increased their output to, respectively, 1.9 and 2.3 papers per AAS member. A scientifically productive staff (note their presence in the list of scientific highlights above) is a sign of an effective national observatory.

5.2 Plan for NOAO Scientific Staff

A national observatory could be a set of telescopes, an office, or even a call center. NOAO is a scientific research organization whose mission is to enable research and discovery in US ground-based astronomy and to communicate widely with its various constituencies in the community. The heart of any research organization is its staff of researchers, and NOAO's scientific staff sets the
overall standards for the institution. These standards include the quality and state-of-the-art nature of the research facilities, their relevance to the key research questions of the day (and of the day after), the research ethos of the institution, the match to university research culture and educational goals, and the ability of NOAO to innovate, to plan for the future, and to anticipate user needs.

To recruit and retain a scientific staff able to fulfill these roles, AURA reproduces in its national centers the conditions of service enjoyed by scientists in major research universities, but substitutes service to NOAO and its users for the university faculty member’s teaching load. A 50/50 split between research and service, and performance standards matching those of major research universities, are intended to ensure that NOAO scientific staff members are the peers of their university colleagues and that they are invested in the research goals of NOAO users. Standards for tenure and post-tenure review are maintained at the level of major research universities, and this is closely monitored by AURA’s Observatory Council and Board of Directors. NOAO’s tenure committee makes innovation a criterion for tenure, in addition to research and service, emphasizing the importance of continuous improvement of NOAO’s research facilities.

NOAO staff earn the respect of their peers, both in science and in service. Recent outstanding achievements include the significant role of NOAO astronomers Nick Suntzeff, R. Chris Smith, and Robert Schommer in the detection of an acceleration term in the expansion of the Universe. The High-Z Supernova team ([http://www.harvard.edu/cfa/oir/Research/supernova/HighZ.html](http://www.harvard.edu/cfa/oir/Research/supernova/HighZ.html)) of which they are members received the “Top Science Result of the Year” award from the editors of the AAAS’s Science magazine in 1998. Another excellent example is the recent election of astronomer Caty Pilachowski to the presidency of the AAS.

In addition to the professional respect of colleagues, NOAO’s mission demands that its scientific staff play a leadership role in the community. Academic or research leadership is a subtle blend of advanced thinking, effective communication, and service/facilitation. Recent demonstrations of NOAO’s credentials in community leadership include the organization, under AURA auspices, of the Maximum Aperture Telescope (MAXAT) workshop (Tucson, 9/16–9/17, 1999), the National Virtual Observatory workshop (Tucson, 2/27-2/28, 2000), the Adaptive Optics workshop and resulting AO road map (Tucson, 12/13–12/14, 1999), the workshop on Gemini AO data reduction (Tucson, 2/26–27, 2001), and co-sponsorship of the Scottsdale workshop on the ground-based O/IR system (10/27–28, 2000). In addition, the participation of some NOAO staff scientists on the relevant blue ribbon panels of the AASC Survey Committee allowed NOAO to play a strategic role in formulating the Committee’s decadal plan for US astronomy.

### 5.2.1 Concept of an “Extended” Scientific Staff

As NOAO evolves to meet the challenges of the next decade, so must its approach to providing the scientific leadership critical to ensuring the success of LSST, GSMT, major new instruments, and the development of data exploration tools. AURA’s vision is not only to invest in a core NOAO staff of exceptional ability and dedication, but over time to develop a mechanism to support and involve non-NOAO scientists from the community as integral partners in planned scientific programs. In its ultimate realization, this vision would thus comprise the core NOAO scientific staff groups in Chile and Tucson, augmented by an “extended” scientific staff with the skills and scientific interests tailored to current challenges.
The goal of providing an effective archive with powerful tools for data exploration is a critical component of the "new" NOAO and as such, can serve as an example of how the "extended staff" concept will operate. Achieving the goals of the data products program will require the expertise of scientists who complement NOAO staff activities in support of surveys and associated data management challenges as we enter the era of petabyte databases and real-time processing of terabytes of data each night. Rather than recruiting an additional cadre of scientists to the NOAO core staff, an alternative plan would turn to the community and support individuals currently at universities, but willing—with support from NOAO—to bring their expertise to bear on key aspects of data exploration challenges for periods of several months to several years. In each case, NOAO would work with prospective external staff members and their home institutions to develop mutually agreeable financial support packages and leave durations and cadences.

This new model has the advantages of great flexibility in assembling the teams and partnerships required to meet evolving needs and opportunities. Indeed, it recognizes that the scientific staff of a national observatory can and should be representative of the national scientific community.

5.2.2 Engaging the Community in Scientific Leadership Roles

In order to establish over the near term, clear scientific leadership that can engage the community, science working groups for the major new programs will be established for GSMT and LSST. They will be led by the best person for the job, which will include non-NOAO staff members.

5.3 NOAO's Users

Service organizations must know their customers and their customers' needs through effective communication. The primary customers of NOAO are individual researchers whose needs vary greatly. The "movers and shakers" of the major research universities look to NOAO for state-of-the-art software tools and survey materials so as to gain maximum advantage from their concentrated investment in their own institutional facilities, such as the Keck Telescope.

At the other end of the spectrum, the users of the facilities accessible through NOAO who have no institutional research infrastructure look to NOAO for everything. Since no institution, no matter how well endowed, no matter how distinguished its faculty, has a monopoly on breakthrough ideas in science, the fundamental commitment of NOAO is to maintain open, competitive access to cutting-edge O/IR ground-based facilities, either directly or through the availability of these facilities via the integrated observing system envisioned by the AASC.

5.3.1 Communication with Users

NOAO has a strong commitment to communicate with and respond to its customers. NOAO maintains a Web site, the quarterly NOAO Newsletter, and a Users' Committee. Through AURA, interaction with and responsiveness to developments in the community are supported through the Observatory Council (OC), the Board of Directors, and the Observatory Visiting Committee (OVC), which reviews and evaluates the performance of the AURA ground-based centers on an annual basis. In addition to oversight and representation of community interests, these AURA groups play an important role in resolving community conflict and controversy—the inevitable by-products of the intellectually dynamic and diverse culture of US astronomical research.
NOAO’s communication with the research community is a broadband interface that operates on a number of levels. The broadest is the grassroots level of the individual astronomer. As seen below in a map of the states of origin of principal investigators at NOAO facilities, the national coverage of the national observatory is virtually complete. Feedback is received from every user of NOAO facilities who completes a report form. More formal and more channeled interfaces are provided by the Time Allocation Committee (TAC) and the Users’ Committee. AURA’s capacity for transferring successful administrative approaches from one center to another is illustrated by the reorganization of NOAO TACs by sub-field, following the example of the Space Telescope Science Institute. The research activities of the NOAO scientific staff provide another effective interface with the O/IR community. In FY 2000, for example, almost 30% of the publications authored by NOAO’s visiting scientists involved the collaboration of at least one NOAO scientific staff member.

5.3.2 Support for NOAO Observers

Since it is the NSF that provides funding to NOAO, there is a tendency to take a 180° view and identify NSF as the “customer.” More appropriately, however, NOAO is accountable to NSF for delivering value for the taxpayers’ investment in its astronomy centers. NOAO conducts itself in many ways as an extension of the Foundation. Where NSF awards grants of funds, NOAO awards grants of telescope time, and like NSF, NOAO conducts a rigorous process of peer review to select awardees competitively and without bias.

NOAO has developed mechanisms for reviewing and scheduling access to its telescopes. NOAO Time Allocation Committees select proposals on the basis of scientific merit. The graphs below show the annual oversubscription rates—i.e., the ratio of telescope nights requested to the number of nights available to be scheduled—for the 10 semesters 1997–2001.
KITT PEAK NATIONAL OBSERVATORY
Annual Oversubscription Rates By Telescope
1997 - 2001

1999: Start of Survey Program; KP 0.9-m closed
2001: Nights available corrected for pre-allocation to NASA mission support

CERRO TOLOLO INTER-AMERICAN OBSERVATORY
Annual Oversubscription Rates By Telescope
1997 - 2001

5.3.3  *Projected Telescope Time Allocations*

NOAO's programs to provide for scientifically robust surveys and coordinated measurement programs with space missions have been widely recognized as extremely valuable despite the impact on user nights. Although external partnerships for the 4-m telescopes would provide funding wedges for new initiatives, at present AURA is not proposing to do so unless, as laid out in Sec 3.8, proposal pressure drops below a critical threshold or, based on consultation with NSF and the community, it is determined that it is advantageous to do so.

The following illustration shows the number of nights that will likely be available as SOAR and Gemini come on line, as additional surveys are carried out, coordinated measurements with NASA missions are carried out, and time trades under the TSIP program are achieved.
5.4 NOAO Divisional Structure

The plans for NOAO presented above are clearly defined and large in scope. The challenge, however, is to realize these plans within the steady-state budget proposed by NSF—as opposed to a “big bang” budget.

The overarching management strategy is to (1) downsize KPNO to basic observatory operations; (2) maintain CTIO as NSF’s fully capable observatory in the southern hemisphere; (3) develop NGSC as a science center with distributed sites, and (4) concentrate major creative engineering in Tucson, one of a few ground-based O/IR hubs in this specialist area.

<table>
<thead>
<tr>
<th>Program</th>
<th>KPNO</th>
<th>CTIO</th>
<th>NGSC</th>
<th>Tucson</th>
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<tr>
<td>Operations &amp; User Support</td>
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<td>X</td>
<td>X</td>
<td></td>
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<tr>
<td>Science Research</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Education &amp; Outreach</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>Data Products</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NIO/GSMT</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>LSST</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
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<tr>
<td>Major Instrumentation</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Financial Management &amp; Administration</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

KPNO, CTIO, NGSC, and Tucson are the four primary divisions of AURA’s management plan. These are presented in the columns of the matrix above; the programs carried out by each division are...
shown in the rows. Though most of the program functions are cross-divisional, each is headed by a manager who reports directly to the NOAO director. The management reporting structure of the NOAO director’s office is presented in the organizational chart above.

5.4.1 Work Breakdown Structure: KPNO and CTIO

The Work Breakdown Structure (WBS) for each of the four NOAO divisions is shown in the following charts. The WBS components of KPNO and CTIO are designed for easy comparison and for the interchangeability of best practice from one to another. (The Chile site testing program mentioned in Section 3.6.1 is part of the NIO/GSMT program. The outreach program in La Serena is described in Section 3.2.4.)
5.4.2 NGSC Organization and Work Breakdown Structure

The NOAO Gemini Science Center is a distributed center with nodes in La Serena and Tucson; conceptually there is provision for an extension to Hilo. A Hilo node would formalize the cross-training of instrument scientists through experience in operations (see Section 3.1.3). Management of NGSC, however, follows functional, rather than geographic lines. The three functional areas are user support, operations, and development.

5.4.3 Work Breakdown Structure: NOAO Tucson

Those work packages that are most efficiently managed centrally are located in NOAO headquarters in Tucson. The Associate Director for Science, Steven Strom, is responsible for fostering a strong science program at NOAO, including organizing scientific and strategic workshops and a science visitor program, operating a mentoring program for postdoctoral and tenure-track scientific staff, bridging observatory divisions to promote observatory-wide science, and promoting science of scale carried out in collaboration with the astronomical community. As seen in this chart, Central Administrative Services (CAS) is the largest unit in Tucson headquarters, with the following functions: financial management, budget, contracting, human resources, procurement, and payroll. These
functions will continue to be managed centrally in Tucson; AURA has no plans to make changes in this unit other than process improvements derived from its experience in other centers. **Central Facilities and Operations (CFO)** handles building maintenance, vehicles, utilities, and communications. **Computer Infrastructure Support (CIS)** includes both network support and all the computer hardware comprising the network. Although Tucson is the largest division of NOAO, it is also the one where the bulk of the creative work implementing the AASC decadal plan will be done, specifically in the LSST, Data Products, and NIO/GSMT programs. These programs make up approximately 40% of the division’s budget. Their organization is examined in more detail in Section 5.6.

### 5.5 NOAO Business Plan: FY 2003–2007

The problem of funding new program initiatives within an inelastic budget envelope which does not in itself provide for new incremental funds is a standard challenge in scientific management. Under the “Cheap Ops” model, funding for the new Data Products and LSST programs will be derived primarily from reductions in the operations costs of the Mayall and Blanco telescopes.

NOAO’s successful experience with telescope cost-sharing in the WIYN and SOAR partnerships demonstrates that AURA need not resort to the drastic solution of closing facilities to realize the savings required for the new initiatives. The funding profile shown in Figure II-2 expresses the relationships among NOAO programs that will allow AURA to grow the new programs called for by the AASC decadal survey, while continuing to provide access to productive telescopes.

#### Figure 2

**Funding Profile of NOAO Major Programs**
FY 2001–2007
(Dollars in Thousands)

![Funding Profile Chart](chart.png)

**Notes to Fig. 2:** The CTIO division is asterisked to indicate that its divisional costs for Data Products, LSST, NIO site testing, and the Major Instrumentation programs have been subtracted for the purposes of this graph and included in the budgets of those programs themselves. Costs of the Data Products and LSST programs are aggregated. NOAO base includes staff research, administration, the Tucson headquarters, and the AURA management fee. The GSMT/LSST funds can be directed to either of these programs as discussed above on page 39. The normalization to FY 2001 dollars in this graph has been performed with a deflator of approximately 3%.
Beginning in FY 2005, the 2.1-m telescope on Kitt Peak will be operated via a consortium, and guaranteed time shares will be offered via partnership arrangements on the Mayall and Blanco telescopes, resulting in the significant cost reductions at KPNO and CTIO projected in the “Cheap Ops” model (Section 3.2.5 above). Details of the milestone activities, deliverables, and timing of the proposed privatization are listed in the “Research and Development Activity Tables” in Section 5.8.1 below. The partnership solution offered by AURA is hardly an unprecedented approach to keeping peak facilities at the frontlines of productivity: ESO has a similar policy of “nationalizing” its La Silla telescopes.

5.5.1 Annual Program Costs By Division

In early 2001, AURA conducted a comprehensive zero-based review of NOAO’s organizational, staffing, and program budgets. The resulting breakdown of NOAO’s program costs by discrete “Work Breakdown Packages” constitutes a more intelligible, and in some respects, a more authentic representation of the true costs of the proposed programs over the course of the proposal period. Unlike the conventional accounting method of reporting costs to the physical site or operational unit where the funds are actually expensed, the financial planning model used in the AURA budget review estimates the costs of each NOAO program “package” by its cross-divisional activities, deliverables, or end functions. Estimates of the Work Breakdown components of each current or planned program were calculated from historical costs and from estimated percentages of payroll and non-payroll costs to be applied to program-specific activities, such as scientific research, travel, supplies, services to tenants, and so forth. (A detailed accounting of proposed costs is provided in “F: Budget and Budget Justification” Section of this proposal.) Tables 1 through 5 below show estimated annual program costs by division at the second level of the Work Breakdown Structure.

5.5.2 Work Package Definitions

The work breakdown costs listed as line items below in Tables 1 to 5 are defined as follows.

- **Science Operations**: includes the Level 1 work package costs for TAC proposal review, pre- and post-observer support, queue and service observing, and the NOAO Users Committee.

- **Telescope**: includes operations, upgrades, and software support work packages by telescope. “Telescope A” refers to the Mayall at KPNO, the Blanco at CTIO, and Gemini North in the NGSC division, respectively; “Telescope B” is the WIYN at KPNO, the SOAR at Cerro Pachón, and Gemini South; “Telescope C” refers to the other telescopes at KPNO and CTIO.

- **Mountain Facilities**: building maintenance, kitchen and accommodations, roads, grounds and utilities at CTIO and KPNO.

- **Staff Research**: costs of scientific staff research, library, administrative support of scientific staff, travel, and publications.

- **Director’s Office**: includes administrative assistance and travel.

- **Headquarters**: includes costs of non-mountaintop building maintenance, roads and grounds, utilities, vehicles, and the computer network.

- **Central Administrative Services**: human resources, accounting, procurement, and payroll work packages.
• **Public Affairs/Outreach** includes education and public outreach programs, public affairs, and graphic arts.

• **Servicing the System:** under the Tucson column, this includes the estimated costs for the proposed system committee and NOAO’s activities in the observing system (Section 3.7); under KPNO, this line refers to the costs of technical support of NSO on Kitt Peak.

• **AURA Management Fee:** listed under the Tucson column in all years. The number listed under NGSC for this line item ($110,000 in FY 2003) refers to the cost of the AURA Gemini Fellowship program and is therefore a budget item separate and distinct from the AURA Management fee.

5.5.3 **Level 2 Budget Tables FY 2003–2007**

<table>
<thead>
<tr>
<th>Program Area</th>
<th>KPNO</th>
<th>CTIO</th>
<th>NGSC</th>
<th>Tucson</th>
<th>TOTAL</th>
</tr>
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<tr>
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<td>72</td>
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<td></td>
<td></td>
<td>742</td>
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<td></td>
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<td>900</td>
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<tr>
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<td>800</td>
<td>535</td>
<td></td>
<td>2,035</td>
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<tr>
<td>Telescope C</td>
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<td></td>
<td></td>
<td>618</td>
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<tr>
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<td>980</td>
</tr>
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<td>Data Products</td>
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<td></td>
<td></td>
<td>800</td>
<td>910</td>
</tr>
<tr>
<td>NIO/GSMT</td>
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<td>1,480</td>
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<td>Major Instrumentation</td>
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<td>597</td>
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<td>$6,369</td>
<td>$1,285</td>
<td>$11,925</td>
<td>$23,501</td>
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*Note: The budget table for FY 2002 is published in the NOAO Provisional Program Plan FY 2002, which is also available on the NOAO web site.*
The difference between the total divisional costs of CTIO and KPNO seen in Tables 1 to 5 (for example, $6.4M vs. $3.9M in FY 2003) derives from the following: (1) CTIO's aggregate costs associated with work on the LSST, Data Products, Major Instrumentation, and NIO/GSMT programs ($1.2M in FY 2003), and (2) CTIO’s support of Chile-based Administration Services and the La Serena Headquarters ($1.08M in 2003). No analogous costs are carried by the KPNO division. It is to be noted, however, that the costs of operating each division’s respective telescope programs (Telescopes A and B) are roughly equivalent.

Table 2
NOAO WBS Level 2 Program Costs By Division
FY 2004
(Dollars in Thousands)

<table>
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<tr>
<th>Program Area</th>
<th>KPNO</th>
<th>CTIO</th>
<th>NGSC</th>
<th>Tucson</th>
<th>TOTAL</th>
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<td>591</td>
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<td>Computer Infrastructure Support (CIS)</td>
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<td></td>
<td>580</td>
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<td>715</td>
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<td>Data Products</td>
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Table 3
NOAO WBS Level 2 Program Costs By Division
FY 2005
(Dollars in Thousands)

<table>
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<tr>
<th>Program Area</th>
<th>KPNO</th>
<th>CTIO</th>
<th>NGSC</th>
<th>Tucson</th>
<th>Total</th>
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</tr>
<tr>
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Table 4
NOAO WBS Level 2 Program Costs By Division
FY 2006
(Dollars in Thousands)

<table>
<thead>
<tr>
<th>Program Area</th>
<th>KPNO</th>
<th>CTIO</th>
<th>NGSC</th>
<th>Tucson</th>
<th>TOTAL</th>
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<td>Computer Infrastructure Support (CIS)</td>
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<td></td>
<td>640</td>
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<tr>
<td>Telescope C</td>
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<td><strong>$1,570</strong></td>
<td><strong>$15,307</strong></td>
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Table 5
NOAO WBS Level 2 Program Costs By Division
FY 2007
(Dollars in Thousands)

<table>
<thead>
<tr>
<th>Program Area</th>
<th>KPNO</th>
<th>CTIO</th>
<th>NGSC</th>
<th>Tucson</th>
<th>TOTAL</th>
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<tr>
<td>Science Ops</td>
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<td>232</td>
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<td>448</td>
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</tr>
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<td>640</td>
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<td>900</td>
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</tr>
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<td>Telescope C</td>
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<td>320</td>
<td></td>
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<tr>
<td>Mountain Facilities</td>
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<td>46</td>
<td>62</td>
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<td>991</td>
<td>1,159</td>
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<tr>
<td>Director's Office</td>
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<td>1,629</td>
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<tr>
<td>Headquarters</td>
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<td>1,230</td>
<td>1,900</td>
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<tr>
<td>Central Admin. Services (CAS)</td>
<td>550</td>
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<td>Public Affairs/Outreach</td>
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<tr>
<td>Data Products</td>
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<tr>
<td>NIO/GSMT</td>
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<td>Major Instrumentation</td>
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<td>4,125</td>
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<tr>
<td>Servicing the System</td>
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<td>816</td>
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<tr>
<td>AURA Mgmt Fee</td>
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<td>125</td>
<td>544</td>
<td>669</td>
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<tr>
<td><strong>TOTAL</strong></td>
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<td><strong>$6,819</strong></td>
<td><strong>$1,625</strong></td>
<td><strong>$16,002</strong></td>
<td><strong>$28,517</strong></td>
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</table>
5.6 Organizational Plan for New NOAO Programs

The new O/IR programs introduced in the decadal survey and described above in Sections 3.3 to 3.8 are designed to grow over the performance period. Work Breakdown Structures for these programs are shown in the following WBS charts.

5.6.1 Data Products Program

Perhaps the most profound change that NOAO will undergo in the proposal period under AURA management will be a new focus on data products (as described in Section 3.3). NOAO will take responsibility for the timely availability of all survey data obtained with its telescopes. The Data Products program will also be responsible for quality assurance of these data. The goal is to make all such products compliant with the emerging requirements of the National Virtual Observatory. NOAO will become one of, and possibly the principal, O/IR node of the NVO.

The considerable reorganization of NOAO's current software group into the Data Products program will be led by the NOAO Deputy Director in order to make this an effective cross-divisional reform.

5.6.2 LSST Phase A

The Phase A study stage of the LSST consists of the work packages shown in the adjacent chart. The telescope design study can be managed in-house using the resources of NOAO's engineering and technical services. If the Steward Observatory straw man design is adopted by the partnership as the leading object of study, a natural collaboration in Tucson would result with a (project scientist-project manager) model for the relationship between the university principal and NOAO's engineering manager.
within this work package. The instrument design study can also be managed in-house, and the option exists to partner with a university or research organization with detector/controller expertise or a strong capability in complex focal plane design. The data management study will be carried out by the NOAO Data Products program. The cost of this Phase A work, including the data management study, was estimated above in Section 3.4, and is carried in the LSST program in the budget tables in the previous section.

**5.6.3 Major Instrumentation Program**

The capacity of the Major Instrumentation program, as described in Section 3.5, is two large telescope instruments (1 and 2) in Phase A, one instrument (3) in Phase B design, and one instrument (4) in construction. This structure can be maintained, provided half the program funding derives from external projects (principally, instrumentation for Gemini). Shared projects meet this requirement too, such as WIYN's One Degree Imager. GSMT and LSST instrument concept studies bring funding from those programs.

The availability and extent of external funds will determine the rate at which NOAO's instrumentation program develops over the period. Success in winning those external funds will depend on the reputation of NOAO's instrumentation program in the astronomical community and its ability to partner effectively with university programs. These factors will in turn depend on the creativity, productivity, and efficiency of the NOAO program. AURA believes that this is an appropriate positioning of the program in the US astronomy context.

**5.6.4 The NIO/GSMT Program**

The NIO/GSMT project is shown below in its organizational configuration in FY 2001 and 2002. The milestones for this program during the proposal period are listed below in the Research and Development Activities table in Section 5.8.
5.7 Broader Impacts: Technology Transfer and Partnerships with Industry

In accordance with NSF policy of cultivating the broadest impacts from the research it funds, AURA will give due emphasis to technology developments which benefit society tangibly.

5.7.1 Sensor Technology

Astronomers have become expert at detecting, imaging and analyzing very weak signals, often in the presence of significant sources of image blurring and noise. They have built cameras capable of detecting radiation over a wide range of wavelengths and at extremely low intensity levels. This effort has led to many practical benefits for society as a whole.

The development of large-format, low-noise imaging arrays in both the optical (CCDs) and in the infrared has been driven by the desire of astronomers to image large areas of the skies to very faint levels at high resolution. NOAO has long been—and will continue to be (e.g., Section 3.5.4)—in the forefront of these developments. For the IR detectors, progress has been achieved via a synergetic relationship with the Department of Defense, leading, for example, to the use of IR detectors in the anti-missile program and for night vision devices. CCD development has progressed to ever-larger and more sensitive devices by direct interactions between astronomers and manufacturers; a specific example is the cooperative efforts between the most prominent US high-performance CCD manufacturer, Scientific Imaging Technologies, Inc., and NOAO. In the industrial sector, these large-format detector arrays are being used in the semiconductor industry and in IR microscopes which examine computer chips for flaws. In the medical sector, IR detectors are being used to image malignant tumors and vascular anomalies, and in spectrographs, to diagnose cervical cancer and genetic diseases.

5.7.2 Volume Phase Holographic Gratings

Astronomers have driven the development of ever higher-throughput and precise spectrometers. In addition, they have perfected precision optical techniques to achieve very high spatial resolution.
These developments have been highly beneficial to the industrial, defense, and medical sectors of the economy. Essential components of all these spectrometers have been invented or perfected by NOAO.

VPH gratings are an example of a technology of widespread interest to astronomy which NOAO Senior Scientist Sam Barden has pioneered as a collaboration with Kaiser Optical Systems, Inc. Grating technology is the heart of all dispersive ultraviolet, optical, and infrared instrumentation, and can be expected, with appropriate development, to command a large market. NOAO is also part of a consortium effort with the Centre Spatial de Liège (CSL) in Belgium. ESO, NOAO, University of Michigan, and the Anglo-Australian Observatory are partners in getting a facility up and running to make large format VPH gratings at CSL. CSL will then attempt to spin this effort off into a stand-alone company. Terrasun, a Tucson based company, is examining the possibility of making VPH gratings.

5.7.3 Software

Astronomers have become experts in the improvement and sharpening of images, and the detection of faint features in the presence of noise. Consequently, they are at the forefront of the development of sophisticated software tools for image analysis. One example of this effort is NOAO's Image Reduction and Analysis Facility (IRAF). IRAF has been used outside of astronomy in underwater imaging, mapping the aerosols in the atmosphere, in medical imaging such as breast cancer detection, in the human genome project (decoding human genetic material), in numerous defense-related applications, for visualization of the images from electron microscopes, and many other applications.
5.8 Reviewing NOAO’s Performance

Key indicators and associated metrics for evaluating NOAO performance over the period of this long range plan would include such criteria as:

1. **NOAO success in providing “forefront observing capabilities and observing support to US scientists on the basis of merit and regardless of institutional affiliation.”**
   - Enhanced science productivity and impact, as measured by publication and citation rates for observations using the US system
   - Competitive access to a wider range of capabilities
   - Ramp-down of older capabilities accomplished with minimum impact on community science
   - Higher system productivity/dollar invested than ESO

2. **NOAO's ability to “implement partnerships with universities, non-federal observatories, and industry to achieve mission goals of the entire US astronomical community.”**
   - Broad community involvement in the “O/IR system” definition
   - Broad community support measured via joint advocacy by representative community bodies (e.g., CAA; ACCORD)
   - New opportunities at NSF resulting from advocacy
   - NSF reviews of O/IR proposals using consensus criteria
   - Enhanced opportunities/access through the TSIP program
   - Endorsement of NOAO five-year plan by representative community groups
   - Requests to form partnerships/collaborations with NOAO engineers and/or managers
   - On-time/on-budget provision of new capabilities resulting from partnerships
   - Scientific return from the products of partnerships, as measured by comparative publication/citation studies

---

1. **Relevant performance metrics:**
   - *Number of refereed papers per $100K invested in the system.* For example, KPNO reports 272 scientific papers published in 1999 for an annual expenditure of $7M. Ignoring the capital value of the facilities, KPNO scores just under 4 on this metric. As an external comparison: if every VLT night resulted in a paper, ESO would score 2 under its relevant Council policy, which permits access to collaborating institutions at marginal cost.

   - *Percentage scientific citations over the last five years per $100M invested.* If this calculation were restricted to the most frequently cited papers following Benn & Sanchez (2000), NOAO would score 2, compared with 3 for the Anglo-Australian Observatory (sampled over the interval 1995-8). NOAO will aim to increase its score in

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2. **Relevant performance metrics:**
   - *Percentage of public access to the system (currently 22% by aperture)*
   - *Oversubscription of the TSIP program*
   - *Partnership fraction in the LSST and GSMT projects*
   - *Delivery of major system instruments on time and budget*
3. NOAO success in "acquiring, analyzing, archiving, and disseminating observational astronomical data."

- Assessment by NASA, NRAO, and NAIC advisory panels of NOAO's abilities to provide needed opportunities
- New opportunities at NSF and NASA to exploit NOAO-initiated options for multi-wavelength programs
- Cost-effectiveness of NOAO pipelines compared to non-NOAO pipelines
- Reduced end-to-end cost of O/IR survey programs
- Level of archive use by community
- Publication and citation rates for NOAO-sponsored survey/campaign teams, compared to other principal investigators and teams

4. NOAO's success in "leading development of new telescopes, instruments, and techniques."

- Broadly supported road maps for development
- Successful advocacy for funding at NSF and/or elsewhere
- Successful competitive review of NOAO proposals to provide new capabilities
- Broad community participation in and funding for planning, designing, and building new facilities and instruments
- On-time/on-budget performance in building major NSF-funded facilities/facility instruments by independent observatories and NOAO

5. NOAO "support of scientific staff who conduct research for its intrinsic value."

- Presentation of invited reviews at major national or international conferences
Membership on/chairmanship of major advisory committees, review panels, visiting committees to peer institutions

Participation in/leadership of major observational campaigns and surveys

Participation in/leadership of major research grants (e.g., LTSA; major HST; Chandra; SIRTF programs)

Leadership of NOAO-organized efforts to involve the community in planning major science programs, facility, software, instrument initiatives

Evaluation of current contributions, future promise, career impact on science via peer evaluation

Innovation in and creative approaches to scientific problems as evidenced by internal and external evaluations

6. Scope and impact of NOAO’s “education and training programs that strengthen US astronomy education at all levels.”

- A framework for more astronomers to get research-quality data into teachers’ hands
- Efficiency in providing materials to teachers, and reaching teachers with more diverse needs, via the Web and Distance Learning courses.
- An active role as a consultant-contributor for educational outreach programs across the national O/IR system.
- Variety of public outreach education programs and hands-on exhibits at the Kitt Peak Visitor Center to reach a more diverse visitor base
- NOAO-related merchandise at the Kitt Peak Visitor Center
- Regular output of astronomical research news releases and image releases of national interest, and participation in major press briefings, either through NSF, NASA or independently
- NOAO presence at meetings of the American Astronomical Society (and similar meetings), including fresh and compelling exhibit features for

6 Relevant performance metrics:
- Number of teachers and students reached per year in RBSE and ASTRO Programs
- Rate of REU students going on to graduate school and/or professional careers in science and engineering.
- Number of press releases and images released per year
- Kitt Peak annual visitor totals, educational and school tours of Kitt Peak facilities
- Participation and growth in fee-based Nightly Observing and Advanced Observing Programs

5 Relevant performance metrics:
- Number of citations per year, e.g., ISI Science Watch (Nov-Dec, 1996) reports 1,108 NOAO citations for the period 1993-95.
- Papers published per year as a measure of recent productivity