Assembly and test of the NOAO Extremely Wide Field Infrared Imager (NEWFIRM) nears completion. This 4K square infrared camera will be available on the Mayall telescope in 2006 and subsequently shared between the Mayall and the Blanco. This powerful infrared survey instrument will complement the scientific capabilities of Gemini.
### TABLE OF CONTENTS

**INTRODUCTION**
- Where We Are Today, 1
- Science-Driven Programs for the Next Decade, 2
- LSST and GSMT, 3
- Data Products Program (DPP) and the National Virtual Observatory (NVO), 4
- KPNO, CTIO, and Gemini, 4
- Major Instrumentation Program (MIP), 4
- Public Affairs and Educational Outreach (PAEO), 5

**SCIENTIFIC RESEARCH**

**THE NATIONAL O/IR OBSERVING SYSTEM**
- NOAO Gemini Science Center (NGSC) ............................................................................. 9
  - Major Program Goals FY 2005 – 2009, 9
  - Science Direction, 9
  - User Support, 10
  - Operations Support, 10
  - Instrumentation Development, 10
  - Building the Gemini Community, 12
- Cerro Tololo Inter-American Observatory ................................................................. 12
  - Blanco 4-m Telescope, 13
  - SOAR 4-m Telescope, 13
  - Small Telescopes and Other Facilities, 13
  - Instrumentation Development for the 4-m Telescopes, 14
- Kitt Peak National Observatory .............................................................................. 14
  - Mayall 4-m Telescope, 15
  - WIYN 3.5-m Telescope, 15
  - KPNO 2.1-m and Smaller Telescopes, 16
  - Instrumentation Development, 16
- Telescope System Instrumentation Program (TSIP) ................................................. 17
  - Major Program Activities, 18
- Adaptive Optics Development Program ................................................................... 19
ADVANCING DECADAL SURVEY INITIATIVES
AURA New Initiatives Office ................................................................. 20
Science with a 30-m GSMT, 22
Next Steps: A Public-Private Partnership to Advance the GSMT, 22
AURA Proposal to the NSF, 23
The Large Synoptic Survey Telescope (LSST) ................................................................. 24
Major Program Goals FY 2005–2009, 24
LSST Design and Development, 25
Data Products Program ...................................................................................................... 26
Major Program Goals FY 2005 – 2009, 26

MAJOR INSTRUMENTATION PROGRAM .......................................................................... 29
Program Objectives, 29
Major Program Goals FY 2005–2009, 29
Program Components, 33
Project Phases and Resources, 33

SCIENCE EDUCATION AND PUBLIC OUTREACH........................................................... 35
Science Education, 35
Public Outreach, 40
Media Outreach and Public Information, 42

MANAGEMENT AND BUDGET............................................................................................ 44
Management Structure and Organizational Chart, 44
The Current Cooperative Agreement (FY 2003-2007), 44
The Next Cooperative Agreement (Est. FY 2008-2012), 45
Estimated FY05-FY09 Funding Allocations by Division and Program, 45
Descriptions of Work Packages, 46
Level 2 Budget Tables FY 2005-2009, 49
INTRODUCTION

The overarching objectives for NOAO as described in the following sections of this document are:

- To support research with the Gemini Observatory through the NOAO Gemini Science Center
- To enhance state-of-the-art facilities at Kitt Peak National Observatory (KPNO) and Cerro Tololo Inter-American Observatory (CTIO)
- To lead community-based planning, design, and development efforts for proposed federally-funded initiatives in ground-based optical/infrared astronomy—especially, the Large Synoptic Survey Telescope (LSST) and the Giant Segmented Mirror Telescope (GSMT)
- To develop the means to archive ground-based data for the National Virtual Observatory (NVO)
- To build a robust capability for design and construction of new instrumentation that will increase the productivity of existing telescopes, while meeting the instrumentation challenges of the next-generation facilities
- To foster the development of a national observing system through the Telescope System Instrumentation Program (TSIP)
- To integrate science education and public outreach with research in all of these areas

In meeting these objectives, NOAO will continue to encourage the development of strong, mutually-beneficial partnerships, consortia, and collaborations with universities, private observatories, and other non-federally funded research institutions.

Where We Are Today

The past decade has witnessed dramatic discoveries, surprises, and advances in our understanding of the Universe. For example:

- Observation of large samples of supernovae in galaxies out to redshifts $z \sim 1$, which provide compelling evidence of dark energy consistent with the inferences from microwave background observations.
- The first observations that quantify fluctuations in the microwave background over a wide range of angular scales. These observations provide both essential independent constraints on fundamental cosmological parameters, 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. This result argues not only that black holes are a fundamental component of all galaxies including our own, 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 space and ground-based telescopes, resulting in the unambiguous association of these incredibly energetic events with extragalactic systems.

- 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.

- 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.

- Detection of large numbers of Jovian mass extra-solar planets, 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.

These advances are the collective achievement of many astronomers. They also represent the culmination of investments in a wide range of observational tools—from ground-based imaging surveys with moderate-aperture telescopes (2MASS, SDSS, CCD mosaic cameras on 4-m class telescopes), through spectroscopy with the Keck and Gemini telescopes, to a variety of space-based and balloon assets, including Explorers (e.g., WMAP) and Great Observatories (e.g., HST and Spitzer). Ground-based O/IR astronomy played an essential role in these discoveries. As we look ahead, NOAO must be prepared to support these advances by offering access to the full system of facilities and capabilities needed by the U.S. astronomical community in the coming decade.

Science-Driven Programs for 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

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., JWST, Hershel, 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 Large-aperture Synoptic Survey Telescope (LSST) and the Giant Segmented Mirror Telescope (GSMT), the major ground-based O/IR facilities recommended in the 2000 decadal survey, *Astronomy and Astrophysics in the New Millennium* (AANM), will play a key role in addressing these questions. The LSST represents an unprecedented advance in opening the time domain. NOAO has joined a partnership—initially formed from the Universities of Arizona and Washington, Research Corporation, and AURA—to develop the survey telescope system; its centerpiece is the 8-m primary mirror design pioneered by Roger Angel of Steward Observatory and fine-tuned by Lynn Seppala of Lawrence Livermore National Laboratory. Other DOE Labs are planning to design and build a gigapixel camera. Funding permitting, this LSST system could go into operation as early as 2012. A mission on a faster track is the University of Hawaii’s Pan-STARRS project, with first light expected in 2006. NOAO regards this project as a source of value-added data products for the community. The science mission for the LSST has been studied in detail by the LSST Science Working Group, chaired by Michael Strauss of Princeton University. The LSST is an explicit part of the NRC Board on Physics and Astronomy plan discussed in *Connecting Quarks with the Cosmos: Eleven Science Questions for the New Century* (2003), which aims to elucidate the nature of “dark energy.”

By 2016, GSMT will represent a comparably larger scientific advance over its predecessors than did the Keck telescope in 1992. This is already apparent from the extraordinary potential of adaptive optics, the heart of the GSMT. The GSMT Science Working Group, chaired by Rolf Kudritzki of the University of Hawaii, is exploring these matters in depth. For the design and development of a thirty-meter telescope concept, NOAO, in collaboration with Gemini under the auspices of the AURA New Initiatives Office (NIO), is partnering with Caltech, the University of California, and the Association of Canadian Universities for Research in Astronomy. The goal is a detailed design ready for contracting in 2008. Both the GSMT and
LSST were conceived by the AASC as public-private partnerships. A fast timeline for these projects is dependent on private fundraising.

Data Products Program (DPP) and the National Virtual Observatory (NVO)

The GSMT will be the driver of spectroscopic understanding for the James Webb Space Telescope (JWST) and the Atacama Large Millimeter Array (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 recent announcement of an agreement between NASA and NSF to solicit proposals for the operation of the NVO is an important step forward. NOAO will certainly respond to the solicitation.

KPNO, CTIO, and Gemini

Our current telescopes support the scientific themes articulated in the AASC decadal survey. “Red envelope” galaxies from O/IR surveys can trace the development of large-scale structures through intermediate to high redshifts. CCD mosaic imagers can provide initial detection of distant supernovae, followed by light curves from Gemini and the Hubble Space Telescope. 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 the Spitzer telescope 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 also will serve as critical precursors to the all-sky monitoring of the LSST.

Major Instrumentation Program (MIP)

Astronomical instrumentation is in a period of rapid change. We enter the period having successfully delivered a $5M facility infrared spectrograph for the Gemini Observatory, and carrying out feasibility and design studies for the “Aspen” generation of instruments. NOAO is now undertaking the design of instrumentation for a 30-m telescope. In addition, we have the challenge of major instruments for the 4-m telescopes, the Mayall and Blanco (which will share
a 30 arcmin infrared imager), the WIYN and Blanco, which are developing one-degree optical imagers; and SOAR, which aspires to develop adaptive optics at optical wavelengths.

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 reionization epoch in the coming decade to learn more of the era of galaxy formation. Resolution and distance limits continue to be pressed back. Productivity continues to grow in photometry and spectroscopy. 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.

**Public Affairs and Educational Outreach (PAEO)**

New astronomical facilities of the scale and productivity we are planning place special responsibilities on NOAO Public Affairs, and offer great opportunities for education and outreach. The growth of PAEO will continue over the planning period with particular emphasis on (1) the role of GSMT and LSST in science education and (2) continued development of the Kitt Peak Visitor Center to meet the growing numbers of tourists and visitors coming from all over the Southwest to participate in our highly successful Nightly Observing Program, our public tours and science exhibits, and other popular Kitt Peak activities.
SCIENTIFIC RESEARCH

Major Program Goals FY 2005 – 2009

- Intellectual leadership for each of NOAO’s programs from a team of both experienced and early-career astronomers
- Measurable, rising research productivity
- A supportive environment for research, with exemplary diversity and equity

NOAO is a scientific research organization whose mission is to enable research and discovery in ground-based astronomy by a broad community of scientists, and to communicate widely with its various constituencies in the community. The heart of any research organization is its staff of researchers. Indeed, 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 today and tomorrow, the research ethos of the institution, the match to university research culture and educational goals, and the ability of NOAO as an institution to innovate, to work with the community to plan for the future, and to anticipate user needs. A strong scientific staff research program allows NOAO to keep track of the pulse of the U.S. astronomical community—the scientific directions and state of the art techniques of U.S. astronomy.

To recruit and retain a scientific staff able to fulfill the multiple roles of (1) scientific excellence, (2) commitment to institutional and community goals, and (3) leadership in the community is a challenge; it requires an observatory culture that encourages all three. Essential to this culture is a stimulating scientific environment within NOAO, along with time required to carry out first-rate scientific programs. Our research staff members are thus granted 50 percent research time and scientist track members 20%. Also critical is a commitment to institutional service and community leadership—roles analogous to the teaching and service missions at peer university institutions. This 50/50 split between research and service, combined with performance standards matching those of major research universities, is intended to ensure that NOAO scientific staff are the peers of their university colleagues and that they are strongly invested in the research goals of NOAO users, both now and in the future.

It is crucial that recruitment of the scientific staff be done with an eye to match the scientific interests of the scientist with the mission of NOAO. If the service role and scientific research of the staff member are matched, both NOAO and the scientist will benefit. For instance, an astronomer whose future research plans center around the LSST or TMT projects will stimulate the precursor science needed to properly engineer the project and provide community leadership with their expertise.

Standards for tenure and post-tenure review are matched to the vision of excellence in science, service, and leadership, and are maintained at the level of major research universities. NOAO’s internal tenure committee also acknowledges innovation as an additional criterion for tenure—thus emphasizing the importance of continuous improvement of NOAO’s research
facilities. The application of these standards in service of NOAO’s institutional roles is closely monitored by AURA’s Observatories Council and Board of Directors.

In addition to the professional respect of colleagues, NOAO’s mission requires that its scientific staff play a leadership role in the community, especially in the service of advancing community aspirations. Academic or research leadership is, of course, a subtle blend of forward thinking, effective communication, and the ability to see advancement of community goals as central. Recent demonstrations of community leadership by NOAO staff include: (1) successful launching of the Telescope System Instrumentation Program (TSIP) and the Adaptive Optics Development Program (AODP); (2) development and implementation of programs to enable planning of joint ground- and space-based observing programs with Spitzer, Chandra, and HST; (3) successful initiation of a survey opportunity that enables research teams to carry out frontier programs of scale and provides the community with access to rich, multiple-use databases as a result; (4) the development of large scientific collaborations that are important precursor projects, such as the Dark Energy Camera and the NOAO Deep Wide Survey, which are test beds for the design of the Decadal Survey projects of GSMT and LSST; and (5) continuing support of science working groups for the GSMT and LSST projects.

The Changing Staff at NOAO

The recent challenges of launching the Data Products Program (and its link to the National Virtual Observatory), the NOAO Gemini Science Center (NGSC), and the LSST and GSMT programs have required the current NOAO staff to play multiple roles: ensuring the continued successful operation of KPNO and CTIO facilities, while providing smooth access to Gemini, and planning new generation facilities and capabilities. NOAO’s ability to meet these challenges over the long run requires investment in new staff whose scientific interests are aligned with these NOAO missions.

An important part of maintaining the scientific environment at NOAO is a strong post-doctoral program. We will continue with our successful Goldberg Fellowship program, which offers a 5-year postdoctoral position either in Chile or Tucson. A named fellowship program of this type has allowed us to compete for the very best postdoctoral applicants in the U.S.

Performance Metrics

Evaluating and enhancing staff performance in research, service, and leadership require regular communication and measurement against clearly understood metrics. NOAO carries out annual performance reviews during which staff members and the associate directors of their “home” programs meet and review professional accomplishments and goals, and determine how well they are being met by the individual and how well the observatory is doing in providing the environment and resources to enable success. In addition, NOAO has established more formal metrics of staff performance, which we intend to use as a key part of promotion, tenure, post-tenure review, merit raises, and internal awards.

Important, too, in the evaluation of the career progress of staff members is a post-tenure review for the senior staff. NOAO has adopted a 5-year cyclic review through the Promotion
and Tenure Committee of all tenured staff, to gauge their research and service record and make recommendations on improvement. A post-tenure review is not intended to be a “re-tenuring” process. Rather, it is seen as a way to evaluate whether the experience of the staff member is being properly utilized for the mission of NOAO. It is also meant to expose any roadblocks in the way of the scientific productivity of the senior staff member.

Mentoring

Mentoring the large number of new staff, along with our post-doctoral fellows, is essential to ensuring their continued research productivity, their commitment to NOAO and community goals, and their personal growth. NOAO management has developed a systematic program of mentoring for scientists at all levels, but particularly for young staff and post-docs. As a new program, this will require test and assessment. The Associate Director for Science also works with the staff during the annual staff retreat to discuss and plan major research programs coherently.

Women Scientists at NOAO

Adding significant numbers of new staff at NOAO provides an opportunity to proactively recruit outstanding women. Success will enable a welcome increase in the diversity of the staff, which in itself will enhance the environment for women. Among the measures we are adopting to attract women to NOAO is to provide opportunities for both spouses in two-career families—critical at both NOAO North and NOAO South, but especially in La Serena.

The ability to attract and retain first-rate female scientists requires, above all, a challenging and exciting environment, and one that is conducive to listening carefully and responding to both men and women. Our annual scientific staff retreats provide an excellent forum for open discussion of the work environment and communication issues at NOAO, and can serve as an early warning to management of problems hiding just below the surface.
THE NATIONAL O/IR OBSERVING SYSTEM

NOAO GEMINI SCIENCE CENTER (NGSC)

Major Program Goals FY 2005–2009

- Meet U.S. community needs for 8-m aperture telescopes
- Provide user support to the U.S. users of Gemini
- Develop input from the U.S. partner perspective to Gemini Observatory in science planning, instrument development, and operations support
- Perform community outreach on Gemini opportunities to the U.S. community
- Make NGSC the most scientifically productive division of the national observatory and a model for other National Gemini Offices (NGOs) in the Gemini partnership.

The twin 8-m Gemini telescopes form the apex of the facilities that NOAO offers to the U.S. astronomical community. Gemini has particular competitive advantages in the infrared, in delivered image quality, and in adaptive optics. 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 extensive community participation in the NOAO telescope time allocation process. NGSC has developed a wide range of scientific and technical expertise that encompasses the Gemini science goals and the Gemini instrumentation, both existing and to be delivered. The co-location of NGSC and Gemini staff in La Serena, Chile presents extensive opportunities for collaboration. The NOAO Major Instrumentation Program offers valuable technical expertise and services to the Gemini Observatory.

Science Direction

Within the structure of the Gemini partnership, each partner agency created a National Gemini Office (NGO) to represent its participation in Gemini. The NGOs form the nodes of communication between Gemini and each partner country, providing input and advice to the Gemini Observatory on partner perspectives and communicating to the national communities the capabilities and science opportunities that Gemini presents. NOAO is the home of the U.S. NGO, and the Director of the NGSC is the U.S. Gemini Scientist.

In order to access and represent U.S. interests, the NGSC Director is assisted by a science advisory committee (U.S. Gemini SAC) that consists of eight to ten prominent members of the U.S. astronomical community. This committee meets annually to advise on science direction, operations models, instrumentation issues, 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 to provide advice to the NGSC Director. Six members from the U.S. SAC are selected to attend the annual international Gemini Science Committee meetings.
User Support

User support at NGSC is the responsibility of a group of a dozen instrument scientists—ranging from quarter-time to nearly full-time—whose areas of scientific and technical expertise are matched to the diversity of Gemini instrumentation. The instrument scientists assist U.S. investigators in preparing observing proposals, which are then peer reviewed and ranked by the NOAO telescope time allocation committee. The complexity of the Gemini instruments and operations requires complex observing protocols and calibration observations. Proposers who are granted Gemini time are required to submit a Phase II observing proposal. NGSC instrument scientists assist U.S. community members in preparing these proposals using the Gemini Observing Tool, and then NGSC staff check these Phase II submissions before passing them on to Gemini for execution.

A remote operations center has been 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 U.S. observers and U.S. instrumentation efforts on Gemini. NGSC staff will also use this center for training and for conducting engineering programs.

In order to attain Gemini science goals, data reduction, pipelining, and analysis tasks must be developed for Gemini data. NOAO and the Gemini Observatory are carrying out a collaborative project with the (appropriately) twin goals of improving both the Gemini reduction software and the underlying IRAF system it uses. The key to success in this case is that the partners are not only dedicating new resources to the project, but also the expertise and institutional commitment required to meet its goals—a combined 70 person-years of IRAF development experience from NOAO, detailed knowledge of the instruments and reduction requirements from Gemini staff, and shared responsibility for development and scientific oversight of the project.

Operations Support

NGSC staff provide support for the commissioning and system verification of U.S. instrumentation, such as GNIRS. NGSC staff are also responsible for operations support of visitor Gemini instruments from the United States, currently Phoenix (an NOAO-provided high-resolution infrared spectrograph shared between Gemini South and SOAR). NGSC staff participate in the testing, maintenance, and calibration of these shared instruments, and provide documentation and training for the Gemini community. NGSC staff also participate in selected Gemini queue observing runs to remain highly knowledgeable about observing procedures and telescope/instrument performance.

Instrumentation Development

As the major partner in Gemini, the United States contributes approximately half of the major Gemini instrumentation. It is the role of NOAO and the NGSC to foster instrumentation development for Gemini in the U.S. community. This effort is divided between projects undertaken directly by NOAO (e.g., GNIRS) and projects under development elsewhere in the
U.S. community (e.g., NIRI, T-ReCS, NICI, FLAMINGOS-2), in collaboration with university groups (thus far, the University of Florida and the University of Hawaii) and corporations (currently, Mauna Kea Infrared). The NGSC fulfills this role through a range of activities, including:

- Encouraging responses to Gemini instrument procurement opportunities by circulating announcements widely, and organizing workshops and facilitating collaborations where appropriate
- Facilitating the instrument review process (conceptual, preliminary, and critical design reviews; NGSC quarterly reviews); providing project management oversight of instrument projects in a collaborative manner that encourages good project management practices by the teams themselves
- Publicizing progress on instrument development within the U.S. community
- Making the NOAO Flexure Test Facility and Gemini Telescope simulator available to realistically test instrument performance prior to on-telescope testing

In early 2002, the Gemini partnership began a community-based initiative to identify the major science opportunities for Gemini in the period 2008–2012 and the instrumentation required for Gemini to capitalize on these opportunities. NGSC organized a workshop for the U.S. community, “Future Instrumentation for the Gemini 8-m Telescopes: U.S. Perspective in 2003,” in May 2003 in Tempe, Arizona. Gemini then conducted an international science and instrumentation planning meeting in Aspen, Colorado in June 2003, with U.S. participation. The instrument concepts that arose from this process were initiated via competitive design and feasibility studies in 2004. Design studies were initiated for a very capable high-resolution near-infrared spectrograph (HRNIRS) and an ambitious high-contrast adaptive optics system and associated imager/spectrograph capable of imaging warm planets around nearby stars (ExAOC). Gemini funded two competing design studies for each of these two concepts.

Gemini also initiated feasibility studies for a very powerful wide-field multi-object spectrograph (WFMOS) and for a ground layer adaptive optics (GLAO) system. Groups in the U.S. are participating strongly in both the design and feasibility studies. NOAO and the University of Florida form one HRNIRS design-study team, while the United Kingdom Astronomy Technology Centre and the University of Hawaii make up the other HRNIRS team. The University of Arizona (with NOAO serving as a subcontractor) and the Center for Adaptive Optics at the University of California are each leading independent design-study teams for ExAOC. Johns Hopkins University and NOAO are collaborators on the Anglo-Australian-Observatory-led WFMOS feasibility study. The University of Arizona is one of three institutions collaborating on the international GLAO feasibility study.
Building the Gemini Community

The NGSC communicates with the user community by means of articles in the NOAO/NSO Newsletter, special brochures, “town meetings,” NGSC booths and special sessions at AAS meetings, electronic announcements, and Web-based information. NGSC has initiated the use of Webcasts to inform the users on specific Gemini issues.

The NGSC intends to organize and conduct science workshops, in collaboration with Gemini and other NGOs, to highlight particular areas of Gemini science that are both timely and productive. NGSC collaborated with Gemini and the other NGOs on organizing the “Gemini Science 2004” meeting in Vancouver in May 2004. This meeting provided a showcase for Gemini science results, and Taft Armandroff (NGSC Director) was the Chair of this meeting’s Scientific Organizing Committee. Currently anticipated topics for future workshops are “Astrophysics in the Mid-IR with Gemini” or “New Frontiers in Coronography.” The NGSC also will sponsor technical workshops—like our previous workshop on AO data reduction—to assist the community in obtaining the highest scientific return from Gemini observations. T-ReCS and/or GNIRS data reduction workshops are envisioned. Future workshops may focus on multiple object spectroscopy in the optical and near-IR (with GMOS and FLAMINGOS-2), on integral field spectroscopy, or on other specialized analysis tools and procedures.

To mark the launch of the NGSC, a new post-doctoral program was created to encourage young astronomers to utilize the Gemini telescopes for innovative science. This program complements AURA’s U.S. Gemini Fellowships for post-graduate study in the United States by members of the South American Gemini community.

Cerro-Tololo Inter-American Observatory

The telescopes offered at CTIO—the Blanco, SOAR, and several smaller instruments—provide U.S. astronomers with a wide variety of state-of-the-art facilities which they can use to study the southern skies in great detail. As such they form a vital part of the suite of capabilities available in the national system. The Blanco 4-m telescope offers wide-field performance superior in $A\Omega$ (aperture $\times$ area) to any other present telescope-instrument combination in the southern hemisphere; the SOAR 4-m telescope first generation instrument complement consists of several very efficient narrow-field instruments, those working in the optical bandpass are blue-optimized so as to complement the IR-optimized Gemini 8-m, both SOAR and Gemini will shortly install Adaptive Optics systems. The smaller telescopes provide a wide range of opportunities, from synoptic and target-of-opportunity programs to large-scale surveys. Additionally, CTIO provides the infrastructural and engineering support that allows the efficient implementation of projects ranging from short-term experiments to major new facilities, at one of the world’s best observing sites.

During the five-year planning period, CTIO expects to take on board an operations partner for some fraction of the Blanco telescope. It is important to ensure that public access to spectroscopic capability is maintained in the southern hemisphere, integrating over the Blanco, SOAR, and Magellan telescopes.
Major Program Goals FY 2005 – 2009

**Blanco 4-m Telescope**

- Operate with a fixed complement of wide-field instrumentation: the Mosaic 8K×8K CCD imager, the ISPI 2K×2K IR imager, and the Hydra multi-object wide-field spectrometer.

- Upgrade the wide-field IR imaging capability in 2007 by sharing the NEWFIRM 4K×4K imager with the KPNO Mayall, on a yearly cadence.

- Build the 0.5 gigapixel Dark Energy CCD Camera in partnership with the Dark Energy Survey Consortium to replace the Mosaic Imager in 2009. The consortium will conduct a major survey with 30% of the telescope time; both the instrument and the survey data products will be available to the community.

- Upgrade the telescope control system in 2006-2008; optimize the telescope performance so the new instrumentation can be efficiently utilized.

**SOAR 4-m Telescope**

- Complete commissioning the SOAR telescope and its initial instrument complement in early 2006, and convert from an early science program to full scheduled operations.

- Support and optimize use of the instruments provided by NOAO: the SOAR optical imager, built at CTIO, the IR imaging spectrometer OSIRIS, which is the product of a partnership with Ohio State University, and the high resolution IR spectrograph Phoenix, which will be shared between SOAR and Gemini.

- Participate with the other SOAR partners (Brazil, University of North Carolina, Michigan State University) to enhance the basic operations provided by CTIO by developing efficient queue observing in a multi-instrument environment.

**Small Telescopes and Other Facilities**

- Extend or renew the operation of the CTIO 1.5-m, 0.19-m and the Yale 1.0-m telescopes as part of the Small and Moderate Aperture Telescope Research System (SMARTS) consortium, which began operating the small telescopes in 2003 for an initial period of three years.

- Provide an efficient infrastructure and engineering support for the NSO Global Oscillation Network Group (GONG), UNC’s Panchromatic Robotic Optical Monitoring and Polarimetry Telescopes (PROMPT), SHASSA (the Southern H-Alpha Sky Survey Atlas), and other experiments and projects that can share Cerro Tololo facilities. Actively promote the site to encourage other such projects to conduct their southern hemisphere research.
- Characterize the potential LSST site on Cerro Pachón by building and installing an all-sky camera and seeing monitor, and by continuing to operate the previously installed weather station.

**Instrumentation Development for the 4-m Telescopes**

The present Blanco instrumentation (Hydra, Mosaic, ISPI) was built either at CTIO or via a partnership with NOAO Tucson. Further development of the Blanco in the context of the U.S. system of telescopes—and new facilities now in planning—involves a substantial enhancement of its wide-field capabilities. The NOAO Extremely Wide-Field Imager (NEWFIRM), a 4K IR imager now approaching completion at both NOAO Tucson and La Serena, will be shared between the Blanco and Mayall telescopes.

A new instrument partnership named the Dark Energy Survey (DES) consortium, with both U.S. and international participants, successfully proposed to build a very large format CCD camera covering a three square degree field, together with optical corrector, data reduction pipelines and catalogs, for the Blanco telescope prime focus. The instrument provides a factor of ten more capability than the present Mosaic Imager, and in both science survey capability and instrument and data handling complexity lies midway between Mosaic and LSST.

CTIO has built the SOAR optical imager, focal plane assemblies and dewars for the optical instruments, and substantial parts of the SOAR instrument infrastructure. Participation in the development of CCD focal planes for second-generation Brazilian instrumentation for SOAR will continue. As part of NOAO’s obligation to SOAR, CTIO is building an adaptive optics facility (SOAR Adaptive Module, SAM) under the aegis of the NOAO Major Instrumentation Program. The instrument is expected to pass its Preliminary Design Review in 2005. It will provide a wide field with improved and constant image quality by using a Raleigh laser beacon to compensate for ground layer turbulence. These techniques are relevant to developments needed for the next generation of extremely large telescopes.

**KITT PEAK NATIONAL OBSERVATORY**

KPNO is a key component in the integrated system of U.S. ground-based O/IR telescopes. The wide-field capabilities of the Mayall and WIYN telescopes provide essential support for the major portion of the U.S. investment in large glass, with six out of the eight independent large-aperture telescopes in the northern hemisphere. Observing programs and survey data sets from the Mayall and WIYN telescopes create a level playing field for effective utilization of Gemini North. These NOAO telescopes greatly enhance the exploitation of national space assets by providing 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. Nevertheless, this planning period will see the privatization of the 2.1-meter as NEWFIRM brings wide-field imaging capability, and the gradual privatization of the Mayall 4-meter as internal resources are shifted toward development and then operations of LSST and GSMT.
It is important to ensure that public access to spectroscopic capability is maintained in the northern hemisphere. The Mayall telescope is a significant contributor to the medium aperture system with the RC Spectrograph, MARS, and the Echelle spectrograph covering a full range of resolutions.

**Major Program Goals FY 2005 – 2009**

**Mayall 4-m Telescope**

- Operations with high reliability and demand-driven suite of competitive instrumentation
- Integration of active optics and thermal controls into an effective system with consistent subarcsecond delivered image quality
- Commissioning and operations of NEWFIRM, the 4K x 4K Near-IR Extremely Wide-Field Imager, starting in late CY05. The instrument will be shared with CTIO on a cadence to be decided.
- Successful continuation and renewal of the instrumentation partnership with the University of Maryland astronomy department, including development and operation of NEWFIRM pipeline
- Expansion of the partnership arrangement to operations; the expectation is that KPNO proposers would have access to a minority share of the telescope time by the end of the planning period, with at least two major partners in addition to Maryland forming the consortium with KPNO.
- Development through growing partnership of next-generation optical spectroscopic capability

**WIYN 3.5-m Telescope**

- High-efficiency operation with maintenance of excellent image quality over the full wide-field
- Strong NOAO participation in design, fabrication, commissioning, and operation of the One-Degree Imager (ODI) with orthogonal-transfer CCDs, with operations in 2009
- Enhanced wide-field spectroscopy, including increased throughput, updated positioning, precision radial velocity modes, and other consortium-driven improvements; bench upgrade improvements in FY06
- Full exploitation of the WIYN tip/tilt module, including extension to near-IR imaging with the WHIRC camera coming on line in FY06
- Pathfinder instrument for ODI, QUOTA, has been funded by an NSF ATI grant, and will provide 8K x 8K fast guiding coverage, with observations starting in FY07

**KPNO 2.1-m and Smaller Telescopes**

- Privatization of 2.1-meter operations largely complete by FY07, since, as stated in previous Long-Range Plans, NEWFIRM will provide wide-field IR imaging capability
- Continued KPNO proposer observing with CCD Mosaic on the WIYN 0.9-m, in exchange for offering the instrument when not scheduled on the 4-meter

**Instrumentation Development**

To support the survey and synoptic capabilities characterizing 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.

KPNO will offer the wide-field Mayall 4-m and WIYN 3.5-m telescopes on a very good continental site. The modern design and fastidious maintenance of WIYN allows it to deliver a median FWHM < 0.7" in R, consistent with the site test values. WIYN image quality monitoring records FWHM <0.55" for 25-30 percent of the time. The program of refurbishment of the Mayall 4-m is complete at the hardware level. This includes dome ventilation, mirror chilling and air flow control, active support of the primary mirror, wavefront sensing, and secondary focus and tilt control. Ongoing integration and operational optimization at the system level is now the priority. CCD Mosaic users report stacking hours of integrations and maintaining 0.8" image quality.

The instrument complement will evolve from versatility toward dedication to wide-field image surveying, particularly on the 4-m telescopes. Currently the Mayall is 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 the late Richard Elston at the University of Florida; the Simultaneous Quad Infrared Imaging Device (SQIID), the four-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 one degree; the direct imager, Mini-Mosaic; and the Tip/Tilt imager with rapid guiding correction, all mounted simultaneously and addressable with the rotatable tertiary. The combination of the 2.1-m plus FLAMINGOS has provided a 20' field of view (FOV) in the near-IR, which will be superseded by NEWFIRM.

Three major new instruments are planned. NEWFIRM will be a wide-field near-IR imager with a 4K×4K mosaic array detector, covering a 30' square FOV on the 4-m, planned for delivery in late 2005. The Goddard Space Flight Center and the Space Telescope Science Institute have built a prototype multi-object near-IR spectrograph with a micro-mirror array as a programmable slit mask, now in final commissioning. When NEWFIRM and the Goddard IRMOS are fully
commissioned, SQIID will be retired and the 2.1-m opened to operations partnership. The WIYN consortium is actively pursuing the development of a one-degree CCD imager with orthogonal-transfer integrated CCD arrays for local fast guiding. The goal is scientific operation in 2009, with the QUOTA mosaic as a precursor on track for delivery in 2006.

TELESCOPE SYSTEM INSTRUMENTATION PROGRAM (TSIP)

Major Program Goals FY 2005 – 2010:

- Strategic development by the community of the U.S. O/IR observing system

The concept of a “system” of private- and publicly-funded ground-based O/IR telescopes, first proposed in the decadal survey, serves as a context for understanding the needs of the research community and for addressing those needs. The system perspective provides a framework for developing mutually beneficial partnerships with the community for much of the NOAO program. In addition, several activities within the program are motivated by the desire to strengthen this system and make it effective. These include the administration of the Telescope System Instrumentation Program (TSIP) and the activities of the community-based System Committee.

TSIP was the highest priority “medium-sized” initiative of the decadal survey. Established by NSF in 2002, the program is aimed at channeling new resources to providers of needed capabilities and to enhance the system of ground-based O/IR facilities. TSIP, through a peer-review proposal process, funds the development and improvement of facility-class instruments for the telescopes of the private and non-federally funded observatories and in exchange provides time on these telescopes to the broad community, thus simultaneously improving the capabilities within the system and broadening access to its main components. It also provides a mechanism through which independent observatories may sell telescope time to the community, further broadening access. NOAO administers this program—providing management of the selection process, as well as contract management, and technical oversight—to ensure that the federal funds are used effectively to provide the capabilities that the community has identified. In addition, the distribution of telescope time from TSIP contracts is integrated into NOAO’s semi-annual telescope time allocation process.

TSIP began in FY 2002 with annual funding allocations of $4M in the first three years; in the fourth year, funding has been cut to $2M. As a result of the first year of activity, two new Keck instruments are under development—one in fabrication and one in design—and 41 nights on the Keck telescopes have been made available to the community. The review of proposals in the second year resulted in a new instrument for the MMT and Magellan telescopes, 27 nights at each of the MMT and Magellan observatories, and 12 additional nights on the Keck telescopes. The third cycle resulted in funding for an instrument for the LBT, together with 25 future nights for the community on that telescope. The cycle of solicitation, proposal review, negotiation of contracts, and contract monitoring is expected to repeat each year. Peer review panel membership will change somewhat as conflicts of interest arise, but the intent is to populate the panel with a broad mix of expertise in astronomical instrumentation and
understanding of community needs. Administration by NOAO costs TSIP approximately $50,000 per year.

In order to help the system evolve to better address the needs of the community, NOAO also must develop a process for understanding those needs. 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 system is the creation of a mechanism by which the community can develop an evolving plan that identifies needed capabilities and 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 and other 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.

In undertaking such 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 conflicts of interest as possible. To fill that role, we have organized a System Committee that will assist with planning and organizing community meetings and workshops. Two such workshops have already taken place. The “First Workshop on the Ground-based O/IR System” held in Scottsdale, Arizona in October 2000 and “Building the System from the Ground Up”, held in Alexandria, Virginia in May 2004. The System Committee has helped to formulate the discussion into a strategic plan, and advocate that plan to the funding agencies.

**Major Program Activities**

- *Continue strategic planning and development of the ground-based O/IR system.* This is based on the activities of the System Committee, which will conduct community discussions about various aspects of the system and synthesize these into an evolving strategic plan.

- *Carry out annual TSIP proposal process.* This activity includes solicitation of proposals, review of the proposals by a peer-review committee, negotiation of sub-awards with the selected proposers, and oversight of the instrument development activity funded by the TSIP sub-award.

In the FY2005 proposal cycle, we have seen increasing proposal pressure from excellent TSIP proposals. However, there has been a glitch in TSIP funding for 2005 and 2006. We assume in this Long Range Plan (see Tables 3 and 4 below) that TSIP funding will be restored in FY2007 to its 2002–2004 levels, so that the U.S. System will continue to develop in capability and access.
ADAPTIVE OPTICS DEVELOPMENT PROGRAM (AODP)

Major Program Goals FY 2005–2009

- Continue to monitor progress of projects awarded funds in the FY04 AODP and terminate funding for any projects that fail to meet their milestones
- When funding permits, make awards to proposers selected in the second-year (FY05) AODP proposal solicitation
- Work with the community-based AO steering committee to update the 2004 road map (http://www.noao.edu/system/aodp/roadmap.html) and recommend any changes in program emphasis to the NSF
- When NSF funding resumes, organize/coordinate the AODP annual proposal review; negotiate terms and conditions for sub-awards; manage and overseeing awarded projects

In conjunction with its ranking of a Giant Segmented Mirror Telescope as the highest-priority major initiative for astronomy in this decade, the decadal survey noted the associated importance of supporting adaptive optics technology and development. Funding for AO on the order of $5M per year for ten years was specifically recommended. The survey also noted that AO development work will enhance dramatically the power of existing large telescopes, allowing them to work at the diffraction limit at shorter wavelengths, thereby greatly increasing their scientific power. In 1999, NOAO sponsored a community workshop aimed at developing a road map to guide NSF investment in adaptive optics. Its report was presented to the NSF in mid-2000. In 2003 and 2004, NSF was able to make available funding in the amount of $3M per year to support the initial phases of a 10-year AO investment program; however, funding was progressively cut in 2005 and for 2006. Our current goal is to restore funding and increase the annual support level to $5M. In the budgets submitted in this current Long Range Plan (Tables 3 and 4 below), we assume that AODP funding will be restored in FY2007 to its 2003–2004 levels, so that adaptive optics innovation will continue on a broad front.

NSF requested that NOAO (1) manage the AODP and (2) update the road map periodically. In August, 2004, NOAO issued the second-year proposal solicitation/program announcement http://www.noao.edu/system/aodp/04aodpao.pdf. In December 2004, 14 proposals were received and evaluated by a peer-review panel comprising astronomers, engineers, and project managers; six of the proposals were selected for awards. However, only sufficient funding was available in 2005 and 2006 to maintain existing awards; the six successful 2004 proposals therefore remain unfunded.

In 2007, NOAO will hold a broad-based community workshop which will provide a summary of ongoing AO activities throughout the world—the context for updating the road map and informing the next AODP proposal solicitation. New AODP funding by 2007 or sooner is an important complement to GSMT design and development because the successful (but unfunded) proposals in the 2004 program involve projects that test prototype systems on existing telescopes.
ADVANCING DECADAL SURVEY INITIATIVES

AURA NEW INITIATIVES OFFICE

Major Program Goals FY 2005–2009

- Provide technical and management support for the GSMT Science Working Group including (a) reviewing progress on U.S. ELT efforts and providing community input regarding their science goals; (b) establishing working relationships with ESO’s science planning effort; and (c) developing an understanding of how the U.S. system of public-private telescopes needs to evolve in order to meet the new requirements of the GSMT era.

- Participate fully and represent the community in the Thirty-Meter Telescope (TMT) Design and Development Phase by: (a) carrying out the design work for the TMT secondary and tertiary mirror assembly; (b) supporting the TMT design effort for the primary mirror assembly; (c) carrying out feasibility and design studies for a mid-IR echelle spectrograph and associated NGS and LGS AO systems; (d) developing the Observatory Requirements Document for TMT; (e) developing and maintaining a public Web site for TMT aimed at informing both the astronomical community and the general public regarding the TMT project and its scientific potential; and (f) providing support for community groups involved in instrumentation design and development.

- Support the TMT Science Advisory Committee as it works with the TMT project to carry out cost-risk-performance trades during the Design and Development Phase.

- With other TMT partners, carry out TMT site evaluation in Hawaii, Mexico, and northern Chile, and assist other ELT groups in evaluating potential sites.

- Carry out computational fluid analysis and other advanced modeling in support of the TMT, other Extremely Large Telescope (ELT) concepts, and the Large Survey Telescope (LST).

- Carry out studies aimed at exploring the modifications in the mid-IR echelle design needed to provide this essential capability on the Giant Magellan Telescope (GMT).

- Work with ESO technical groups to align technology investments in service of exploring a wider range of technical approaches and encouraging vendor development on both sides of the Atlantic.

- Review progress against plan for ELT program activities that may be supported via the AURA proposal to NSF.

- Develop an understanding of the scientific potential and technology drivers for next generation O/IR facilities (e.g., 50-100-m single aperture telescope; O/IR interferometer; South Pole science) via small, structured community workshops. The goal is to develop the background material needed in order to shape and inform discussion for the next decadal survey.
The decadal survey recommended as its highest ground-based initiative the design of a 30-m Giant Segmented Mirror Telescope early in this decade, with a construction start before 2010. Following this recommendation would ensure completion of a GSMT early in the operations phase of the Atacama Large Millimeter Array (ALMA) and the James Web Space Telescope—thus providing the U.S. community with a next-generation telescope that enables full exploitation of these powerful international facilities.

In response to the decadal survey, AURA established the New Initiatives Office (NIO) in January 2001. Located in Tucson and initially involving engineers from both NOAO and Gemini, the primary goals of the NIO are: (1) to develop a public-private partnership to design, build, and operate a GSMT and (2) to develop, in consultation with a broad cross-section of the U.S. community, a comprehensive understanding of key science drivers, instrumentation needs, and telescope design and technology issues. As ELT concepts evolve toward mature designs, NIO aims to engage the U.S. community in efforts to develop instrumentation and key subsystems for a GSMT, to work with the community to ensure that emerging GSMT concepts achieve community aspirations, and to engage international partners in a constructive way that will achieve mutual goals. In the longer term, NIO plans to work with the U.S. community to develop an understanding of the scientific potential and technology requirements for potential next generation ground-based facilities—either >50m O/IR telescopes or interferometers.

Following an 18-month effort involving 11 full-time engineers and scientists and aided by input from multiple community groups, NIO published the results of a major study in the “GSMT Book” (http://www.aura-nio.noao.edu/book/index.html). This study developed an NIO point design that established the feasibility of a 30-m class GSMT, identified areas of technical risk, developed a plan for technology development, and established initial cost estimates. The NIO point design, along with those developed independently by the California Extremely Large Telescope (CELT) group, and the Canadian Very Large Optical Telescope (VLOT) served to inform the “reference design” for TMT—now the basis for developing a fully costed preliminary design for a 30-m telescope by the completion of the design and development phase at the end of 2007.

As a consequence of AURA’s investment in the NIO, key engineers responsible for developing the NIO point design have been hired by the TMT Project Office and are assuming leadership roles in advancing the design of TMT, its instrumentation, and AO systems.

AURA also established the GSMT Science Working Group—a broadly representative community group charged with developing the science case and justification for any federal investment by NSF or other agencies in GSMT. This guidance is intended to be a product of all public, private, and international groups that expect to play a role in the GSMT. The GSMT SWG presented its first report “Frontier Science Enabled by a Giant Segmented Mirror Telescope” to the Astronomy Division of the National Science Foundation in July 2003. The report urged timely federal investment in technology development in order to ensure that the Design and Development Phases for ELTs proceed on a schedule consistent with beginning construction of one or more telescopes by the end of the decade. In February 2005, the SWG presented its second report: “The Power of Two: Synergy between a GSMT and NASA’s JWST” to the NASA-NSF Astronomy and Astrophysics Advisory Committee (AAAC). This report illustrates with quantitative examples both the unique and complementary roles of GSMT...
and JWST in addressing frontier scientific problems, and the “value-added” of having the “power of two” operating in tandem by the middle of the next decade.

Science with a 30-m GSMT

The science enabled by the exquisite images that can be delivered by a 30-m diameter telescope is truly remarkable. By concentrating near-infrared light into an image with a core of 0.02 arcsecond size, the GSMT will be able to measure the internal motions, chemical composition, and star-forming activity in the first gravitationally bound star-bearing systems to form following the Big Bang. This would provide the essential tool for analyzing these “building blocks” for the spiral and elliptical galaxies familiar to us today.

The GSMT’s superb imaging quality also will provide the key to resolving the crowded star fields into individual stars in galaxies as far away as 3 Mpc. Analysis of the brightness and color for samples of millions of such stars will reveal the distribution of chemically and chronologically distinct stellar subsystems—the presumed relics of the pre-galactic building blocks that merged together to form galaxies like the Milky Way.

Its power to image fine detail in high contrast scenes and to feed concentrated light from faint sources into powerful spectrographs will enable the GSMT to image and analyze planets and zodiacal dust clouds around hundreds of nearby stars.

The GSMT will yield direct insight into the diversity of architectures characterizing extra-solar planetary systems, the physics and chemistry of extra-solar planetary atmospheres, and the nature of weather on other worlds. For the first time, it will be possible to study a sample of thousands of newborn stars to locate planets in the process of formation, to understand where and when planets of different masses form, and to determine whether planets similar to Earth are likely to survive at distances from their parent suns favorable to the development of life.

At optical wavelengths, the GSMT’s photon-collecting power will enable simultaneous spectroscopic measurements of thousands of galaxies, thereby providing a stereoscopic “image” of how young galaxies and intergalactic gas are distributed in the early Universe, and how the large-scale structures defined by these probes are linked to the inhomogeneities (manifest in the cosmic microwave background) built in during the instants following the Big Bang.

The ground-breaking science enabled by the GSMT requires a telescope that (1) delivers extremely high quality (near-diffraction-limited) imaging in the near-IR and wide-field coverage in the visible, and (2) incorporates instruments (cameras and spectrographs) that fully exploit its potential.

Next Steps: A Public-Private Partnership to Advance the GSMT/TMT

The decadal survey, and later the GSMT Science Working Group, recommended that design and technology studies for a GSMT begin immediately so that the facility can be completed early in the ALMA and JWST era. Toward that end, in June 2003, AURA signed a Letter of Intent to partner with the California Institute of Technology, the University of California and ACURA to advance the design and development of a 30-m GSMT (the “Thirty Meter Telescope” or TMT)—thus fulfilling the vision of the decadal survey report that the GSMT be realized via a public-private partnership. Indeed, this is a logical extension of the new
paradigm for U.S. astronomy—public and private institutions collaborating to provide a “system” of facilities that will ensure continued access by the U.S. community to world-leading capabilities.

The NIO’s role during the three-year Design and Development phase will be:

- To represent the U.S. community during the period in which systems trades critical to ultimate performance will be made, thus ensuring that the resulting TMT design will satisfy broad community aspirations
- To take the lead in evaluating candidate sites for TMT and other ELT projects
- To provide technical support for the TMT project

**AURA’s Proposal to the NSF**

In summer 2003, AURA submitted a proposal to the NSF for the funds needed to ensure community participation (through NIO) during the Design and Development Phase of TMT, and also to ensure eventual community access to TMT in proportion to federal investment. In spring 2004, the proposal was revised, and now requests funds from the NSF to invest in the key technologies and design studies needed to advance two concepts for Extremely Large Telescopes: (1) TMT and (2) a concept that proposes an alternate technical solution, such as the Giant Magellan Telescope (GMT).

Federal investments in the ELT design and technology studies will:

- Enable completion of preliminary designs for TMT and GMT or an alternate concept by the end of 2007. These designs will provide the basis for understanding the performance, cost, and risk of two concepts early enough to enable completion of at least one telescope early in the JWST era—thus meeting the highest priority goal for ground-based astronomy set by the AASC decadal survey.
- Ensure effective and broad community input during telescope design and technical development so that the delivered performance of each telescope concept meets the scientific aspirations of the community. This will be accomplished through a broadly representative Science Working Group convened by AURA on behalf of the U.S. community.
- Provide opportunities for merit-based public access to the resulting ELT(s) proportionate to the federal investment during the D&D Phase.
- Engage experienced and skilled groups from throughout the community in the ELT D&D Phases via open competition to carry out key design and technology development tasks and instrument concept studies.
- Support the development of technologies and design tools with utility and applicability for the entire U.S. scientific, engineering, and technological community.
- Evoke significant non-federal funding via (1) an already established partnership among AURA, ACURA, Caltech and the University of California to complete the D&D Phase for TMT; and (2) the requirement of significant private funding for GMT or another complementary ELT design and technology development effort supported by NSF.

- Promote, through AURA’s auspices, open communication between these complementary ELT design efforts in service of accelerating both and preserving the option of a convergence path.

**LARGE SYNOPTIC SURVEY TELESCOPE (LSST)**

**Major Program Goals FY 2005 – 2009**

**2005:**
- Assemble initial data management development sub-teams
- Narrow site options for final evaluation
- Establish LSST Corporate Office with private funding
- Initiate primary mirror development with private funding
- Start NSF Design and Development Phase

**2006:**
- Test data pipeline prototypes with precursor data sets
- Select primary and alternate site
- Conduct industrial development studies of hardware systems
- Conduct Concept Design Review
- Develop and submit construction proposal

**2007:**
- Initiate detailed site planning
- Down select secondary and tertiary mirror designs
- Chose data management technology and platforms
- Conduct Project PDR; select array type

**2008**
- Initiate long lead procurements with private funding
- Conduct Critical Design Reviews for subsystems and for total project

**2009**
- Begin construction

The Large-aperture Synoptic Survey Telescope (LSST) is one of three major ground-based facilities recommended for construction during the coming decade by the AASC. It also has been recommended by two other National Research Council (NRC) studies—one on priorities for solar system research and the other on priorities for studying problems on the interface between physics and astrophysics. 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—as well as
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 of the Near-Earth Asteroids (NEAs) with diameters greater than 200 m—i.e., nearly meeting the goal recently recommended by a NASA study committee of detecting potentially hazardous asteroids larger than 150 m in size. The data will also make it possible to derive orbital parameters. The LSST will detect about 10,000 supernovae per year, thereby making it possible to understand more accurately any systematics (such as reddening and evolution) that may affect the use of these events as standard candles. Observations of gravitational weak lensing will enable mass tomography and constrain the nature of dark energy. Scanning the sky with repeated short exposures, as is required for discovery of NEAs, and reducing the systematic errors for weak lens analysis, also will 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 and 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 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.”

**LSST Design and Development**

NOAO has joined with the Universities of Arizona and Washington and the Research Corporation to form the LSST Corporation, which will carry out the project. Six other institutions, including some Department of Energy laboratories, have now joined the corporation, and others are likely to apply for membership in the near future. During the past year, the partners have developed a plan for the Design and Development phase of the project, which is estimated to cost ~$30M and last for 3 years. A proposal for half of the required funding has been submitted to the NSF. NOAO, DOE labs, and the Research Corporation, in collaboration with private donors, will supply the other half. The main deliverable is a fully costed construction proposal, which we plan to complete by the end of the second year of the D&D effort. If cash flow is not the pacing item, first light can be achieved in 2012. The baseline design that LSSTC is developing has a 3.5-degree field with an 8.4-m primary telescope as devised by Roger Angel (Steward Observatory) and his collaborators, and subsequently optimized by Lynn Seppala (LLNL) and Ming Liang (NOAO).

A science working group (SWG) chaired by Michael Strauss has submitted a report describing the high priority science to be done with the LSST, and this document is being used in establishing the detailed science requirements for the LSST. Four science areas that are being given priority are: (1) ultra-deep imaging with emphasis on weak lensing and as a method for constraining the properties of dark energy; (2) the characterization of small bodies in the solar system; (3) the study of variable objects; and (4) mapping the structure of the Galaxy.
Strauss committee is now reviewing the LSST and MultiStarrs designs to determine which, if either, has a strong advantage given the science goals. If both prove satisfactory in principle, then the down selection will be based on cost and schedule. NOAO will take primary responsibility for construction of the LSST and enclosure and for developing the site. We have established the telescope team, which includes people with experience on the SOAR and Gemini projects. NOAO will also develop prototypes for some of the data pipelines and for the archive. Data management is the primary challenge of the LSST project, which will generate about five terabytes of data per night during routine operation. Certain information—particularly about variable, transient, and moving objects—must be extracted and made available in near real-time. 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. A number of precursor projects will provide both experience and test beds for LSST data management. The SuperMACHO project at CTIO is one example, and the data rates from ODI, the wide-field imager planned for the WIYN telescope, and the Dark Energy Camera, which is planned for the CTIO 4-m, approach LSST data rates closely enough to provide a real test for the data pipelines as they are developed for the LSST. NOAO is an active participant in the National Virtual Observatory (NVO) and currently is working on plans to serve data to the community from Pan-STARRS, the survey project being developed by the University of Hawaii.

DATA PRODUCTS PROGRAM (DPP)

Over the five-year period of this plan, the Data Products Program will address the opportunities described above by establishing a node of the National Virtual Observatory (NVO) that specializes in ground-based O/IR data. This node will provide access to ground-based O/IR data (through the NOAO Science Archive) and services for the analysis and exploration of data, in addition to being a portal to other NVO providers. Because the largest single data set in this category is that from the LSST, the entire activity must be designed to accommodate an evolution to that scale, and must emphasize those tools and interface functions—such as visualization and analysis of time-domain data—that will be required for the community to exploit the LSST data set.

Major Program Goals FY 2005–2009

- Through AURA, respond to the NSF solicitation for proposals to operate the NVO.
- Create and operate an archive that supports data discovery, visualization, analysis, and mining for a combination of pointed observations and coherent surveys, together with derived, value-added data products. This archive should be scalable to handle the petabyte-scale data sets from projects such as LSST and Pan-STARRS.
- Put in place and operate an automatic data transport infrastructure to feed raw data from NOAO telescopes automatically into a “save-the-bits” safe store within the NOAO Science Archive. This will incorporate all NOAO data into the NVO.
Begin ingesting pipeline-reduced pointed observations from NOAO telescopes into the NOAO Science Archive; begin ingesting data from very large surveys, (e.g., Pan-STARRS, Dark Energy Survey, LSST) when they become available, perhaps as early as FY 2007.

Continue to develop reduction and analysis software for NOAO and Gemini instruments, together with improvements in the IRAF system aimed at (1) facilitating community development of new applications using IRAF, and (2) maintaining its relevance in the VO era.

Develop a portal that integrates access to all the capabilities listed above. This portal will access both local (NSA) and distributed data through VO-compliant protocols. It will combine the ability to discover and federate large multi-wavelength data sets with configurable reduction pipelines, and analysis and mining tools pertinent to the use of ground-based O/IR data.

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 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 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 become a critical element of the national O/IR system and address the needs of researchers and educators who have limited access to telescope facilities and other opportunities. The potential of these revolutionary developments was recognized in the decadal survey, 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 capable of mapping the entire visible sky once per week, thus enabling detection of variable/transient or moving objects by summing frames acquired over a decade, providing images of unprecedented depth. The panel for ground-based OIR astronomy also called particular attention to the need to develop archives for ground-based data.

**NOAO Science Archive (NSA)**

Work is now underway on the evolution of the “interim” NOAO Science Archive to an “engineered” facility that will be extensible to the LSST era. Additional efforts to improve
functionality include development of time-domain, science-specific tools, development of visualization tools for O/IR data, and integration of catalogs and other data products with image data in the archive. Future phases of this work will be carried out in collaboration with supercomputer centers. Additionally, the NSA will enable the community to serve their data sets through VO-compliant interfaces.

**Data Reduction Pipelines**

Initial development is aimed at providing a common pipeline management infrastructure and specific modules to reduce data from the NOAO Mosaic CCD imagers. This will be followed by development of a pipeline for NEWFIRM. The University of Maryland participation is planned in this work.

**Data Transport Infrastructure**

Implementation of this system for automatic transport of data from telescopes to archives has major implications for operation of our facilities. Over the next year, this capability will allow both observing teams and archive researchers to begin accessing NOAO data directly from the NSA. The “Save-the-Bits” safe store will be incorporated into the archive, and data will be automatically mirrored between Tucson and La Serena.

**National Virtual Observatory (NVO)**

The Data Products Program maintains involvement with the NSF ITR-funded effort in scientific and technical areas, and our intent is to continue that participation into the operations phase of the NVO. In addition, we are developing a portal that integrates VO-capable tools with data access mechanisms, guiding the user through data discovery, access, understanding, and analysis, in a way that emphasizes the use of ground-based O/IR data.

**LSST Data Management**

The Data Products Program is focused on enabling effective community use of these and other large survey data sets. NOAO is participating in the LSST-partnership-wide effort to carry out exploratory and prototype work in support of a future LSST proposal. NOAO is also negotiating a partnership with the Pan-STARRS project in which DPP provides community access to useful Pan-STARRS data products as a precursor to the similar LSST effort.

**Instrument Data Reduction**

Collaboration with NGSC, CTIO, and KPNO instrument scientists continues to guide development of instrument data reduction software. In addition, software developers are working in collaboration with Gemini personnel to develop data reduction tools for Gemini instruments.
MAJOR INSTRUMENTATION PROGRAM (MIP)

Over the past decade, there has been unprecedented investment in new telescopes in the 8-m to 10-m class. The challenges in the next decade will be to take full advantage of these facilities by equipping them with advanced technology instruments and to leverage that experience into construction of the first instruments for the next generation of telescopes. Experience with the first generation of 8-m telescope instrumentation shows that these instruments typically will each cost tens of millions of 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 to maximize the range of available capabilities and to optimize the expenditures on the infrastructure required to support the building of complex instruments.

Program Objectives

1. Establish a robust pipeline for delivery to the Gemini telescopes instruments that simultaneously meet performance, cost, and schedule requirements, in partnership with other major instrumentation providers

2. Supply key instrumentation technologies to the developers of instrumentation for other large telescopes in return for community access where appropriate

3. Develop the broad range of capabilities needed to serve as a prime contractor for the still larger and more complex instruments that will be required for the GSMT and LSST

The FY 2002-2006 Long Range Plan actually identified #3 above as a secondary objective. However, experience over the past year has clarified the importance of an early start in this area, so developing these capabilities has been put on a par with the first two objectives.

Decisions on the major work packages have been based on the principles outlined in the FY 2002-2006 Long Range Plan. First, the NOAO program will focus on major instruments (estimated total cost at least $6M with detectors and controllers), with priority given to building instruments for telescopes of 6.5-m aperture or greater. Second, the instruments must be integral to the strategic plan for the U.S. ground-based system of telescopes or synergistic with it. Third, the evaluation of instruments with respect to the strategic plan should be carried out in the context of community workshops on the national system. For FY 2006, the realignment of the NOAO budget shifts significant funding from the Major Instrumentation Program to the New Initiatives Office. For that reason, in FY 2006 a fourth principle is being added: all new work packages must be fully supported by revenue from outside the NOAO base budget.

Major Program Goals FY 2005 – 2009

- Design, construct, and deliver the NOAO Extremely Wide-Field Imager (NEWFIRM) (FY05-06)
- Build and deliver the remaining Monsoon scalable data acquisition systems for which there are outstanding orders (FY06)

- Develop the engineering changes to the Monsoon system needed to achieve the high channel densities required for large focal planes such as the WIYN One-Degree Imager (FY06–07)

- Design, build and commission an adaptive optics system for the SOAR telescope (FY05–08)

- Build at least one new instrument for Gemini, preferably in partnership with a university instrumentation group (FY05–11)


The following paragraphs give some background and description of the major work packages, showing their connections to the major program goals described above.

- Design, construct and deliver NEWFIRM

NEWFIRM is a wide field near-IR survey camera designed to image a field almost 30 arcminutes square. Its science goals range from population statistics for methane brown dwarfs to searches for primeval galaxies at high redshift. An imager of this type was identified as one of the highest-priority needs of the U.S. observing system by the NOAO-sponsored community workshop on the future of the U.S. system (Scottsdale, October 2000). In addition to its intrinsic merits as an integral part of the U.S. system of ground-based facilities, NEWFIRM allows NOAO to retain an essential core of engineers, designers, and managers until the next Gemini instrument enters the design and construction phase. After a slow start in early FY 2003 (largely due to the demands of completing GNIRS), the NEWFIRM team has re-organized itself and successfully completed its Preliminary Design Review in June 2003, with a targeted delivery date early in FY 2006. As of mid-FY 2005, most of the parts have been fabricated, and integration of the instrument is beginning. This work package meets the first goal, that of maintaining a robust pipeline for the delivery of Gemini instruments, by allowing NOAO to keep the core instrument design and construction team working between completion of GNIRS and the beginning of the next major Gemini instrument.

- Build and deliver the remaining Monsoon systems for which there are outstanding orders

Monsoon is the NOAO-designed detector controller system that will be versatile enough to drive both optical CCDs and IR diode arrays, and scalable enough to control large mosaics of individual detectors. This capability is essential for the next generations of instruments with very large focal planes, beginning with NEWFIRM and continuing on through the next generation of Gemini instruments to LSST and even beyond. Also, Monsoon is designed to be sufficiently flexible that it can be used by other instrument making groups, and specific requests have been received from several groups outside of NOAO. The Monsoon team completed its first working prototypes in FY 2003 and delivered the first “production” systems in FY 2004,
for NEWFIRM and the NOAO IR detector test facility. The Major Instrumentation Program has
developed a structured way of making Monsoon systems and their underlying technology
available to the community at large. Under these structured collaborations, systems are being
delivered in FY 2005 to teams working on new or proposed instruments for the WIYN and
Blanco telescopes. FY 2006 will see the delivery of the remaining systems under contract, and
the costs of this effort will be covered by the programs receiving these systems (in this case,
KPNO). This work package meets the second program goal, that of supplying key
instrumentation technologies to other builders, by directly supplying them with a critical
subsystem that is not currently available elsewhere. It also meets the third program goal, that of
developing the capabilities needed for GSMT and LSST instrumentation, by providing a path
towards control of the massive focal planes that will be needed for those telescopes.

- Develop the engineering changes to the Monsoon system needed to achieve the high channel
densities required for large focal planes such as the WIYN One-Degree Imager (FY 06–07)

The Monsoon system was designed to be scalable to permit the control of arbitrarily large
focal planes, and the current design fully delivers that scalability. The first systems to use
Monsoon controllers, such as NEWFIRM, did not have particularly stringent requirements on
physical size. Some future instruments, such as the Dark Energy Camera for the Blanco
telescope and the One-Degree Imager for WIYN, will require both very large numbers of video
input channels and a very small physical size, thus very high channel densities. Some further
engineering will be needed to repackage the Monsoon design into this significantly smaller
format; this work package covers the MIP engineering effort needed for this repackaging. Some
additional engineering effort is expected to be contributed in-kind by staff at collaborating
institutions. This work package meets the second program goal, that of supplying key
instrumentation technologies to other builders, by developing a critical subsystem that is not
available elsewhere. It also meets the third program goal, that of developing the capabilities
needed for GSMT and LSST instrumentation, by taking the next step along the path towards
control of the massive focal planes that will be needed for those telescopes.

- Design, build, and commission an adaptive optics (AO) system for the SOAR telescope

A properly designed AO system will allow the SOAR telescope to provide low-order partial
seeing corrections at shorter wavelengths (optical and ultra-violet) than can be achieved on
larger telescopes. Further, such a system, in combination with a Rayleigh laser artificial guide
star, would provide an ideal test bed for the technology of “ground-layer adaptive optics”
(GLAO) seeing improvements that are essential to several science goals of a Giant Segmented
Mirror Telescope (GSMT). Finally, such a system gives NOAO staff experience in the AO field
that will be critical in building instruments for the GSMT. The design work for this AO system
has already begun, and the design underwent a conceptual review in April 2003 and a follow-up
“delta review” for changes in January 2004. There are still a number of issues to resolve with
the design and with the plans and resources needed for construction, but it is expected that the
system will be ready for a Preliminary Design Review in the second half of FY 2005, with
construction beginning shortly thereafter. Construction is expected to proceed in two phases—
the first being the development of a system capable of limited use with natural guide stars, and
the second being the integration of the laser artificial guide star for full-sky ground-layer
correction. This work package meets the second program goal—that of supplying key
technologies in return for community access—by satisfying part of NOAO’s obligation to
provide two additional instruments to the SOAR consortium in return for continued community
access. It also meets the third program goal—that of developing the technology and capabilities
needed for next-generation telescopes—by providing a test bed for GLAO technology and
giving the NOAO staff critical experience with AO developments.

- Build at least one new instrument for Gemini, preferably in partnership with a university
  instrumentation group

In December 2003, Gemini published Announcements of Opportunity to propose for design
studies on two instruments. NOAO staff participated in proposals responding to both
Announcements.

- A design study for a large-format, cross-dispersed, high-resolution, near-infrared
  spectrograph that will provide complete coverage of all or most of each infrared wavelength
  band in one exposure at very high spectral resolution ($R \sim 70,000$). As requested by Gemini,
  the instrument will also incorporate a multi-object mode allowing simultaneous spectra of
  15-30 objects at moderate resolution ($R \sim 30,000$). The science goals include more detailed
  analysis of the properties of brown dwarfs, star formation regions, active galactic nuclei,
  and high-redshift galaxies. NOAO is collaborating closely with the instrumentation group at
  the University of Florida on this proposal.

- A design study for a very high-order adaptive optics system with a coronagraphic imager for
direct observation of giant planets orbiting nearby stars. The science goals include a census of
nearby extrasolar planets, and initial studies of the physical properties of the planets detected.
NOAO is supporting a proposal from the University of Arizona for this study.

We anticipate that at least one of the proposals mentioned above will be successful,
resulting in the next major project for the core instrumentation group at NOAO. In addition,
such a project would present an excellent opportunity to join or lead a partnership with another
institution, thus realizing the organizational model that would be needed for building even
larger instruments for the GSMT and LSST. The exact nature and scope of this work package
clearly depends on developments yet to happen, but according to the schedule in the Gemini
Announcements, construction contracts for the first instruments of this new generation would
not begin until approximately the end of FY 2005. All effort under this work package will be
funded entirely by Gemini. If neither proposal is successful, substantial reductions in force will
be needed within the core engineering groups. This work package meets the first program
goal, that of maintaining a robust pipeline for delivery of Gemini instruments, by actively
constructing an instrument in partnership with another institution, thus fostering the instrument-
building capabilities at both NOAO and the university partner—a “win-win” arrangement for
the partner and NOAO. It also meets the fourth program goal, by being entirely supported by funding external to the NOAO base budget.

**Program Components**

The following elements are important to achieving the goals of the Major Instrumentation Program:

- **Strong in-house capability in project management, as well as in the core engineering disciplines: systems, optical, mechanical, electronics, and software.** As instrumentation projects grow and partnerships become the norm for instrument development, strong project management will become even more important. NOAO must build on its already good reputation in this area.

- **A program to develop, test, characterize, and deploy detectors and controllers.** The needs for even larger and more capable focal plane arrays will continue through the next generations of instruments and telescopes. Again, NOAO can cement a key position in these next generations by continuing to build on its recognized strengths in these areas, as exemplified by the ORION detector program and the Monsoon controller development.

- **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 and to NOAO projects.

- **A program to develop and evaluate a limited number of new key technologies, as exemplified by recent contributions to the international efforts to further the development of vacuum phase holographic gratings.**

- **A program to train post-doctoral associates in the skills required to provide scientific leadership in the building of large instruments, and an intern program expanded to include graduate students.** A small program of this kind was a successful feature of the GNIRS project. The HRNIRS project would also offer similar training opportunities; such a program would be advertised and coordinated with our University of Florida partner.

**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. 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, although some instruments can take significantly longer. From the standpoint of smoothing out the cash flow and manpower requirements, it makes sense to undertake two instruments, staggered by two years, and this indeed was the model recommended for the NOAO program in
the FY 2002-2006 Long Range Plan. However, reality has a way of being too messy and uneven to permit this kind of neat phasing. This problem was made painfully clear when Gemini awarded the construction of the Gemini South Adaptive Optics Imager (GSAOI) to another institution, leaving NOAO without an externally funded project just as the GNIRS project was winding down. In general, Gemini does not call for proposals for a new instrument on a neat two-year cycle, nor can NOAO expect to win the competition every time or even every other time. It does not make sense to plan on starting a new Gemini instrument every two years.

Since the FY 2002-2006 Long Range Plan was drawn up, there has been further work to make both the LSST and GSMT more real, and both programs are beginning to enter phases where some work on their instrumentation is needed in technology development and conceptual design. However, this work is of a much longer range and riskier nature than the four-years-to-build envisioned in the two-instrument model. NOAO must be prepared to invest some seed money over the next couple of fiscal years without any assurance that a full instrument construction project will follow. Beginning in FY 2006, NOAO is making that investment in the form of a realignment of its base budget away from traditional instrument construction and towards conceptual design work as needed to support the GSMT efforts. This realignment results in a substantial decrease in the MIP base budget, thus requiring that any new MIP work packages be wholly funded from other sources. This funding model carries increased risks for the Major Instrumentation Program, in that any interruption in the flow of externally funded work would lead to losses of critical personnel from which recovery may not be possible. However, the realignment of base budget funding is the only way to make the investments now needed in the design and development of GSMT capabilities.
SCIENCE EDUCATION AND PUBLIC OUTREACH

The overall mission of the NOAO Office of Public Affairs and Educational Outreach (PAEO) is to advance the cause of science education and science inquiry in all sectors of American life using the interdisciplinary appeal of astronomy. Our ultimate goal, consonant with NSF Education and Human Resources priorities, is to contribute to the development of a scientifically literate citizenry capable of meeting the science, mathematics, engineering, and technology challenges of 21st-century society.

The use of NOAO science and its unique facilities as the framework for promoting public understanding, awareness, and support of U.S. science also underscores NOAO outreach activities to the non-specialist public. Whether via NOAO’s public-friendly Web site (www.noao.edu), the popular exhibits, programs and guided tours at the Kitt Peak Visitor Center, or the stream of press releases and imagery produced by the Media and Public Information group, NOAO regularly communicates the excitement and significance of astronomical research to a wide range of audiences.

NOAO PAEO programs are governed by two main principles:

- We will provide top-quality products and services in all of our outreach activities, incorporating the latest research results from the national observatory wherever possible.

- We will provide national leadership and exemplary program models in astronomy education, whether our immediate audience is local, regional, national, or international.

This Long Range Plan emphasizes excellence in these fundamental areas through a range of high-visibility programs. NOAO PAEO is organized to create a synergy across our department that allows us to innovate and respond to the most pressing needs of the entire formal and informal educational system, without becoming overly devoted to one area.

Science Education

NOAO Educational Outreach (EO) programs are designed to support and energize national science education reform efforts and the national science education standards, while being compatible with international educational programs. This broad view is necessitated by the international nature of astronomy and the wide geographic distribution of NOAO-supported facilities. Our program staff have a keen awareness of our obligation to reach underserved groups, and to constantly be a source for developing and testing novel ideas.

Our educational program goals emphasize national leadership even as many of our educational programs serve a local and regional audience. Our goal is to provide “flagship” programs that illustrate both best practices and new approaches in the field. Current and future NOAO EO efforts span the educational spectrum, including:
Teacher professional development
- Teacher-astronomer partnerships
- Instructional materials development
- Informal and community-based science education
- Research experiences for students and teachers

Our programs are designed to extend beyond a narrow “astronomy-only” focus to include technology education, optics education, and the physical sciences, based on the realization that the field of astronomy has a strong instrumentation/engineering component and that astronomy education in the public school community is often a part of Earth science education. Thus we extend our programs to encompass an understanding of technology, and we base our formal education programs on a willingness to work with and to be part of the larger earth and space science education community.

Through the use of strategic partnerships, we participate in larger projects where we can leverage resources, innovate, and play an intellectual leadership role:

1. Strategic partnerships with professional societies such as the American Astronomical Society, the Astronomical Society of the Pacific (ASP), the American Geophysical Union, the Optical Society of America, and SPIE–The International Society for Optical Engineering

2. Cooperation with educational societies and organizations such as the American Association of Physics Teachers, the National Science Teachers Association, the National Association of Earth Science Teachers, the Association of Science-Technology Centers, the Society for the Advancement of Chicanos and Native Americans in Science (SACNAS), and the International Dark-Sky Association

3. Active teaming arrangements with our closest geographic partners, including the Spitzer Science Center, the VERITAS project at SAO, the University of Arizona in general, and Steward Observatory and the Flandrau Science Center in particular

4. Multicultural activities in the Spanish language with astronomy materials and outreach programs in Chile, and several emerging thrusts in Native American science education, such as support for a new introductory astronomy class at the Tohono O’odham Community College

To work effectively with these organizations, NOAO EO staff often serve on advisory committees and proposal review panels, chair education sessions, and run workshops as part of professional meetings. The NOAO educational outreach staff, which includes four Ph.D.-level educators with extensive experience in a variety of major educational outreach efforts in astronomy and space science, has given more than 75 workshops and presentations at conferences in the last five years on innovative methods in science education.
NOAO also strives to be a leader in incorporating scientific data—and data tools like image processing—into the classroom. As new facilities produce prodigious amounts of data, NOAO will be exploring new methods of distributing that data for educational purposes, leading toward the data-intensive era of LSST outreach.

**Teacher Leaders in Research Based Science Education (TLRBSE)**

The TLRBSE program is a cornerstone activity of NOAO educational outreach. TLRBSE competitively selects about 20 experienced middle school and high school teacher leaders annually from across the United States to receive advanced training in cutting-edge astronomical research projects. This training enhances their pedagogical and leadership skills, their content knowledge in astronomy and physics, and their grasp of computer-based tools such as data and image processing. These master teachers in turn are prepared to mentor novice teachers in their local area, helping with the ongoing challenge of teacher retention and renewal. In the process, TLRBSE is developing a leading model for Internet-based, actively moderated distance-learning course that encompasses pedagogy, leadership, and science content.

Over the next five years, as the program becomes fully funded within the core NSF AST budget for NOAO, TLRBSE will grow to offer an even greater range of research experiences to its ever-expanding cadre of trained master teachers (>100 and counting), from fresh observing experience (with student participation) on Kitt Peak to the use of small remote telescopes to cutting-edge astronomical facilities ranging from the Spitzer Space Telescope to the VERITAS array.

TLRBSE program will be maintained at its current level of quality and depth as it becomes completely supported in the core program. TLRBSE represents our flagship teacher professional development program and is a national model for teacher enhancement and the value of incorporating science research into the middle and high school classroom.

**Project ASTRO**

Project ASTRO forms the core of NOAO’s highly successful regional educational outreach program. Project ASTRO-Tucson is a flexible program with broad content coverage and great utility for a diverse educational audience.

Project ASTRO is aligned with the National Science Education Standards. Its relatively simple, hands-on activities appeal to different teaching and learning styles, and they can easily be adapted for constraints on space, staff, and money at individual schools. ASTRO-Tucson also addresses the scientific process, best practices and pedagogy, student misconceptions, and authentic assessment issues. In Tucson, it has been used successfully with elementary, middle, and high school students of different ethnic backgrounds, as well as with physically challenged and underserved students. One of 13 sites nationally, ASTRO-Tucson has reached more than 15,000 students via more than 400 teacher-astronomer partnerships.

The program’s main ongoing feature is the partnering of volunteer professional and amateur astronomers with K-12 teachers and community educators who want to enrich their astronomy and science teaching. The partnerships are developed through an annual training
workshop, hands-on activities, effective educational materials, follow-up workshops, continued staff support, and connections to community resources.

Family ASTRO-Tucson will focus on continuing to reach a variety of underserved groups in the Tucson area, including the Tohono O’odham Indian Nation, the Hispanic community of the Sunnyside School District, and the Girl Scouts of America. Because it can be adapted to address the needs of a diverse audience and varied circumstances, Family ASTRO has experienced immediate success and acceptance in Tucson and elsewhere, which has led us to incorporate it as a long-term commitment to local and regional outreach in the informal arena.

**Spanish Language Astronomy Education**

In a further expansion of the ASTRO concept, NOAO North and South have jointly sponsored videoconference workshops for teachers in Tucson and La Serena. The teachers exchanged methods and ideas about how to explain and demonstrate the nature of light and color to students of various ages. Each workshop was held in Spanish with bilingual science teachers from the Tucson area. The workshops are envisioned as the beginning of an even larger collaboration dubbed ASTRO-Chile. This effort is meant to take advantage of successful efforts in the United States, such as Project ASTRO, and efforts in Chile, like REDLASER, by merging the strategies and techniques from each into a cross-cultural exchange. Future areas of emphasis will likely include the common issue of dark skies and light pollution.

Astronomy and space science educators cannot easily find high-quality instructional materials in Spanish for elementary and secondary formal education; informal educational materials in Spanish are difficult to find at all levels. With its strong connections to Spanish-speaking science teachers and science district coordinators, NOAO is creating a national resource to enable educators to find and apply quality materials in Spanish that have already been produced.

This NOAO Spanish Language Materials Educational Center is providing a Web-based, user-friendly catalog of generally available Spanish language materials for all grade levels in astronomy and space science. Published in both Spanish and English, the Web pages include materials appropriate for school guidance counselors, administrators, and teachers.

**New Programs in Educational Outreach**

Consistent with our educational outreach philosophy and as part of our strategic partnerships with professional societies and educational institutions, we have established a variety of innovative teaming arrangements.

NOAO has several ongoing partnerships with the Flandrau Science Center, including a joint effort with the University of Arizona in an NSF-funded project titled “Revealing the Invisible Universe From Nanoscopes to Telescopes”, a program to train student interns in informal science education. This IPSE project has produced new programs and exhibits on infrared astronomy and the use of the infrared in remote sensing.

NOAO is also a key partner with the Optical Society of American and SPIE-The International Society for Optical Engineering, in a project called “Hands-On Optics: Making an
Impact with Light”, funded by the NSF Informal Science Education. NOAO will develop optics instruction modules and provide professional development for this program, which will reach more than 40,000 middle school students in after-school programs and at science centers.

NOAO is an active part of the nationwide GEMS materials network led by the Lawrence Hall of Science, and has helped establish a successful Southern Arizona GEMS Center, which provides professional development throughout the state of Arizona on guides for teachers developed by the Great Explorations in Math and Science program.

NOAO is a partner on the University of Arizona NSF GK-12 Track 2 program “Collaborative to Advance Teaching Technology and Science (CATTS)”. Two NOAO CATTS Fellows work each year to advance local and regional science teaching through a commitment of 15 hours per week.

“Astronomy from the Ground Up” is a new collaborative effort between the Astronomical Society of the Pacific, NOAO, and the Association of Science-Technology Centers to provide professional development in astronomy for informal science educators nationwide. This NSF ISE project, which began in March 2005 and will continue for at least four years, represents major movement toward even greater synergy between NOAO formal and informal outreach.

The NOAO manager of science education and other staff will be key contributors to a new NSF Instructional Materials Development program titled “Investigating Astronomy,” which will develop a high school astronomy curriculum in partnership with the Astronomical Society of the Pacific and TERC, the project lead. This program will produce a standards-based, technology-rich, one or two semester astronomy course that emphasizes the processes of modern astronomical research including its tools and imagery.

These projects serve as preparation for the data and technology rich efforts required to support the education and outreach programs proposed for the LSST and GSMT.

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) from 1980-1984, and since 1989, with the Research Experiences for Undergraduates (REU) program.

The NSF-funded NOAO REU program has encouraged undergraduates—especially women, underrepresented minorities, and students from institutions lacking access to first-rate research staff and facilities—to pursue careers in science. The NOAO 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. NOAO currently is providing research experience to about a dozen undergraduates annually, and this rate is expected to continue, along with increased recruiting of underrepresented groups via expanded mailing lists and attendance at meetings of Historically Black Colleges and Universities (HBCUs), the Hispanic Association of Colleges and Universities, and the American Indian Science and Engineering Society.
**Astronomy Education Review**

The Astronomy Education Review (http://aer.noao.edu/) is a refereed electronic journal that aims to bridge the gap between current astronomical research and science teaching, science learning, and broad science communications to the public. Conceived by Sidney Wolff and Andrew Fraknoi (Foothills Community College) as a lively compendium of research, news, and opinion, the journal has published five virtual “issues” and counting using start-up funding from NASA and core funding from NOAO for its editor. It has been endorsed by both the AAS and the ASP.

The on-going goals for AER during the next five years are to continue operations, automate the receipt and tracking of manuscripts to minimize the time required from the scientific editors, and find a long-term home and funding source for the journal.

**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/volunteer program, educational programs for visiting school classrooms and the general public, and the popular nighttime observing experiences for both the general public and advanced amateurs. Public outreach staff also participate in several informal outreach programs based in the PAEO educational outreach group, including Family ASTRO and local use of a mobile planetarium.

Kitt Peak attracts more than 60,000 tourists annually. The Visitor Center serves as the hub for all of these visitors, providing information, services, and educational activities on the mountain. NOAO is executing a series of significant upgrades to the Visitor Center facility, with new audiovisual displays and updates to its colorful display posters, along with the addition of more hands-on exhibits and interactive activities led by docents. The daily revenues generated by the Visitor Center attendees and programs help to offset some of the costs of NOAO’s Public Outreach activities, including much-needed capital improvements to the Visitor Center building.

The Kitt Peak docent program—which includes three daily tours of the Mayall 4-m, the 2.1-m, and the McMath-Pierce solar facility—constitutes a rewarding volunteer experience for the 40 docents themselves and 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 in effect since 2001.

The Kitt Peak Nightly Observing Program (NOP) is a fee-based program aimed at introducing the general public to the wonders of astronomy. The NOP is one of the most popular educational attractions at Kitt Peak, with more than 30,000 participants since its inception in 1996. Each NOP session features an in-depth, three-hour observing experience for up to 34 people at the two sites. Participants use star charts, binoculars, and the 0.6-m telescope at the Visitor Center Observatory or the 0.4-m telescope at the new site to gain an in-depth understanding of the wonders of the night sky.
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 that uses 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.

Over the next five years, major expansion of the Kitt Peak Visitor Center and its associated programs is planned, including new exhibits and a greater variety of products for sale. Increasing the number of visitors to the mountain, thus informing larger numbers of people directly about the mission of NOAO and the NSF, and providing a better taste of the excitement and rewards of scientific research is also planned.

In addition to the regularly scheduled NOP/AOP programs, the Visitor Center conducts special observing events throughout the year, including public sessions for astronomical events such as meteor showers and lunar eclipses. Some new initiatives include working with the Boy/Girl Scouts, colleges and other similar clubs on special stargazing nights. Classes are being offered to the general public on such topics as asteroid hunting, solar observing, CCD imaging, the Moon, and an introduction to astronomy as a hobby, and the intent is to expand the number and type of these classes/special programs in the next five years.

One special focus is increasing the number of school groups visiting Kitt Peak, with the aid of science education students from the University of Arizona and a grant from the NSF for the development of curriculum and hands-on activities for schools wishing to visit the mountain. A greater concentration on marketing, along with the production of a planning guidebook for teachers, has been implemented, with the goal of enticing greater numbers of students to visit the mountain.

The Visitor Center staff and 0.4-m telescope are an integral part of the TLRBSE teacher professional development program on Kitt Peak, and they will play a significant role in the new "Astronomy From the Ground Up" effort. With these activities taken in total, it likely will be necessary to add an educational coordinator to the PAEO Public Outreach staff in the 2005-2006 time frame.

With the approval of NSF, the NOAO Public Outreach group has begun to prepare a campaign to establish a membership program at Kitt Peak". In return for a nominal membership fee, the members of this program will receive a newsletter, opportunities to experience special events, and discounts on Visitor Center programs. The NOAO Public Outreach group will also 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.

New marketing relationships with the Arizona Office of Tourism, and all of Arizona’s observatories and science centers, are also being explored.

Visitor Center Exhibit Expansion and Improvements

- Continue Visitor Center exhibit upgrades currently underway
- Complete interpretative master plan
· Finish Visitor Center improvements, new flooring, painting of walls, reconfigure gift shop cash register addition of ticket window

· Add the following exhibits:
  — “What are Astronomers Doing Tonight?”
  — Tohono O’Odham (refurbished and expanded)
  — Natural History of the Mountain
  — NOAO science/observatories
  — Dark Skies

**Staffing/Tours**

· Develop walking tour info booklet and routes

· Offer several new paid specialty tours; possibilities include 4-meter, WIYN, VERITAS

· Offer unique historical tours

· Work toward doubling the number of docents

**Membership Programs and Marketing**

· Develop a Kitt Peak Membership Program > 500 members

· On-line store

· Hands-on science in place at the Visitor Center

· Expand class and program offerings

· School Program on-site in place, with related offsite marketing

· Signage replacement

· On-line RSVP system for NOP

· Double the number of AOP guests

· Develop a formal fundraising plan and begin raising donations

· Work toward development of an off-site NOP at a local resort, etc.

**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.

  NOAO generates an average of one press release per month, and imagery from NOAO research telescopes and its public outreach telescopes is often featured on popular sites such as
the “Astronomy Picture of the Day” and the Space.com image of the day. NOAO plans to expand its media outreach into the growing world of Internet Webcasting by offering Real Video press conferences based on newsworthy results as they are published.

Related efforts include a major exhibit presence at each biannual meeting of the AAS, based on the latest imagery and scientific results being presented at the meeting by NOAO. By working closely with the AAS press officer and by 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. Live local news and weather broadcasts from Kitt Peak resumed in February 2004, and are expected to be more frequent in the future, such as during the July 2005 collision of the NASA Deep Impact spacecraft with a comet.

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 sites. NOAO intends to redesign the presentation of this archive on the Web for greater eye appeal and usability, while expanding its holdings by increasing interaction with researchers at CTIO and with the users of the Gemini telescopes. Past collaboration in science news and imagery with the Space Telescope Science Institute and Chandra X-Ray Observatory has expanded to include the Spitzer Space Telescope, and these collaborations are only expected to grow—highlighting the synergistic relationship between ground-based and space-based infrared astronomy—and in the process, the connectivity between NSF and NASA.

The NOAO home page on the Web will continue to be programmed with the central principle of presenting a clear and interesting site for a Web surfer from the general public, with regular, near-weekly updates to its featured story.

Proposed major program initiatives such as the GSMT and LSST will be highlighted by new information products on the Web, and related displays and exhibits at professional meetings, such as the cohesive, NOAO-designed LSST poster session at the January 2005 AAS meeting. In addition, NOAO public affairs is now serving the host and managing editor of the public Web site for the TMT project (www.tmt.org.), and PAEO staff are actively engaged in the LSST outreach working group chaired by S. Jacoby of LSST Corp. Each of these programs has an extensive developmental outreach program tied to successful D&D phase funding.

The future goals of NOAO—and the observatory’s emerging roles in the larger astronomical community—are an integral part of the NOAO Newsletter. This quarterly publication (circ. 2,300) continues to serve as a lively and graphically attractive source of key information for NOAO’s many disparate customers, partners, and public stakeholders.

The five-year Cooperative Agreement with NSF currently in effect encompasses new directions for NOAO, especially the challenge of funding, within a level budget, the high-priority initiatives proposed in the decadal survey, i.e., LSST and GSMT. NOAO is meeting—and will continue to meet—these challenges by building strong partnerships with non-federally funded institutions and universities also working on these projects. In the LSST Corporation, the goal is to carry out design and development for that facility; in the Thirty Meter Telescope (TMT) consortium, to advance design and development of the GSMT up to preliminary design review. Common ground in instrumentation between the two projects will allow the Giant Magellan Telescope (GMT) project to benefit from this work. In FY 2004, an instrumentation partnership with the University of Maryland went into operation. A partnership in the form of the Small and Moderate Aperture Research Telescope System (SMARTS) consortium now operates the four small telescopes on Cerro Tololo. Together, these changes have resulted in significant cost reductions at KPNO and CTIO.

This trend in productive collaborations between NOAO and external partners will accelerate throughout the planning period. Depending on the outcome of the NSF Senior Review, more of these partnerships—with an emphasis on shared operations rather than on
development—will be undertaken in 2006 and 2007. In addition, the NVO is expected to transition into operations during this period, and NOAO plans to continue taking responsibility for the ground-based optical/infrared node through the work of the Data Products Program.

The Next Cooperative Agreement (Est. FY 2008–2012)

Because planning under this NOAO Long Range Plan extends two years beyond the expiration of the current cooperative agreement, we believe it is appropriate to describe here some of the structural changes to be proposed for the management and operations of NOAO during the five-year period of the next cooperative agreement.

By FY 2009, the current NOAO structure, as seen in Tables 1–4 below, will have been consolidated into two divisions: NOAO North and NOAO South. Instead of the current four-division budget structure (KPNO-CTIO-NGSC-TUCSON), which basically groups all NOAO programs, activities, and costs by observatories, this more rational structure, in which telescope operations, observer support, and associated “observatory” work packages formerly assigned to the KPNO and CTIO divisions are considered part of a single “program” (KPCT), with analogous activities taking place in Tucson (NOAO-N) or La Serena (NOAO-S). NGSC also takes its place as a unified program, with its various scientific, technical, management, and support activities more rationally allocated to the sites where these costs are incurred. In the case of KPNO and CTIO, this programmatic re-structuring will better reflect the transformation and evolution of senior NSF facilities anticipated in the coming years. With more than $16M (42%) of the proposed FY09 budget allocated to specific decadal survey initiatives—LST, GSMT, NVO, TSIP, and AODP—the new organizational structure also reinforces NOAO’s role as the community’s enabler of forefront initiatives and the central coordinator of the “system” approach to U.S. facilities and research:

Estimated FY05–FY09 Funding Allocations by Division and Program (Tables 1 – 5)

Funding allocations within divisions/programs in the tables below are based on the WBS and work packages currently in place (FY05) and those projected for FY06. Estimates of NOAO operational base funding for FY05–FY09 were determined as follows:

- FY05 – Already submitted and approved by NSF following NOAO budget allocation process and NSF funding cycle.
- FY06 – Based on information provided by NSF; currently moving through the NOAO budget allocation process and within the NSF FY06 funding cycle.
- FY07 – Based on original AURA-proposed yearly funding for the current Cooperative Agreement; also includes TSIP and AODP programs.
- FY08 – Based on the FY05 proposed budget and structure, extrapolated to 2008. The current Cooperative Agreement with NSF expires 9/30/07; it will be necessary to develop new estimates at that time.
FY09 – Based on the FY06 proposed budget extrapolated to 2009. The FY09 table incorporates the proposed changes in NOAO divisional structure (NOAO North/South) discussed here.

**Descriptions of Work Packages in Tables 1–5**

- **Science Operations/System.** Costs of coordinating/administration of the telescope time allocation process (TAC) and related meetings, such as the NOAO Users’ Committee, the annual meeting of the NOAO survey teams, and the System Committee. Under KPNO, includes observing run preparation, advice on performance for use in proposals, a modest amount of service observing, and the KPNO Observing Support Office activities. Under CTIO, this work package covers administrative, scheduling, and scientist support for observers; the subsidies to graduate students doing thesis research, and certain mountain costs.

- **Instrument Upgrades.** Costs of projects such as detector or controller upgrades or commissioning of new capabilities. Instrument upgrades are management responsibilities of the CTIO and KPNO directors.

- **Computer Infrastructure Support (CIS).** Computer system support to each division, network maintenance, and software support. CIS is a management responsibility of the NOAO deputy director and CTIO director.

- **Telescopes A-B-C.** Operations, upgrades, and software support by division and telescope. In budget tables for FY05–FY08, “Telescope A” refers to the Mayall under KPNO, the Blanco at CTIO, and Gemini user support in the NGSC division. “Telescope B” is the WIYN at KPNO, the SOAR at Cerro Pachón, and Gemini South operations support. “Telescope C” refers to the smaller telescopes at KPNO and CTIO. (The CTIO packages also contain projected operational costs as per the annual AOSS agreement between tenants.) The decline of budgeted funds in CTIO “Telescope C” reflects its reduced operational role in the Small and Moderate Aperture Research Telescope System (SMARTS) consortium to operate the four small telescopes located on Cerro Tololo.

- In the FY09 budget table (Table 5), KPNO and CTIO costs have been consolidated in a single program line called “KPNO-CTIO” (KPCT), which reflects the new divisional structure of NOAO N and NOAO S. Also beginning in FY09 (Table 5), NGSC ceases to be represented as a separate NOAO division, but as a unified program under both NOAO-N and NOAO-S, reflecting more precisely the location of operations, activities, and costs associated with the program.

- **Mountain Facilities.** Building maintenance, kitchen and accommodations, and roads, grounds, and utilities at CTIO and KPNO. At CTIO, some of the costs are allocated through the AOSS structure and annual agreement of the tenants.

- **Staff Research.** Costs of scientific staff research, administration of scientific staff, travel, and publications. The staff research program is the management responsibility of the
associate director for science. The “Staff Research” entry under NGSC refers to benefits and incidental expenses for the NGSC Fellows and Post Doctoral programs.

- **Director’s Office.** Administrative support, Tucson library, risk management and safety coordination.

- **Headquarters.** Central facilities operation costs of non-mountaintop building maintenance, roads and grounds, utilities, vehicles, and the computer network. The Tucson infrastructure program is the responsibility of the Associate Director for Administration and Facilities.

- **Central Administrative Services (CAS).** Human resources, accounting and financial management, sponsored projects, procurement, payroll work packages, and AURA corporate and other AURA center support. Headquarters and CAS are management responsibilities of the Associate Director for Administration and Facilities in Tucson and the CTIO director in La Serena.

- **Public Affairs/Outreach.** Science education and public outreach programs, REU programs, public affairs, and graphic arts and image production.

- **LSST.** Preparation and implementation of a technically sound and well-budgeted proposal for the Large-aperture Synoptic Survey Telescope (LSST) program. NOAO is committed to a construction and operations partnership in the LSST Corporation for the duration of the design and development phase. Logistical support is also provided for the LSST Science Working Group.

- **ETS Infrastructure.** Costs of management, administration, training, travel, and contract hire expenditures, as well as AOSS charges. The operation and maintenance components and upgrades of the ETS infrastructure are also included. Under “NGSC,” this work package refers to instrument development and project oversight of instruments for Gemini in the U.S. community. ETS infrastructure is the management responsibility of the associate director for instrumentation in Tucson and the CTIO Director in La Serena.

- **Data Products.** All planning, administrative, and day-to-day management of the Data Products program for both DPP North and DPP South. Efforts required to expand the interim archive involve all data sets in the NOAO Survey Program and initial storage of raw data from both CTIO and KPNO; design and implementation of a fully engineered archive facility for NOAO; increasing management of the day-to-day archive system, media, and user support; and cross-divisional support for development of major IRAF system utilities, NGSC instrument data reduction software, data management planning for the LSST, and other initiatives.

Beginning with the FY09 budget, the Data Products Program has been subsumed under the program line NVO (National Virtual Observatory), on the assumption that the NVO will be operative by that time, and the NOAO Data Products group, with activities situated at NOAO-S as well as NOAO-N, will be closely involved in its ground-based/OIR-related activities.
- **NIO/GSMT.** Support for the AURA New Initiatives Office in the development of a Giant Segmented Mirror Telescope (GSMT); science merit functions; integrated modeling of GSMT design concepts; site testing in NOAO South; cost estimates; developing a road map for technologies for ELTs and their instruments; and exploring partnerships that will advance the design and support of a GSMT concept to ensure national community involvement. AURA is a partner in the TMT collaboration for the design and development phase.

- **Major Instrumentation.** Includes NOAO North and NOAO South completion of design and fabrication of instruments; responses to calls for proposals for instruments; continuation of support as requested to other NOAO/NSO programs, including LSST, KPNO, CIS, NSO, and GONG, as well as some outside programs such as Gemini and Steward Observatory; and support and maintenance for the infrastructure (shops, labs, and so on) used by MIP and other programs at the current level of functionality.

- **Servicing External Entities.** Under KPNO in FY05–FY08, this line refers to the costs of technical support of NSO and other tenants on Kitt Peak. This work package is not represented as a separate line item in the FY09 projected budget because these costs are incorporated in KPNO operations in the new KPNO-CTIO (KPCT) program.

- **AURA Management Fee.** For the sake of simplicity, this cost is listed under the “Tucson” division in FY05–FY08, under the “NOAO-N” division in FY09. The number listed under NGSC for this line item ($100,000) refers to the cost of AURA’s U.S. Gemini Fellowship Program and is therefore a budget item separate and distinct from the AURA management fee. Under the current Cooperative Agreement, the AURA management fee is calculated based on a G&A indirect rate of 2.49% and an additional negotiated flat fee amount of $97,000 for NOAO out of the total NOAO/NSO allocation of $150,000.

- **Telescope System Instrumentation Program (TSIP) and Adaptive Optics Development Program.** The estimated costs of these programs, which are funded under Scientific Program Orders separate from the NOAO base budget, include, in addition to the estimated available grant monies, the costs incurred by NOAO for administration of the programs, such as solicitation of proposals; coordinating meetings and travel for external peer reviewers; negotiation of contracts and sub-awards with successful proposers, and ongoing technical oversight of the awarded projects.
Table 1
FY05 Funding Allocation (act.)
By Division and Program
Total = $27,203
(Dollars in Thousands)

<table>
<thead>
<tr>
<th>Program/Division</th>
<th>KPNO</th>
<th>CTIO</th>
<th>NGSC</th>
<th>Tucson</th>
<th>Total</th>
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<td>108</td>
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<tr>
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<tr>
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<td><strong>TOTAL FY05 (act.)</strong></td>
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<td><strong>$6,291</strong></td>
<td><strong>$1,156</strong></td>
<td><strong>$15,984</strong></td>
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\(^1\)TSIP and AODP funding includes estimated NOAO administrative costs.
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<tr>
<th>Program/Division</th>
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<th>CTIO</th>
<th>NGSC</th>
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<sup>1</sup>TSIP and AODP funding estimates include NOAO administrative and oversight costs.
Table 3

Est. FY07 Funding Allocation
By Division and Program
Total = $34,568
(Dollars in Thousands)

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<th>Program/Division</th>
<th>KPNO</th>
<th>CTIO</th>
<th>NGSC</th>
<th>Tucson</th>
<th>TOTAL</th>
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</thead>
<tbody>
<tr>
<td>Science Ops/System</td>
<td>51</td>
<td>100</td>
<td></td>
<td>320</td>
<td>471</td>
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<tr>
<td>Instrument Upgrades</td>
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<td>232</td>
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<td>448</td>
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<tr>
<td>Computer Infra. Support</td>
<td>100</td>
<td>400</td>
<td>500</td>
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<td></td>
</tr>
<tr>
<td>Telescope A</td>
<td>961</td>
<td>1,013</td>
<td>720</td>
<td>2,694</td>
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</tr>
<tr>
<td>Telescope B</td>
<td>852</td>
<td>900</td>
<td>720</td>
<td>2,472</td>
<td></td>
</tr>
<tr>
<td>Telescope C</td>
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<td></td>
<td></td>
<td>320</td>
<td></td>
</tr>
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<td>2,002</td>
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<td>1,800</td>
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<td>1,400</td>
<td>2,125</td>
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<td>Svce External Entities</td>
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<td>80</td>
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<tr>
<td>AURA Support/Mgmt Fee</td>
<td>125</td>
<td></td>
<td>752</td>
<td>877</td>
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Subtotal NOAO: 3,636, 7,469, 1,625, 14,192, 26,922

Funding for TSIP\(^1\): 4,371, 4,371

Finding for AODP\(^1\): 3,275, 3,275

TOTAL FY07: $3,636, $7,469, $1,625, $21,838, $34,568

\(^1\) Est. TSIP and AODP funding from FY04 projected allocations; includes NOAO administrative costs
Table 4
Est. FY08 Funding Allocation
Total = $36,928
(Dollars in Thousands)

<table>
<thead>
<tr>
<th>Program/Division</th>
<th>KPNO</th>
<th>CTIO</th>
<th>NGSC</th>
<th>Tucson</th>
<th>Total</th>
</tr>
</thead>
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<tr>
<td>Science Ops/System</td>
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<td>119</td>
<td>322</td>
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<tr>
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<td>660</td>
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<td></td>
<td>466</td>
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<td>229</td>
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</tr>
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<td>Mountain Facilities</td>
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<td>1,069</td>
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<td>2,592</td>
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<td>578</td>
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<tr>
<td>Data Products</td>
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<td>1,685</td>
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<td>Servicing NSO</td>
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<tr>
<td>AURA Mgmt Fee</td>
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<td></td>
<td>677</td>
<td>677</td>
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</tr>
<tr>
<td>Subtotal NOAO</td>
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<td>7,648</td>
<td>1,297</td>
<td>15,834</td>
<td>29,126</td>
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<tr>
<td>Funding for TSIP</td>
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<td>Funding for AODP</td>
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<td>3,300</td>
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<td>Total FY08</td>
<td>$4,347</td>
<td>$7,648</td>
<td>$1,297</td>
<td>$23,636</td>
<td>$36,928</td>
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</table>

1 Est. funding for TSIP and AODP programs includes NOAO administrative and oversight costs
Table 5
FY09 Est. Funding Allocation
Total = $37,835
(Dollars in Thousands)

<table>
<thead>
<tr>
<th>Program/Division</th>
<th>NOAO-N</th>
<th>NOAO-S</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science Ops./System</td>
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<td>73</td>
<td>541</td>
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<td>Instrument Upgrades</td>
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<td>400</td>
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</tr>
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<td>1,223</td>
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<td><strong>Subtotal NOAO</strong></td>
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</tbody>
</table>

| Funding for TSIP²         | 4,660  |        | 4,660  |
| Funding for AODP²         | 3,326  |        | 3,326  |
| **Total FY09**            | $26,585| $11,250| $37,835|

¹ The eventual sites for the GSMT and LSST are unknown at this writing (May 2005); thus, our assignment of FY09 costs to either NOAO-N (LST) or NOAO-S (GSMT) is purely arbitrary.

² Est. NSF funding for the AODP and TSIP grants programs include NOAO administrative and oversight costs.