NATIONAL OPTICAL ASTRONOMY OBSERVATORIES

LONG RANGE PLAN

FY 1999 - FY 2003

May 7, 1998
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I. EXECUTIVE SUMMARY

NOAO MISSION STATEMENT

The mission of NOAO is to provide leadership in the establishment and operation of premier ground-based astronomical research facilities, to promote public understanding and support of science, and to advance all aspects of US ground-based astronomical research.

In order to accomplish this mission, NOAO shall provide peer-reviewed access to state of the art observing facilities; develop and promote new astronomical initiatives in cooperation with other institutions, both domestic and foreign; maintain an active scientific staff that is engaged in both carrying out vigorous research programs and providing essential program leadership; develop and construct leading edge astronomical telescopes, instrumentation, and software; encourage public information and science education through an active outreach program; serve when appropriate as a coordinating agency for the dissemination of new technologies, data bases, and information about other astronomy related issues; and act as an advocate for US ground-based astronomy.

New Technology Telescopes
- WIYN
- SOAR
- Gemini
And Beyond

This five year plan for NOAO spans the time interval 1999-2003 and defines the program that will fulfill the obligations outlined in the mission statement. The next five years are a critical phase in the evolution of NOAO. The nighttime program will complete the transition from an earlier generation of telescopes and instruments to an almost completely new suite of facilities, and we will begin planning for the next generation of ground-based facilities. During this same time interval, the solar program will be redefined, and what is at stake is nothing less than the scope and future of ground-based solar physics in this country.

It has been nearly forty years since a large-aperture solar telescope was built by NSO. In that same period of time, the nighttime program has built two generations of facilities: the Mayall and Blanco telescopes, followed by new technology telescopes in the form of WIYN, SOAR, and Gemini. The GONG project is an excellent example of how new techniques can yield fundamental advances in our understanding of solar structure. Application of modern technologies to the construction of a large-aperture solar telescope for studies of the solar disk and atmosphere can be expected to lead to equally profound advances in our understanding of the nature, variability, and origin of solar activity.

Advanced Solar Telescope

During the next five years, the central effort in the solar program will be to define the scientific requirements for a large-aperture telescope, establish the technical feasibility of building a telescope that will meet those requirements, identify the best possible site, and prepare and submit a proposal for such a telescope to the NSF.

The remainder of the NSO program is well defined and includes: the continuation of GONG for at least one 11-year solar cycle; the upgrade of the spatial resolution of the GONG cameras by a factor of 4; the construction of SOLIS, which is a suite of instruments designed to support Synoptic Optical Long-term Investigations of the Sun; operation of the PSPT (Precision Solar Photometric Telescopes) to study irradiance variations; demonstration and use of a low-order adaptive optics system at the NSO/SP Vacuum Tower Telescope; and the continuation of the infrared program at the McMath-Pierce Telescope with upgraded cameras based on the 1K x 1K InSb arrays.

More specifically, during the next five years we will complete a Phase A/B study for an Advanced Solar Telescope (AST). This study, for which we will submit a separate
Automated Delivery of Solar Activity Data

The proposal to the NSF, will include: (1) completion of the site survey and selection of a site, probably a lake site because of the superior daytime seeing; (2) completion of an 80 Zernike adaptive optics system, which has the complexity required for near-infrared observations with the AST; (3) experiments in the control of telescope seeing in an open air solar telescope; and (4) completion of a Phase B design study to establish a high degree of confidence with respect to technical feasibility and estimated construction cost of the AST.

The construction of SOLIS is now in progress, with three years required to complete the project. The three instruments that will be built are: (1) a vector spectromagnetograph for high-sensitivity full-disk measurements of the Sun's magnetic field; (2) a full-disk imager for high-fidelity spectral images of solar disk activity; and (3) a solar spectrometer for accurate measurements of spectral line profiles of the Sun as a star. Reduced results will be made available immediately over the Internet.

The proposed upgrade of GONG will make it possible to use the network for time-distance helioseismology and to probe the changes in resonant oscillation properties as a function of solar activity levels. Funding is required to replace the existing cameras, which have 256x256 arrays, with cameras equipped with 1024 x 1024 arrays.

The major instrumental initiative is replacement of the existing 256x256 IR array camera at the McMath-Pierce Telescope with Aladdin arrays. Work will continue on improving the image quality of the solar telescopes and on replacing the control systems.

The second of the two Gemini telescopes is currently scheduled to begin scientific operations in 2002. This milestone will mark the completion of an effort to replace essentially the entire complement of telescopes offered by NOAO to the nighttime community with the exception of the Blanco and Mayall 4-m telescopes, which will remain in operation.

Preparing for the Next Groundbased Initiative

Long range planning for NOAO—and for nighttime astronomy in general—must therefore deal with very different sets of issues depending on the time scale involved. We must begin planning now for the project that will follow after the 8- to 10-m telescopes, although construction is not likely to start for another 10 years. What is the scientific case for building a major facility of 30- to 50-m equivalent aperture that would significantly extend the angular resolution or sensitivity offered by the facilities now under construction? In order to begin to address this question, AURA will work with ACCORD, its council of directors of major US observatories, to establish a study committee to evaluate the major scientific opportunities in groundbased astronomy and to define the scientific case and the corresponding technical requirements for a facility that would represent a major advance in capabilities. That effort will be initiated in the summer of 1998. The realization of any such facility will require the combined efforts of NOAO and the independent observatories and will have to be preceded by the continued development of key technologies, including adaptive optics. After we achieve a reasonable degree of community consensus on the long term goal, NOAO expects to play a leadership role in coordinating community activities and making sure the necessary technology development and design studies are completed. NOAO will also continue to work on the development of interferometric techniques through our participation in CHARA, which is building an interferometer on Mt. Wilson.
Instrumenting Gemini Class Telescopes

On an intermediate time scale, the question is how does the US community marshal the resources to remain the world's leader in groundbased optical and infrared astronomy. We will be strongly challenged by ESO, whose total investment in the VLT and associated facilities exceeds the investment of the US and independent O/IR observatories combined. The issues for NOAO are the following. (1) What can we do to develop the resources needed to ensure that the Gemini telescopes are well instrumented? Resources include not only funds (a major instrument fully funded typically costs about $4M) but also the engineering and management capability for building large and complex instruments. (2) How can we best coordinate activities through ACCORD to make sure the independent telescopes are also well equipped and that the aggregate efforts of the community in the development of instrumental technologies allow us to advance across a broad front? (3) What should NOAO do about working with the community to identify (a few) scientific initiatives and concentrating sufficient resources on those initiatives to enable major advances? NOAO has already begun experimenting with providing selected survey data to the community that will be useful to Gemini observers, but what are the other opportunities?

Gemini Science Operations

In the next five years, which is the period covered by this plan, the NOAO nighttime program is focused on providing support for the Gemini telescopes and on operating facilities with capabilities that either are not offered by the Gemini telescopes or are complementary to Gemini. Such capabilities include imaging to very deep limiting magnitudes to identify and characterize objects for Gemini observations and multi-object spectroscopy with fibers, both over very wide fields. We also plan to provide software to remove the instrumental signature from observations made with the Gemini telescopes; develop the procedures for reviewing US Gemini observing proposals; assist users with optimizing their observing strategies; complete the instruments contracted to us by Gemini; and explore innovative scheduling and observing modes to support new types of scientific programs.

Telescope Construction

More specifically, in terms of new telescopes, concept design work has begun on the 4-m SOAR telescope, a partnership involving Brazil, the University of North Carolina, and Michigan State University, with groundbreaking scheduled for 17 April 1998. A proposal has been submitted to the NSF to build a 2.4-m wide-field O/IR imaging telescope on Kitt Peak with the Universities of Minnesota and Colorado as partners, and we are actively seeking partners for a southern hemisphere counterpart. The 2.4-m telescopes are designed to support the wide-field imaging to faint limiting magnitudes that is essential for supporting Gemini observations.

During the next five years, we also expect to complete several major instruments, including 8K x 8K mosaic CCD imagers for both CTIO and KPNO; a multi-fiber spectrograph for the Blanco telescope, which will match the capability of the Hydra spectrograph already at WIYN; medium resolution IR spectrometers for both CTIO and KPNO, with the CTIO instrument being a clone of the Gemini IRS and the KPNO spectrograph being a simpler device with more limited capability; wide-field IR imagers for both sites; a single high resolution (R = 100,000) spectrometer to be shared by both sites and with Gemini; and possibly a very high throughput single object optical spectrometer. A high resolution IR imager will be shared between CTIO and Gemini South during commissioning. We expect to provide a tip/tilt system at WIYN.
At the end of this time period, NOAO will be the only organization that offers observing time in both hemispheres, on telescopes with a range of apertures, and with a broad complement of infrared and optical instrumentation. In order to take advantage of this uniqueness, we must learn how to use this suite of telescopes in an optimum fashion. How do we match complex observing programs to telescopes in order to maximize the scientific output? How do we inform the community most effectively about options for their programs? How do we best support programs that require the use of more than one facility? What kinds of supporting infrastructure are required in order to use the time on Gemini and the large telescopes at the independent observatories most effectively? This plan outlines some steps that we propose to take to develop answers to these questions and to provide user support that is unified across all of the facilities accessed through NOAO.

The changes in the nighttime offerings of NOAO, including access to Gemini and some of the independent observatories through the NSF instrumentation program, represent a qualitative change in what we offer the community. There will be fewer (by about a factor of 2) individual nights available, but the throughput of photons per unit time will in some cases be literally orders of magnitude higher than it was two decades earlier. It is almost certainly true that we will support fewer users than we have in the past, but this higher throughput will enable new types of science, including much larger sample sizes for programs ranging from the study of stellar activity levels in nearby open clusters to the analysis of the dynamics of distant clusters of galaxies. The use of new observing modes, such as queue scheduling, can potentially increase efficiencies still further and can enable studies—which have until now been impossible—of variable objects and targets of opportunity. During the period covered by this long range plan, we will re-examine the ways in which we schedule the telescopes and experiment with a variety of modes of observing (queue, remote, and service, in addition to conventional observing with the astronomer present) so that we can understand what strategies will best support the diverse science proposed by the large community served by NOAO.
II. NIGHTTIME ASTRONOMY: THE FACILITIES

A. Overview

This long range plan covers the time period when both Gemini telescopes will begin science operations, access to the independent observatories will be offered to the community, and the construction of SOAR will be completed. We also hope to initiate the construction of two moderate aperture telescopes for wide-field imaging, especially in the near-infrared part of the spectrum. This section gives an overview of the program changes and issues associated with the replacement of nearly all of the facilities offered through NOAO to the nighttime user community. Subsequent sections of the long range plan provide information about the detailed implementation plans.

1. The Telescopes

The following table compares the nighttime facilities available in each hemisphere at the time that NOAO was established and those that we expect to be operational in 2003, at the end of the five-year period of time covered by this long range plan. The number in parentheses indicates the fraction of time that will be available to the NOAO community.

<table>
<thead>
<tr>
<th>Table II-1</th>
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</thead>
<tbody>
<tr>
<td><strong>Capabilities – North</strong></td>
</tr>
<tr>
<td>1984</td>
</tr>
<tr>
<td>4-m Mayall</td>
</tr>
<tr>
<td>2.1-m</td>
</tr>
<tr>
<td>1.3-m</td>
</tr>
<tr>
<td>Coude Feed</td>
</tr>
<tr>
<td>0.9-m</td>
</tr>
<tr>
<td>0.9-m</td>
</tr>
<tr>
<td>Burrell-Schmidt (1/4)</td>
</tr>
<tr>
<td><strong>No. of Nights:</strong> 2281</td>
</tr>
<tr>
<td><strong>No. of nights × (D)^2:</strong> 9056</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Capabilities – South</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1984</td>
</tr>
<tr>
<td>4-m Blanco</td>
</tr>
<tr>
<td>1.5-m</td>
</tr>
<tr>
<td>1.0-m (Yale)</td>
</tr>
<tr>
<td>0.9-m</td>
</tr>
<tr>
<td>Curtis-Schmidt (Mich.)</td>
</tr>
<tr>
<td><strong>No. of Nights:</strong> 1460 (est.)</td>
</tr>
<tr>
<td><strong>No. of nights × (D)^2:</strong> 7264</td>
</tr>
</tbody>
</table>

D = Diameter

Table II-1 highlights the major issue confronting nighttime astronomy: the number of telescopes being operated is decreasing but the aperture is increasing. More specifically, the number of nights available to be assigned to the user community will decrease by about a factor of two in the north and somewhat less in the south. However, the number of photons collected will increase by a factor of about 2.5. If we allow
for the increase in throughput of the instruments (multi-object fiber spectroscopy, mosaics of CCDs, large format infrared detectors), the throughput of the telescopes will be literally orders of magnitude higher in 2003 than it was two decades earlier. This change in capability should not be taken to imply that we can support more programs and more astronomers with fewer telescopes. Just as more powerful computers enable researchers to undertake more complex calculations, so too astronomers are taking advantage of improved telescope throughput to increase sample sizes, spectral resolution, angular sky coverage, etc. Nevertheless, this qualitative change in the types of observations that are possible does require a re-examination of how we should schedule this powerful suite of telescopes in order to use them most effectively. What innovative approaches to operation will be required?

2. Observatories or Observatory?

NOAO is the only observatory in the world that offers open, competitive access to a balanced suite of telescopes with a range of apertures and instrumentation in both hemispheres. If the limited number of facilities we operate are to make a disproportionate contribution to advances in astronomy, we must take maximum advantage of what we alone can offer. That means we must emphasize a systems approach to scheduling scientific programs. Observers must have the opportunity to optimize their observing strategies by being able to submit proposals for entire programs that make use of a variety of telescopes in a variety of locations with optimum observing run lengths on each.

What this means conceptually is that there should be “one-stop shopping” for observing time. There should be a single interface to the user community—one source for information about observing capabilities, one form for observing proposals, and one deadline for proposal submission. Observers should not have to be concerned (at least until, or if, they have to buy plane tickets) where the telescopes are located or who operates them. In other words, we should become the National Optical Astronomy Observatory—not several different National Optical Astronomy Observatories offering independent and uncoordinated observing facilities.

This concept is more easily stated than realized. And realizing it will affect every aspect of the way we interact with the user community. The diversity of our offerings will be so large that we will need to reinvent the way we provide information to the community. Now people can request manuals for particular instruments on particular telescopes because they already have a good understanding of the best place for a particular type of observation. In the future, we may have to construct a “smart system” for helping observers to decide where observations should be done; observers should be able to enter a Web page with information about what they want to observe (resolution, limiting magnitude, S/N, etc.) and obtain a list of options for where they might make those observations. Gemini is planning to offer simulators for complex instruments so that observers can optimize observing strategies in advance, and NOAO may well have to follow suit for its own instruments. We will have to take advantage of queue scheduling for at least those types of observations that require observing conditions significantly better than the median. In many cases, people may not require whole nights of observing but perhaps only a few hours of imaging on a 2.4-m class telescope to select objects, several nights for spectroscopy at a 4-m telescope to characterize the selected sample, and a few hours on one of the Gemini telescopes for detailed spectroscopy of the faintest and/or most interesting members of the class.

If we view the role of the national observatory as delivering data rather than nights, as is implicit in some of the alternative approaches to scheduling, then additional questions arise. What level of investment should we make in archiving? With larger format detectors and higher throughput, it is more likely than 20 years ago that the utility of a dataset will not be completely exhausted by the observer for whom it was obtained. The value of the HST archive is already apparent. Gemini does have plans for putting data
into an archive; what investment should NOAO make to ensure that the archive is accessible? And what data from our own telescopes should be archived?

And what about providing datasets and surveys? For example, Gemini can do IR spectroscopy at least five magnitudes fainter than the limiting magnitude of the 2MASS survey. Similarly, optical spectroscopy will be possible to faintness limits well beyond the deepest large area sky surveys currently planned. Should NOAO undertake very deep surveys over limited parts of the sky and make the data available to the entire community?

It is likely that the efficient use of Gemini will require not only deep surveys but also other preparatory observations. Should observing time for these preparatory measurements be granted automatically to successful proposers for Gemini time? How much time will be required for this purpose and what will be the impact of such a policy on other types of science that may not depend on the Gemini telescopes?

B. The Transition Plan

The astute reader will notice that most of the telescopes listed as available in 2003 are not yet in operation. And several others now in operation will not be supported by NOAO after the turn of the century. How do we plan to get from here to there? In the following sections, we discuss first the plans for telescopes operated directly by NOAO, then the support for US participation in the Gemini project, and finally the implementation of access to the independent observatories.

1. SOAR

The primary nighttime initiative within NOAO is the SOAR project, which has as partners CNPq (Brazil), Michigan State University, the University of North Carolina, and NOAO. Observing time will be allocated in proportion to the financial contributions of the partners. The goal is to have these contributions to construction, commissioning, instrumentation, and operations be such that NOAO and Brazil will each receive 30 percent of the observing time, UNC and MSU will receive 15 percent each, and the remaining 10 percent will be allocated to Chilean astronomers in accord with the agreement under which AURA operates in Chile. Letters of intent for sufficient funds to complete the SOAR project have been signed by the persons in each participating organization who are authorized to commit funds.

The project manager is Tom Sebring, formerly project manager for the Hobby Eberly Telescope (HET); the project scientist is Gerald Cecil from UNC, who is now resident in Tucson. The project is now in the concept design phase, which will lead to specifications for the telescope subsystems and better cost estimates. An external review committee will be convened in early June to evaluate this phase of the project. An interim board, consisting of one member from each partner institution, has been established, with Sidney Wolff as chair. The telescope will be sited near Gemini South, and groundbreaking has been scheduled for 17 April.

The current status of the project is described in a paper presented at the SPIE meeting in Kona in March 1998; this paper is included in Appendix B.

2. WIYN

WIYN has now completed nearly three years of successful science operations. The median delivered image quality throughout that time has been maintained at 0.8 arcseconds. However, there are a number of issues that must be addressed in order to obtain maximum productivity from this telescope.
The WIYN agreements as originally drafted covered the construction and minimum operations only. Omitted were plans for re-instrumenting the telescope, upgrading its performance over time, and scientific support. In a series of retreats, the WIYN partners have determined that the level of performance that they want this telescope to achieve—and that we have demonstrated is possible—is incompatible with the current level of the operations budget. We are now trying to identify additional funding. A long range instrument plan is being developed, and a proposal to implement a tip/tilt system for imaging has been submitted to the NSF. There is a clear need for focused leadership (a "director"), and the universities need to provide greater scientific support for evaluating telescope and instrument performance, for building instruments, and for preparing funding proposals.

As an immediate step, the WIYN partners pledged $400,000 over a two-year period to make improvements to the telescope. During the first two years of science operations, a number of concerns were identified that relate to the safety of the equipment during operation (hardware and software safety interlocks, etc.) and to the efficiency of observing (for example, automation of the procedure for obtaining wavefronts). We are now in the second year of implementing this program.

A final issue for WIYN is to continue to assess the effectiveness of the queue observing program currently being operated by NOAO. The WIYN queue program requires between 2 and 3 staff in addition to what would be required if we were supporting observers who come to the telescope to make their own observations. The queue program has enabled certain types of science not possible with conventional scheduling models, most notably the measurement of supernova light curves in distant galaxies. The experience to date is summarized in a paper to be presented at the SPIE meeting in Kona (Appendix A), and based on this information, the joint KPNO/CTIO users committee has voted that we continue the experiment for at least one more year. The experience that we are deriving from WIYN will be crucial in planning how to implement queue observing at the Gemini telescopes. In our survey of users and our experience to date we find that: 1) users are happy with the quality of data received; 2) the queue increases the overall efficiency of the telescope, especially for observations requiring rare conditions; 3) we are succeeding in completing a larger percentage of highly rated programs than with conventional scheduling; 4) a larger percentage of programs obtain no data at all compared with conventional observing, and this is one of the primary sources of dissatisfaction with the queue; 5) we have enabled some new types of science, most notably the study of variable objects and targets of opportunity; and 6) many observers would still prefer to come to the observatory to make their own observations even if the data delivered are entirely satisfactory.

3. Access to the Independent Observatories

The NSF has funded instruments for the Hobby-Eberly Telescope and for the upgraded (6.5-m) MMT. In return, approximately 7% of the time on each will be available to the community for six years. The proposals for this observing time will be received and reviewed by NOAO. We have signed an MOU with the Hobby Eberly Telescope describing how this time will be made available. The NOAO will handle the entire interface to the user community, will submit queue observing forms to the HET for successful proposers, and will then distribute the data received to the users. In this way, NOAO becomes in effect a single user of the HET and does not increase the operations costs for this university facility. There will be increased costs at NOAO for this program. Negotiations are still in progress for the MMT. It is likely that time will not be available on the HET and MMT until fall 1999 at the earliest.

It now appears unlikely that the other large telescope consortia will be willing to make time available to the community through this NSF program. The problems that the McCray committee hoped would be solved by this initiative therefore remain and have implications for long range planning. First, most of the time that is available competently to the community will continue to be provided by NOAO's own
facilities, including NOAO’s share of joint projects such as WIYN and SOAR, not through the independent observatories. Therefore, NOAO must continue to operate a significant number of facilities with a broad range of capabilities. Second, the cost of instrumentation for the new generation of very large telescopes is much higher than for 4-m class telescopes, and we must find new arguments for a significant increase in NSF instrumentation funding for both NOAO and the independent observatories.

4. Gemini

Gemini North is scheduled to achieve first light at the end of 1998 and Gemini South in 2000, with operational handover occurring about two years after first light. That means that both telescopes should be producing scientific data before the completion of this five-year plan. NOAO is responsible for providing US user support for those activities that do not occur at the telescopes themselves (help with proposal preparation, evaluation of proposals, assistance with planning observations, data reduction, and access to the Gemini archive). The staffing and support required for these activities have been summarized in earlier long range plans and in the proposals to renew the cooperative agreement, and we are beginning to transfer resources from other parts of NOAO, mainly KPNO, to support these activities.

NOAO is also responsible for managing the entire Gemini infrared instrumentation program, including those instruments being built outside NOAO, and is itself committed to providing the Gemini infrared spectrometer, the controllers for the IR arrays, the characterization of the IR arrays, and integration of the hardware/software/detectors for the CCD systems. The risks to NOAO in building instrumentation for Gemini are substantial. There is the financial cost: the international agreement clearly states that the funding for instruments is not intended to be high enough to cover the full costs (direct plus indirect) of the instruments. There is the financial risk: we are to agree to fixed price contracts, with the costs of overruns to be borne by us. And there is the impact on other NOAO programs as we direct our most experienced personnel to work on Gemini instruments.

An important issue in the instrument program is to develop an effective model for the hand-off from the construction team to the operational teams at the sites where the telescopes are located. I am not aware of any observatory that has successfully solved the problem of ensuring a graceful transition from construction to maintenance. Traditionally, KPNO and CTIO instruments were built locally, with the construction teams only an hour and a half away from the operating telescopes. Therefore, responsibility for maintenance was never fully transferred. In the new model, where instruments are built in Tucson to be shipped to Chile and Hawaii (or in the case of the Arcons, built in Chile for use at Kitt Peak), we must learn to manage this transfer effectively.

5. 2.4-m Telescopes

The two telescopes on the list of operational facilities in 2003 for which we have not identified funding are the 2.4-m class imaging telescopes. It remains NOAO’s point of view that wide-field imaging, especially in the near-IR, will be essential to select and characterize objects for detailed study with the Gemini and other large telescopes. A recent workshop on supporting capabilities for large telescopes underscored the need for deep IR and optical surveys (Appendix D). We have also found that there are at least half a dozen universities interested in sharing construction and operations costs for telescopes of this aperture. Therefore, we are attempting to establish partnerships that would fund half the cost of each of the 2.4-m telescopes we plan to build, and will seek funding from the NSF for the other half in order to provide open, competitive access to deep imaging capability to the community. The first proposal has already been submitted (Appendix C), with the site being Kitt Peak because of the universities’ requirement for low cost access for students. We are now trying to firm up a partnership for a southern hemisphere telescope.
6. Telescope Closures

According to the plan outlined above, several operating telescopes are slated for closure. CTIO has already transferred the Yale 1-m back to Yale, which has recently reached agreement with Portugal and Ohio State for joint operation; ten percent of the time will still be available to the US community. KPNO has already closed the 1.3-m telescope and will issue an Announcement of Opportunity seeking another operating university or consortium. KPNO withdrew support for the Burrell-Schmidt effective 1 October 1997. Case Western has arranged to continue operation by bringing in several new partners, and NOAO will leave all of its equipment at the Schmidt on long-term loan so that the telescope remains operational. KPNO is exploring the feasibility of closing the Coude Feed. Because the high resolution mode ($R = 200,000$) is a unique capability, we would like to move the spectrograph optics to the 4-m Mayall and feed them with a fiber, thereby increasing the limiting magnitude. However, this project cannot be carried out until other higher priority tasks, including the image improvements program at the 4-m Mayall, can be completed.

In all of these closures, the goal is to preserve scientific capability while reducing the operational support to levels sustainable by the current staff. For example, the Mosaic CCD Imager at the 0.9-m offers better capability for wide-field photometry because of better sampling of the point spread function than does the Schmidt. While the competition for observing time may become more intense, the intention is not to eliminate any classes of science.

Additional closures of telescopes would be linked (in the optimistic case) to the initiation of operations at the new facilities listed above or (in the pessimistic case) to further decreases in budget. It should be noted that the staffing level at KPNO is already below the minimum that we estimate is required for sustained operation of three telescopes, and we are currently operating five and providing some support to NSO. We are no longer planning or carrying out any upgrades or improvements to either the 0.9-m or Coude Feed telescopes, and so operation of these telescopes cannot be maintained for very many more years.

7. Management Structure

In order to operate this complex suite of facilities as an observing system (effectively as a single observatory with “one-stop shopping” for the user community), we have recently implemented a change in management structure. This change will result in unifying all activities relating to support of users before and after their observing runs at all observatories accessed through NOAO (Gemini, KPNO, CTIO, and the independent observatories), and the common interface to the community will be managed by an office within the USGP, which is referred to as ScOpe (Science Operations). This office is headed by Todd Boroson, who continues to serve as US Gemini Project Scientist. The logic behind this change is that the USGP must perform this support function for the US observers at the Gemini telescopes. There will likely be efficiencies within NOAO if these services are provided for all telescopes by a single office, with minimum duplication of functions within the different units (USGP, KPNO, and CTIO). There will certainly be simplifications for the users.

To support this suite of activities, a number of KPNO scientific staff have been assigned to the USGP (Pilachowski, Jannuzi, De Young, and Lauer). This office will immediately begin to handle the receipt and evaluation of KPNO proposals, with the actual scheduling of the selected proposals to be handled by KPNO. It will also handle proposals for the independent observatories and the Gemini telescopes when they become available. A Web-based proposal form has been designed that is the same for all of the telescopes accessed through NOAO, including those at CTIO. Other aspects of ScOpe activities will be
extended to the southern hemisphere only when the users and CTIO staff agree that science would be well served by doing so.

As part of this re-organization, Richard Green has been named Director of KPNO, and he also continues to serve as head of the instrumentation program, which is responsible for building instruments for KPNO, CTIO, and Gemini. Again, this combination of programs unifies activities along functional lines. All of the engineering and technical staff based in Tucson (and outside of NSO) report to Green, who can easily handle trades among programs and also work toward common hardware and software standards across all of NOAO.

While scientific staff will be assigned to KPNO, CTIO, the instrumentation program, or the Science Operations Division as their primary home, responsibilities will still be shared across divisions. Staff will also be reassigned from one division to another from time to time. Jay Elias (CTIO), for example, is currently resident in Tucson as project scientist for the Gemini IRS, while Ron Probst (KPNO) has been temporarily transferred to CTIO to help support the IR program. This flexibility in staff assignments is consistent with a more unified observatory. Careful coordination of functional responsibilities will, however, be required in order to ensure that staff has time for research.

A further advantage of the recent re-organization of NOAO is that it reduces the number of directors by one. As we slim down all parts of NOAO and realign our priorities to be consistent with the facilities that we plan to offer in 2002, it is only appropriate that the management structure should be streamlined and modified to emphasize our changed priorities.
III. NIGHTTIME ASTRONOMY: SCIENTIFIC DIRECTIONS

The priority for groundbased IR and optical astronomy for the next decade will be to exploit fully the capabilities of the facilities that are now on line or will be completed in the next few years. The Gemini telescopes have been designed to take advantage of modern technologies to achieve unprecedented image quality combined with low emissivity in the infrared. These new telescopes will almost surely increase the demand for observing time on 2.5-m to 4-m class telescopes; observers will use these telescopes to conduct surveys to select objects suitable for detailed study with the Gemini telescopes; to obtain calibration data on nearby bright objects that can be used to interpret limiting observations made with the Gemini telescopes; and to test new observing protocols, techniques, and instruments for subsequent use by the Gemini project. In addition, there are some types of key observations, such as wide-field imaging in the optical with CCD mosaic arrays and multi-fiber spectroscopy over a wide field, that will not be possible with the initial Gemini implementation. Therefore, a key priority for the nighttime program is to increase access to 2.5-m to 4-m class telescopes and to equip those telescopes with state-of-the-art instrumentation, with emphasis on wide-field and deep imaging.

It is not at all clear how groundbased optical/IR astronomy will evolve after this generation of 8-m and 10-m telescopes is completed. NOAO is actively exploring this issue with a number of groups, including the AURA Coordinating Council of Observatory Research Directors (ACCORD). One obvious extension is the inclusion of adaptive optics at varying levels of sophistication on both the 4-m and 8-m to 10-m class facilities. Following this development, it is widely thought that an interferometric array is the most likely candidate for a major new facility, but many technical issues remain to be resolved before such a facility could be designed. This is the decade of prototype interferometers, and NOAO will contribute technical and scientific assistance to one of these arrays in order to gain experience with interferometry, understand the technology, and begin developing community interest in the technique. Only after the prototype arrays begin delivering scientific results will it be possible to set the design parameters for a major array.

In summary, then, the emphasis in the nighttime program is on exploiting fully the facilities we have, including the Gemini telescopes, by ensuring that they are properly instrumented and effectively operated, and on exploring some potential new technologies that may provide the basis for the facilities of the next century. In addition, if overall economies can be realized by replacing older facilities with more efficient state-of-the-art 2.5-m to 4-m class telescopes, then such possibilities should also be fully explored.

A. The Scientific Program

Approximately 13,900 scientific papers have been published between 1961 and 1997 by visitors who made use of NOAO facilities and by NOAO staff. In this plan, we summarize key observational results in a few particularly active areas of research, and in addition we briefly describe how these areas will benefit from use of the current and planned NOAO facilities during the next five years.

1. The Large-Scale Structure of the Universe

At the heart of cosmology is the "cosmological principle," which posits that the universe is homogeneous and isotropic on large scales. Thus if one examines a large enough volume of the universe, its average properties and the structures formed by the galaxies within, that volume should be no different from those in any other large volume of the universe. The size of the volume that is required to include a fair sample of the universe is, however, unknown. In recent years, observations made with telescopes operated by NOAO and by other institutions have shown that the universe is organized on scales so large that
all current theories, in order to explain how galaxies formed and clustered to develop the structures that we see, must either be fundamentally flawed or be in need of significant revision.

The first glimpses of large-scale structure were seen over a decade ago when in 1981 R. Kirshner (Center for Astrophysics) and his collaborators used the KPNO telescopes to identify what appeared to be a gigantic void in the direction of the constellation Boötes. In 1986, this same group used the KPNO facilities to confirm the existence of this void, which occupies a volume of over one million cubic megaparsecs and is roughly spherical in shape, with a diameter of about 120 Mpc. Also in 1986, V. de Lapparent, M. Geller, and J. Huchra (all Center for Astrophysics) published results from the extended Center for Astrophysics redshift survey, which showed galaxies residing on the surfaces of contiguous bubble-like structures whose diameters are typically 25 Mpc with a maximum of 50 Mpc. A similar picture of the distribution of galaxies in space emerged from a 21-cm survey of 2,700 galaxies published in 1986 by M. Haynes (Cornell U.) and R. Giovanelli (Arecibo Obs.). Data on even larger structures has emerged from the work of D. Koo (Lick Obs.) and his collaborators. Using pencil beam surveys of the north and south Galactic poles, these investigators have sampled the distribution of galaxies over an unprecedented scale of 2000 Mpc, which is far deeper than any previous surveys. They find evidence for large-scale features in the galaxy distribution out to the limits of the survey. Work is continuing on this project using many different telescopes, and the existence of walls and voids on scales of 100 Mpc has recently been reported by Bellanger and de Lapparant (Institut d’Astrophysique) using the ESO telescopes. In short, so far observers continue to find galaxies organized into larger and larger structures as they survey larger portions of the universe.

Equally exciting has been the discovery of streaming motions of galaxies on an extremely large scale. These motions result from the clumpiness of matter in the universe and provide separate evidence that matter in the universe is organized on extremely large scales. In the late 1970s, M. Aaronson (U. of Arizona), J. Huchra, and then-KPNO staff member J. Mould pioneered the infrared Tully-Fisher technique for determining distances to spiral galaxies. In 1986, Aaronson and collaborators employed this method on a sample of ten northern hemisphere clusters, observed mostly at KPNO and Arecibo, and obtained a positive detection of the motion of the local group toward the 3K dipole anisotropy. In the same study, Aaronson, et al. concluded that the rms peculiar velocities of clusters must be smaller than 500 km/sec. This picture of a relatively quiescent local Universe was very short-lived, however, and in 1987 a group of seven investigators (A. Dressier, D. Lynden-Bell, S. Faber, D. Burstein, R. Davies, R. Terlevich, and G. Wegner) announced the discovery of streaming motions of galaxies. Their analysis of spectroscopic and photometric data of 400 elliptical galaxies, obtained with telescopes at KPNO, CTIO, and other sites, revealed a net streaming motion of galaxies over a region about 100 Mpc in size, with a velocity at the Sun of roughly 570 km/s over and above the uniform Hubble flow. The source of this bulk motion was attributed by Dressler and collaborators to the existence of a “Great Attractor,” located in the direction of the constellations of Hydra and Centaurus, at a distance of 20-30 Mpc and with a mass of about $5 \times 10^{16}$ solar masses.

Observations of galaxies from the southern hemisphere are thus of crucial importance in assessing the all-sky nature of peculiar velocities. Unfortunately, the largest radio telescope in the southern hemisphere, the Parkes 64-m, has only 1/12 the collection area of Arecibo, and so does not generally provide high quality data for galaxies with velocities greater than 5000 km/s. Using an imaging Fabry-Perot interferometer on the CTIO 4-m telescope, however, R. Schommer (CTIO), T. Williams (Rutgers U.), G. Bothun (U. of Oregon), and J. Mould (Mt. Stromlo Obs.) developed an optical Tully-Fisher method, which has been used to determine distances to galaxies with velocities as great as 10,000 km/s. This group has published an analysis of peculiar velocities for a sample of 48 late-type spiral galaxies that are located in the vicinity of the Great Attractor. These data confirm the existence of positive velocity residuals, with amplitudes of 500-2000 km/s, in the Hydra-Centaurus region, but a symmetric infall.
pattern centered on the Great Attractor is not seen. These results suggested that the identification of the source of the observed streaming motions was as yet not well determined and that the possibility of large peculiar motions on scales of 100 Mpc remains.

This possibility may well be confirmed by some recent results on large scale structure obtained by T. Lauer (KPNO) and M. Postman (STScI). Using facilities at both CTIO and KPNO, these observers have determined that the brightest galaxies in clusters of galaxies can be used as reliable standard candles because the luminosity measured within a fixed metric radius of 10 kpc is nearly constant, with a dispersion of 0.24 magnitude. This leads to an error of only 17% when these objects are used as distance indicators. With this technique they have derived redshifts for 119 clusters of galaxies and have determined the velocity of the Local Group with respect to all Abell clusters within 15,000 km/s redshift. The objective was to determine whether the motion of the Local Group relative to this very distant set of clusters is the same as the motion of the Local Group relative to the microwave background. If so, then the largest scale anisotropic streaming would be confined to scales smaller than that sampled by the clusters. Lauer and Postman do not find this convergence. A straightforward interpretation of their results is that the entire volume enclosed by the cluster sample is itself streaming at a velocity of about 700 km/s relative to the microwave background. If this result is confirmed, it implies streaming and inhomogeneities on a scale much larger than previously observed.

All of these large-scale features in the galaxy population pose severe challenges to current cosmological models. The difficulties lie in the inability of the models to produce such large structures by purely gravitational means. The hot dark matter models use the hot particles to suppress excessive small-scale fluctuations, but in conventional cosmologies with $\Omega = 1$, they do not reproduce the galaxy-galaxy correlation function, and they have difficulty producing the giant mass fluctuations required to explain the large-scale streaming motions. Cold dark matter models cannot produce the large structures, and they yield too much small-scale structure unless ad hoc assumptions such as biased galaxy formation are introduced. If the most recent results of Lauer and Postman are confirmed, then virtually all current cosmological models, including hybrid models and those with ad hoc fixes, are in serious jeopardy. Non-gravitational theories using shock waves to initiate galaxy formation may successfully account for the observed structure, but they require as yet unobserved explosive events of enormous energy, about $10^{65}$ ergs per event, which is equivalent to the energy radiated by 10,000 galaxies over the age of the Universe.

An essential element in any study of large scale structure and cosmology is the issue of the distance scale. The determination of this fundamental yardstick has had a colorful and controversial history, and the elements of controversy remain to this day. Arising from work carried out with NOAO telescopes is a growing hope that agreement may finally be near on the value of the Hubble constant. Two recent techniques for distance determination that have shown significant promise are the use of planetary nebula luminosity functions (PNLF) and surface brightness fluctuations (SBF). Both of these techniques claim accuracy in distance determinations of about 10% out to distances of 20 Mpc. Development of both methods has relied on the use of NOAO facilities, and recently a collaborative effort among the proponents of these methods sought to test the similarity of their results. G. Jacoby (KPNO), R. Ciardullo (Penn State U.), and J. Tonry (Massachusetts Inst. of Tech.) compared direct observational results for a sample of 15 galaxies. This test shows that the two methods yield scales which are offset only by 0.07 mag, and this offset can be attributed entirely to uncertainties associated with measurements of extinction toward the calibration galaxies M31 and M32. The very strong consistency between the two methods, one using radiative heating and cooling of gaseous nebulae and the other depending on our understanding of the evolution of stars on the giant and asymptotic giant branches, provides a high level of confidence in the distances derived. These methods provide a relatively large value of about 80 km s$^{-1}$ Mpc$^{-1}$ for the
Hubble constant. This value poses yet another challenge for conventional closed universe cosmologies when the ages of the oldest stars are compared with the predicted age of the Universe. Support for value of the Hubble constant only about 10 percent lower than this has now been provided by observations of Cepheids with the repaired Hubble Space Telescope. Work by the CTIO group, by Perlmutter and his colleagues, and by Kirshner and his collaborators on the use of light curves from type Ia supernovae can, when coupled with Cepheid data, provide values for both $H_0$ and $q_0$. Early results from this technique are yielding values for $H_0$ of around 65-70 km/s/Mpc, with indications that we do not live in a critical density universe. Intensive work continues in this area, and the queue-scheduling, good image quality, and large aperture of the WIYN make it particularly well-suited for obtaining light curves of supernovae in distant galaxies.

Future programs investigating the large scale structure of the Universe will push out to higher redshifts. Early results by Steidel and others using Keck indicate that large scale structure (bubbles and voids) is already present by redshift 3, thereby creating severe problems for models that assume critical density. A thorough investigation of the evolution of large scale structure with cosmic epoch requires the execution of wide-field surveys that can identify, and determine the distribution of, galaxies and QSOs at various times. Such deep wide-field surveys are ideal for the 4-m and WIYN telescopes at NOAO. Further into the future, the large collecting area of 8-m telescopes and the upgraded MMT, when coupled with the speed of fiber-fed multi-object spectrometers, will result in an improvement of more than two orders of magnitude over current NOAO facilities. This capability will allow the analysis of faint quasars and clusters of galaxies at redshifts between 1 and 3, which is an essential period in the study of the evolution of large-scale structure. In addition, the reddest galaxies at redshifts greater than 3 have no spectral features in the optical region and must be studied exclusively in the infrared. It is these most distant and possibly evolved galaxies that will provide constraints on basic cosmological parameters and on the age of the Universe through use of the Gemini telescopes.

2. **The Formation and Evolution of Galaxies**

The question of how galaxies form and evolve is one of the fundamental problems in modern astronomy. The current view is that galaxy formation is a complex, dynamic process in which small objects first become gravitationally unstable in the early universe, cluster, and then eventually merge to form a larger galaxy-mass object. The subsequent evolution of this galaxy-mass object is governed by the aging of its stellar populations, variations in its star formation rate, and its merger history. These processes determine the morphological, dynamical, and spectral properties of the final product: the present day galaxies. Although the theoretical investigation of this problem, which began with Sir James Jeans in 1928, has now reached a level of considerable sophistication where predictions can be made of galactic properties (mass, luminosity, spectra) as a function of time, it is only recently that the observational data necessary to confront the theoretical studies have become available.

a. **Galaxies in Clusters**

One of the first indications that the effects of galaxy evolution are directly observable was revealed nearly 18 years ago in a study by H. Butcher (Kapteyn Obs.) and G. Oemler (Yale U.). Using KPNO telescopes in an observing program spanning several years, Butcher and Oemler discovered that although nearby rich clusters like Coma tend to be populated with old, quiescent elliptical galaxies, more distant clusters (observed at earlier epochs) contain an increasing fraction of blue galaxies, which are undergoing significant amounts of star formation. The clusters surveyed extended out to a redshift of approximately 0.4, which corresponds to looking back nearly one-third of the age of the Universe (we adopt $H_0 = 50$ km/s/Mpc, $\Omega = 0.2$). This result, which was confirmed spectroscopically by Dressler (Carnegie),
Gunn (Princeton), and their collaborators, indicates a rapid evolution of galaxies in rich cluster environments. High resolution optical imaging of the redshift 0.3-0.4 clusters with HST shows that the blue star-forming galaxies tend to be disk systems, with the majority showing distorted morphologies and signs of interactions, suggesting that galaxy interactions may drive the star formation and the morphological evolution of galaxies in clusters.

Less is known about the evolution of the reddest galaxies in clusters; although there is evidence that some of them (the so-called E+A galaxies) may have undergone recent episodes of star formation, there is also some evidence that the red elliptical galaxy population evolves fairly passively from redshifts greater than 2 (when our Universe was less than one-quarter of its present age) to the present. For example, the study by S.A. Stanford (IGPP/LLNL) and his collaborators using the NOAO telescopes found evidence for only mild evolution in the red elliptical galaxy population in clusters between redshifts around 0.4 and the present. The questions of the age and evolution history of the reddest galaxy population (the ‘red envelope’) is of great importance, since these objects represent the oldest stellar conglomerates; age-dating them can provide the epoch when the bulk of their stars were formed and, for the objects in the most distant clusters, can place a lower limit on the age of the Universe.

Clues to a method for finding distant clusters of galaxies may be found in the systematic study of the environments of quasars out to redshifts of ~ 0.7 by H. Yee (U. of Toronto), R.F. Green (KPNO) and E. Ellingson (U. of Colorado). Using telescopes at NOAO and Steward Observatory and the Canada-France-Hawaii Telescope, these investigators established that both radio-loud and radio-quiet quasars tend to be situated in regions of higher-than-average galaxy density, and in particular, that higher redshift radio-loud quasars are found in much richer environments than their lower redshift counterparts. Similar evidence was also found by J.A. Tyson (Bell Labs.), who used the CTIO and KPNO telescopes to observe quasars at two different epochs (redshift ranges 0.1-0.5 and 1.0-1.5). Tyson found that the more distant quasars had ten times more galaxies around them than did the nearby sample. Similarly, T. Heckman (Johns Hopkins U.) and his collaborators have used NOAO telescopes to determine that galaxies associated with radio sources often reside in regions of higher galaxy density than do similar galaxies that are radio-quiet. These results have the important implication that quasar and radio galaxy evolution may be a strong function of environment, and also that distant clusters can be found from searches around distant quasars and radio galaxies. Using KPNO telescopes, M. Dickinson (STScI) has identified a few rich clusters at redshifts around 1 (looking back more than half the age of our Universe) by using high redshift radio galaxies as signposts of rich environments. In one redshift 1.2 cluster, Dickinson has discovered a population of red, elliptical galaxies, which have colors similar to present-day ellipticals, suggesting that the old population in clusters may be very old, indeed. Dickinson, A. Dey (KPNO), and H. Spinrad (UC, Berkeley) are now following up the KPNO imaging study by obtaining optical spectroscopy of the cluster members using the Keck Telescope. A search for normal galaxies in the vicinity of very distant quasars (at redshifts around 3; when the Universe was less than a fifth of its present age) has been carried out by C.C. Steidel (Caltech), D. Hamilton (Heidelberg), and their collaborators using the NOAO 4-m telescopes. Their imaging survey identified several faint candidate star-forming galaxies on the basis of their colors. Steidel and his collaborators have spectroscopically confirmed the redshifts and the star-burst nature of these galaxies using the Keck Telescope.

What about the primeval galaxies: systems undergoing their first epoch of star formation? Over the last decade, several searches have been carried out for these elusive objects with null result. The best candidates may still be the highest redshift radio galaxies discussed above, but even the most distant ones known (observed when the Universe was less than 10 percent of its present age) show signs of metal enrichment over a large volume. Extremely low-metallicity, dynamically young, star-forming galaxies are yet to be discovered. Since the forming galaxies may be faint, novel methods that make use of gravitational amplification by foreground clusters or of the absorption imprints they leave on the light of back-
ground quasars may be the only recourse. Gravitational lens arcs were first discovered at KPNO by R. Lynds (KPNO) and V. Petrosian (Stanford) and are now thought to be images of distant galaxies produced by the foreground cluster which acts as a gravitational lens. Several such lens systems are being studied by various groups in an attempt to both determine the mass distribution in clusters and deconvolve the lensed images to catch a glimpse of the distant, young galaxies.

b. Field Galaxies

The modern study of field galaxy evolution was pioneered by J.A. Tyson (Lucent Technologies) and P. Seitzer (U. of Michigan), who conducted deep CCD surveys of the sky using the CTIO and KPNO 4-m telescopes. They found a vast population of faint, blue galaxies whose number counts appeared to be in excess of that predicted by simple "no-evolution" models, implying that this population of galaxies evolves very rapidly. Recent detailed studies (high resolution imaging with HST and groundbased spectroscopy) strongly suggest that the faint blue galaxies are fairly low mass dwarf galaxies that happen to be undergoing a burst of star formation at low redshifts (between 0.5 and 1.0). At present it is unclear why the dwarf galaxies appear to undergo delayed formation or starburst activity, or how this is a function of environment. In contrast, studies of the red field galaxies appear to show little evolution out to redshifts of around 1. This has been demonstrated by D. Hamilton using the NOAO telescopes, and most recently in the deep Canada-France-Hawaii Redshift Survey conducted by a team led by S. Lilly (U. of Toronto). These results are also supported by the HST Medium-Deep Survey, which finds that the bulk of the bulge-dominated field galaxy population is in place by about half the age of the Universe and then evolves only passively to the present time, in contrast to the disk galaxies which appear to show signs of interactions and mergers. Spectroscopy of the MDS survey galaxies for the purpose of redshift determination is now proceeding at NOAO facilities. More evidence that galaxies of higher mass undergo more slow evolution is found in a study by Steidel and Dickinson, who used the KPNO and Michigan-Dartmouth-MIT telescopes to study the population of galaxies responsible for causing MgII absorption lines in QSO spectra. They found that this unbiased sample of luminous field galaxies exhibits little evidence for evolution in their photometric properties or space densities out to redshifts of around 1.

The culmination of the road paved by the groundbased CCD surveys is the Hubble Deep Field, the deepest image of the sky ever obtained. KPNO telescopes are already being used in follow-up studies: a team led by Dickinson (STScI) obtained deep infrared images of the field (currently impossible with HST) and made them available for general study. Investigations of the faintest galaxies in the HDF will be crucial to our understanding of the earliest epochs of galaxy formation. The existing data, however, already demonstrate that the relationship between morphological type, galaxy mass, and evolutionary history in both field and cluster populations appears to be complex and at present is not well understood. At least at the low and intermediate mass end of the galaxy mass function, several unanswered questions remain.

Future programs in galaxy formation and evolution will fully utilize all of the planned observing capabilities at NOAO through the end of the current millennium. The combination of deep optical and infrared imaging surveys on 2.5-m and 4-m class telescopes with sub-arcsecond resolution using the imaging arrays under development at NOAO, together with follow-up optical and infrared spectroscopic studies available with the Gemini telescopes, will provide a combined observing capability of immense power. This world-class facility will permit the deepest and most thorough look yet at the epoch of galaxy formation and early evolution. Photometry and spectroscopy of distant galaxies in the infrared is critical, since most of the well understood optical features are shifted into this wavelength regime at high redshifts. The importance of wide-field imaging surveys, especially in the infrared, cannot be overemphasized. The use of 4-m class telescopes for such surveys will be a necessary condition for the efficient and productive use of the Gemini telescopes. In addition, targeted narrow band imaging surveys with 4-m telescopes can be used to search for high redshift protogalaxies and protoclusters in the redshifted Lyman
The spectroscopic power of the 8-m telescopes will not only address galaxy evolution at early epochs, it will also allow study of the dynamics of galaxy clusters at redshifts greater than one, thus gaining access to the epoch of cluster formation, and it will in addition permit a first view of the internal kinematics of individual galaxies at high redshifts.

3. The Structure of Nearby Galaxies

The investigation of galaxy formation and evolution would be incomplete without a complete understanding of the physical processes that govern the large scale properties of nearby galaxies. The stellar populations, global and local star formation rates and efficiencies, gas content, and kinematic properties of the nearby ellipticals and spirals are being studied by various teams. Nearby massive star-forming regions like 30 Dor have been explored at both optical and UV wavelengths using groundbased telescopes, IUE, and HST. In addition, galactic scale winds driven by large scale starbursts have been discovered in several edge-on spirals by Heckman and his collaborators using NOAO telescopes. The importance of recent mergers in the late evolution of ellipticals has been studied by D. Silva (KPNO) and G. Bothun (U of Oregon), who find that recent bursts of star formation in ellipticals account for less than ten percent of the light, suggesting that the nearby ellipticals are predominantly old systems. Other investigators are searching for low surface brightness galaxies, which may be quiescent or failed massive disk galaxies. These investigations (and others) of nearby galaxies will outline the parameter space occupied by the end products of galaxy evolution, and in addition they will allow us to study in detail the physical processes that play a role in galaxy evolution.

A low redshift population of galaxies that may be undergoing dramatic evolution and is often touted as protogalaxies are the ultraluminous galaxies detected by the Infrared Astronomical Satellite (IRAS). These objects emit 10 to 100 times the luminosity of a normal spiral galaxy, with the emission mostly in the far infrared region, and are found to have very disturbed morphologies indicative of mergers between two massive systems. The presence of copious amounts of dust and molecular gas has now been established through millimeter and submillimeter wave studies, but the origin of their prodigious luminosity is still not understood. It is thought that these galaxies may be undergoing violent global star formation or harboring a proto-quasar, but more observations will be required to define these objects properly. Other candidates for galaxies in the earliest stages of formation are the extremely hydrogen-rich and star-poor objects found nearby, such as the hydrogen cloud discovered by Giovanelli and Haynes. This elongated cloud seems to offer support for the idea that disks of galaxies can form slowly throughout the history of the Universe.

Thus, recent observations suggest that galaxy formation was far from coeval, that galaxies may have been forming throughout the age of the Universe, and that many, but not all, have undergone dramatic evolutionary changes in that time. In many cases, those galaxies that show strong evidence for evolution are found to exist in special circumstances: in clusters of galaxies, near quasi-stellar objects, or associated with strong radio sources. It is by no means clear which of these processes is relevant or dominant, and much further work needs to be done. Future NOAO facilities can play a prominent role in these investigations. For example, the 8-m Gemini telescopes using spectroscopy in combination with adaptive optics will permit examination of the metallicities and kinematics of nearby galaxies out to an R magnitude of about 24. Such fundamental investigations of the internal structure and star formation history of nearby galaxies could in principle consume all available Gemini observing time over a period of five years.
4. Star Formation

Many aspects of the process of star formation remain poorly understood. The formation and evolution of the parent clouds, their fragmentation and collapse, the role of angular momentum and magnetic fields, the establishment of the initial mass function, and the evolution of protostars and very young stars are all areas of active investigation. NOAO facilities have been used to observe regions of star formation in our own and in nearby galaxies, and the advent of two-dimensional detector arrays that operate in the infrared is stimulating even more observing programs relevant to this topic. Moreover, these arrays are particularly well-suited for use in multi-wavelength, multi-observatory programs that address key questions in the area of star formation. In particular, they will complement observations by HST, SIRTF, SOFIA, and millimeter and sub-millimeter telescopes and arrays.

It has become well established that the collapse of a protostellar cloud to form a new star is accompanied by an outflow of mass from the central region, and several programs have used NOAO facilities to investigate the nature of these outflows and their implications for the star formation process. The outflow is usually anisotropic, often bipolar, and sometimes very highly collimated. The origin of this outflow and the mechanism for its collimation have been examined by several groups. In some cases, the outflow is seen to be collimated to within 100 AU of the surface of the young stellar object, but it is still unclear whether the wind is intrinsically bipolar or is collimated by material around the star. Evidence that circumstellar disks are found around virtually all young stellar objects has been obtained by S. Strom (U. of Massachusetts) and his collaborators, arguing for an external collimation mechanism. Moreover, these observers also find the inner portion of the disks to be cleared away over a period of about 10 million years, leaving a small remnant of material that may eventually aggregate into planets. Understanding this very common outflow phenomenon would provide valuable information about the role of angular momentum in the star formation process, about the efficiency of stellar collapse and the role of circumstellar material, and about the conditions at the surface of the young star itself.

The Herbig-Haro objects (emission line nebulae thought to originate from the interaction of matter ejected from a young star with the interstellar medium) also hold clues to the star formation process. Recent work by J. Bally (U. of Colorado) and his collaborators now make it clear that these objects are associated with very highly collimated and narrow outflows from a young stellar object. In many cases several HH objects are associated with one outflowing stream, and Bally and his co-workers have found spectacular symmetric outflows extending in opposite directions from young stellar objects. In some cases these supersonic double jets extend more than a parsec and contain many HH objects. The relation of these outflows to the more massive, slower, and less collimated molecular outflows in which they are often imbedded is not yet clear, nor is the mechanism known that produces the high degree of collimation. Once the relationships among these outflow phenomena are understood, we will have a much clearer picture of the early evolution of protostars and of star formation itself.

Studies of angular momentum in evolving protostars shed further light on the role of disks in star formation. For example, J. Stauffer (Smithsonian Astrophysical Obs.) has obtained rotational velocities for stars in the Pleiades cluster. He finds that nearly half of the stars observed have rotational velocities that are much higher than expected. This indicates that at least some stars retain a major portion of the angular momentum of the protostellar cloud during collapse. Further insight into this phenomenon has come from a study by S. Edwards (U. of Massachusetts) using optical and IR data obtained at KPNO. A sample of 34 T Tauri stars with and without accretion disks was examined for rotational periods; those stars with accretion disks were found to have lower rotational velocities than those without. These results suggest that the disk is a sink of angular momentum, presumably through a magnetic field link between the disk and the star. Once the disk is lost, stars can spin up as they contract due simply to the conservation of
angular momentum. The most rapidly rotating stars on the main sequence may be those that, for whatever reason, lost their disks during the early stages of their collapse.

Productive areas for future investigation include the local phenomena of protostars, mass outflow, circumstellar shells, and accretion disks, along with such global aspects as the initial mass function and the variation of star formation with changes in metallicity, turbulence, and magnetic fields. A major impetus for new and continuing programs in star formation has come from the availability of two-dimensional infrared array detectors. Already these arrays have detected circumstellar disks of molecular gas around protostellar objects, and they have also revealed rich groups of very young stars whose existence was heretofore only assumed. P. Hartigan and his collaborators at the Center for Astrophysics have used a two-dimensional array to determine that molecular cooling is a principal energy loss mechanism in the deceleration of outflows from Herbig-Haro objects. In another study using the four color infrared imager (SQUID), E. Lada (U. of Florida) and C. Lada (Center for Astrophysics) have studied the star formation history of the young cluster IC 348. These new results show that star formation in this object did not take place in a single burst (as seems to be the case in the Orion clusters) but instead extended over a period of 5 to 7 million years. About 20% of the cluster members show an infrared excess indicative of a protoplanetary disk. The differences shown in star formation history for this cluster when compared with Orion are indicative of the many factors that influence the complex phenomenon of star formation. These programs are the beginning of what is seen as an era of major advances in the understanding of star formation, not only in our own Galaxy but eventually in other galaxies such as the Magellanic Clouds and members of the Local Group. In the Galaxy itself, the problem of low mass star formation and the definition of the initial mass function (IMF) for low-mass stars can now be addressed. Studies of the upper end of the IMF, where many of the more massive stars have been heretofore obscured by the dust associated with their birthing process, have also become possible. It will be feasible to identify and study stars below the critical mass for nuclear ignition and to examine accretion disks around protostars and young stellar objects. The arrays will also make possible the search for particle disks around main sequence stars, these being the presumed progenitors of planetary systems.

Complementary to large scale surveys are detailed studies of individual star-forming regions. KPNO Astronomer Phil Massey has studied the formation of massive stars in many nearby galaxies, and his intensive examination of these objects has provided new insights into the upper end of the mass function and its dependence on both local and global factors. For example, Massey and his co-workers, in studying the Magellanic Clouds from CTIO, have found that the most massive field stars are as massive as those found in large OB complexes, but that the slope of the IMF for field stars is much steeper than that for the OB complexes. More recently Massey and his collaborators have found circumstellar disks around intermediate mass stars in M16. The observations of these short-lived disks, as well as observations of the young stars themselves, will permit definitive tests of current ideas on mass loss and angular momentum transfer in the earliest stages of stellar evolution.

Future facilities at NOAO will ensure active and forefront programs in this area through the end of the century. In addition to the infrared imaging of specific regions described above, the deep, wide-field optical and infrared surveys used for extragalactic programs will also yield valuable new data about the populations of brown dwarfs and protostars as well as sampling the stellar mass function at the elusive but critical faint low mass end. Four-meter class telescopes with sub-arcsecond seeing can now be used to examine specific protostellar objects to determine in detail the disk kinematics. The advent of the Gemini telescopes will permit these kinematic studies to proceed to fainter objects and to probe much closer to the young star itself. Use of the infrared regime will allow studies of protoplanetary disks and provide new high resolution data about the cores of molecular clouds where the youngest protostars are formed.
5. Stellar Populations

The study of stellar populations not only provides information about stellar evolution, it also sheds light on such diverse topics as star formation, the chemical and dynamical evolution of the Galaxy, the calibration of the distance scale, and the age of the Universe. One area of stellar populations that has been especially fertile in recent years is the chronology of the formation of the Galactic halo, as evidenced by globular clusters and field stars. A number of studies have presented findings that are not accounted for by the traditional model for the formation of the Galactic halo via a rapid, monolithic collapse.

One major development in the area of stellar populations is the methodology for dating globular clusters and the resulting age range in the cluster system, and inter alia the Galactic halo. Independently, groups at DAO and Yale proposed overlaying the main sequence and subgiant regions of the color-magnitude diagrams of globular clusters of similar metallicity and deriving the age difference rather than the absolute age. Age differences can be derived with minimal reliance on theoretical isochrones. Such studies revealed a significant age range among globular clusters of intermediate metallicity (~ 3 Gyr). This favored the Searle-Zinn accretion picture for the formation of the Galactic halo over the rapid collapse model. The majority of the color-magnitude diagrams on which this work relies were constructed using CCD images from the CTIO 4-m telescope. In particular, the cluster pair with the most convincing age difference, NGC 288 and NGC 362, was studied differentially at CTIO by M. Bolte (UC, Santa Cruz), and independently by B. Green (Steward Obs.) and J. Norris (Mt. Stromlo Obs.). Another cluster that figures prominently as a young halo cluster, Pal 12, was observed with the CTIO 4-m by P. Stetson (DAO) and collaborators.

Another observation that has had a strong influence on scenarios for the formation of the Galactic halo is the discovery of the Sagittarius dwarf galaxy. Found serendipitously during a survey for Galactic bulge stars, Sagittarius is located only 16 kpc from the Galactic center and shows distortions that are likely indicative of its being disrupted by the tidal forces of the Galaxy. Sagittarius may thus be a system where the accretion of a dwarf galaxy by the halo is in progress. The field population of Sagittarius and M54, the globular cluster that lies at its center, have been studied by Sarajedini (KPNO) and Layden (then at CTIO) using the CTIO 0.9-m. These authors investigated the metallicity distribution in Sagittarius and found both metal-rich and metal-poor components. The metallicity-luminosity relation for dwarf galaxies then suggests a much larger integrated magnitude for Sagittarius than is measured, suggesting that its interaction(s) with the Milky Way have stripped away a significant fraction of its original stars. M54 and Sgr have the same distance modulus and radial velocity within the uncertainties, and thus M54 may represent the nucleus of Sagittarius.

Another approach to understanding the formation of the halo is mapping the space velocity and metallicity of stars in selected areas. Majewski (U. of Virginia), Munn (U. of Chicago), and Hawley (Michigan State U.) are carrying out such a program in SA57 at the north Galactic pole. The first step in their study is a deep absolute proper motion survey using multi-epoch KPNO 4-m plates. They use these data to isolate a relatively pure sample of halo stars by selecting only objects more than 5.5 kpc above the Galactic plane. Spectra are then obtained with Hydra, yielding radial velocities and metal abundances. This survey has revealed large scale streaming motions in the Galactic halo. Thus the halo is not dynamically mixed, but contains a significant fraction of stars with membership in correlated stellar streams. This suggests that the accretion of satellite systems likely played a significant role in the formation of the Galactic halo.

The above examples illustrate the broad range of stellar populations programs being carried out with NOAO facilities. For many of these problems, spectroscopy of more stars, intrinsically fainter stars, and more distant stars is needed. Scientific programs in the area of spectroscopy of stars in clusters and stars found in selected area surveys benefit especially from multi-object capability, which allows observations
of many individual stars simultaneously. Both CTIO and KPNO have multi-object fiber-fed spectrographs in operation, and the NOAO instrumentation program for the next five years plans to enhance this capability. In addition, many programs require precise photometry for samples of stars over a significant number of square degrees. The deployment of the NOAO 8K x 8K CCD Mosaic Imager will be an asset to such scientific endeavors, especially when used in conjunction with the planned wide-field optical and infrared surveys.

6. The Chemical Evolution of the Galaxy from High-Resolution Spectroscopy

Spectroscopy of stars in our Galaxy is providing additional constraints on the formation of the Galaxy, and by implication, on the formation of all spiral galaxies. K. Gilroy and C. Sneden (U. of Texas), C. Pilachowski (KPNO), and J. Cowan (U. of Oklahoma) used the KPNO 4-m echelle spectrograph to investigate the abundances of very-heavy \((Z > 30)\) elements in metal-poor halo stars. Such elements may be formed via slow neutron captures \((the \ s\text{-}process)\) on Fe-peak seeds during the late quiescent stages of the evolution of low to intermediate mass stars or by rapid neutron captures \((the \ r\text{-}process)\) during the supernova explosions of high mass stars. Their results suggest that for stars more metal-poor than about \(1/100\)th of the solar composition, evidence only for \(r\text{-}process\) nucleosynthesis could be found in the abundances of these elements. The \(s\text{-}process\) contributions to the observed abundances seemed to appear only at higher metallicities. This allows an estimate to be made for the timescale of the formation of the very metal-poor galactic halo: about 10 million years.

The Gilroy, et al. study raised the possibility of large star to star scatter in the abundances of very heavy elements. Such a scatter, if confirmed, could set important limits on the mixing timescales of the early galactic halo. At what overall metallicity does one see evidence for “local” nucleosynthesis events in the then-young Galaxy? To answer that, T. Armandroff, C. Pilachowski (KPNO), D. Burris and J. Cowan (U. of Oklahoma), and C. Sneden (U. of Texas) currently are analyzing the very heavy element abundances of a sample of metal-poor field halo stars, using spectra again acquired with the KPNO 4-m echelle spectrograph. The focus will be on the balance of \(r\) and \(s\text{-}process\) contributions to the very heavy element abundances and on star to star element scatter, both as functions of stellar overall metallicity. Such questions can be cleanly addressed only with large sample sizes.

In another study of chemical evolution, Beers, Preston, and Shectman have produced a catalog of ultra metal-poor stars \((those \ with \ metal \ abundances \ less \ than \ 1/1000\)th of the Sun’s). Out of a high resolution study of some of these stars came the discovery of a star with a huge overabundance \((10-40 \ times \ more \ abundant \ than \ the \ ordinary \ metals \ in \ this \ star)\) of very-heavy elements. C. Sneden and B. Armosky (U. of Texas), A. McWilliam and G. Preston (Carnegie Obs.), and J. Cowan and D. Burris (U. of Oklahoma) performed the most detailed very heavy element abundance investigation ever attempted in a metal-poor star, using CTIO 4-m echelle spectra. Abundances for 20 elements with \(Z > 30\) were determined, including 5 elements \((Tb, Ho, Tm, Hf, \ and \ Os)\) never before detected in metal-poor stars. An excellent match to a scaled set of solar system \(r\text{-}process\) abundance fractions was found; no other nucleosynthesis model can be made to fit the observed abundances. The very-heavy elements in this star must have been made in prior supernova explosions. And the huge overabundance of all very-heavy elements argues that only one supernova was the culprit: the nucleosynthesis event was a local one. Finally, the clean detection of thorium in this star sets an approximate age for its supernova progenitor: about 15 billion years.

The Beers, et al. survey of ultra metal-poor stars has been used for only a few abundance studies to date. Even so, hints of more abundance peculiarities in individual stars have been slowly appearing in the literature. Abundances of ultra metal-poor halo stars provide the cleanest “laboratories” for testing explosive nucleosynthesis theories. Thus, detailed abundance studies of other very metal-poor stars will be
carried out in the future with 8-m class telescopes; these stars are generally found only in the more distant galactic halo regions.

Another important site for studying chemical evolution in the galaxy lies in globular clusters. Abundance variations have been known to occur in the stars residing in these clusters for more than 30 years, but only now are we reaching any understanding of the causes. It is now clear that the CNO element group as well as Na, Al, and now Mg, have large and mostly correlated variations among giant stars of many clusters. The average abundances of each of these elements also vary from cluster to cluster. All of these abundance variations are probably due to a complex set of several (often coupled) proton capture chains that operate in the hydrogen burning shells of low mass, low metallicity stars as they evolve up the first ascent red giant branch. These abundance variations in many globular cluster giants imply envelope-shell mixing that extends far beyond the expectations of ordinary “first dredge up” from the CN-cycle. The CNO reactions deplete C and O and enhance N. At the same time, Na manufactured from (unobservable) Ne and Mg is reduced as it is turned into Al.

An effective study of the C-N-O-Ne-Mg-Al abundance variations requires the acquisition of high resolution spectra of many stars in several globular clusters. A series of papers by R. Kraft (Lick Obs.), C. Sneden (U.of Texas), and E. Langer (Colorado Coll.) used Lick 3-m Hamilton echelle spectra to study samples (~10) of red-giant-branch tip stars in six clusters. But even those sample sizes do not allow coverage of stars in different evolutionary states of these clusters, so these investigators have joined with C. Pilachowski (KPNO) to acquire spectra of not ~10 but ~100 evolved stars in several clusters, employing the WIYN Hydra multi-object fiber positioner and bench spectrograph. Their study of 130 M13 giants shows that Na and Mg abundances vary by large amounts from star to star in M13, and that the variations occur in the faintest stars on the red giant branch.

For Na in M13, there is a very large star to star abundance scatter among the lower luminosity red giant branch stars. The Na abundances are nearly always large among stars of the red giant branch tip. But the Na abundances are smaller in the (presumably more evolved) asymptotic giant branch stars. These Na differences as a function of evolutionary state obviously argue for evolutionary changes in envelope compositions of elements that are affected by proton capture synthesis chains. These changes require deep mixing of substantial amounts of envelope material through the region of the hydrogen-burning interior shells of the stars that are observed (as opposed to acquisition of the abundance peculiarities at stellar birth). The giants with highest Na contents probably also have enhanced envelope He contents.

All of these observations of M13 thus imply that our understanding of the interior structure and dynamics of these stars is incomplete, and that more sophisticated theoretical modeling is required, especially concerning the role of convection. These insights into the interior nucleosynthesis in giants of M13 could only have been accomplished with the multi-fiber Hydra system. The next step is a parallel study of M3, a cluster that has a metallicity comparable to M13 but whose red giant tip stars show milder star to star abundance variations. In addition similar observations are needed of the more metal-poor cluster pair M92 and M15 in order to investigate how the stellar envelope mixing efficiency changes with cluster metallicity. This and similar studies in the area of chemical evolution would benefit in a truly significant way from the use of a multi-object high resolution spectrometer coupled to an 8-m telescope. With the current generation of telescopes, it is possible only to study the evolution of element abundances in stars no fainter than those of the cluster horizontal branches. Clearly the final story will not be written in this field until large samples of lower luminosity giants and subgiants can be subjected to the same type of spectroscopic scrutiny as we can now give the brighter cluster stars.
B. Telescopes and Upgrades

1. Plans for Observing Facilities at KPNO

Adaptive Optics at Kitt Peak

Three very different field-of-view domains with different technical requirements and different scientific applications can be addressed by existing telescopes: (1) diffraction-limited images over a few arc-seconds achieved by high-order corrections with adaptive optics; (2) sub-half arcsecond images over 3-5 arcminutes achieved by relatively low-order adaptive corrections; and (3) uncorrected images over as wide a field-of-view as the telescope-detector combination delivers. This third capability, imaging over wide fields-of-view with detectors of the highest possible quantum efficiency, has traditionally been one of the strengths of NOAO/KPNO, and the new 8K x 8K CCD Mosaic imager will keep the observatory at the cutting edge with respect to this type of observation. Through NOAO/KPNO leadership, the WIYN Consortium is developing a high speed tip-tilt imaging system (WTTM) for the 3.5-m WIYN telescope as a critical step in achieving the second capability on Kitt Peak.

The system WIYN is pursuing was chosen after a careful study of other tip-tilt and low-order adaptive optics (AO) systems and direct measurements of the time dependent imaging characteristics at WIYN. Our studies show that with WIYN's existing active optics, high quality site, and thermally-controlled enclosure, there is less advantage in low-order AO at this modern facility than at previous generation telescopes (e.g. CFHT). High speed image motion studies show that tip-tilt correction alone at WIYN has the potential of reducing median 0.8 arcsec imaging to 0.6 arcsec at R (0.67 μm) and producing nearly diffraction limited images (0.15 arcsec) at H (2.5 μm). This conclusion is in agreement with models showing that for a 3.5-m aperture telescope, atmospheric turbulence primarily induces image motion at the focal surface, which can be readily corrected by tip-tilt.

The WIYN Tip/Tilt Module (WTTM) will be a facility instrument permanently mounted on the telescope, providing both the University partners and the entire US community—through NOAO—a relatively wide 5 arcmin field with high resolution imaging. Initially, the WTTM will deliver a field of 4.7 x 4.7 arcmin at 0.14 arcsec per 15 μm pixel resolution with a 2048 x 2048 CCD for its science detector. The WTTM is being optimized for the R and I band-passes (0.5-1.0 μm), while maintaining an operating band-pass of ~ 0.4-2.2 μm. A proposal has been submitted to the NSF Major Research Instrument program for construction of a suitable IR camera (based on a Rockwell 1024 x 1024 18.5 μm HgCdTe device, giving a field of view of roughly 3 arcmin at 0.17 arcsec per pixel) and to enable our current Integrated Field Unit (DensePak) to be used for spectroscopy with WTTM. The optical design will allow a future effort to relocate the tip-tilt mirror and to allow a planar pupil mirror to be low order deformable, features which could be used to add fast focus and/or low order adaptive optics correction in the future.

There are no current plans for installation at Kitt Peak of a high order AO system, which would require laser guide stars. Recent experience has somewhat dashed expectations because of the complexity of high-order AO systems, the limited scientific results achieved to date, and the high cost of operation. The US is, however, likely to be strongly involved in delivering laser guide star adaptive optics to Gemini South. Through its role in the procurement process, NOAO will have the opportunity to assess what is available in the community and determine how to proceed with such a system at its existing telescopes and on what timescale.
2. KPNO Telescope Improvements

Telescope improvement projects have the dual goals of enhancing performance, especially image quality, to meet changing science requirements of our users and of reducing maintenance costs.

Milestones for Telescope Improvements

1999  
Initiate design and construction of 2.4-m telescope  
Design and construction of WIYN tip-tilt system  
Commissioning the Mayall 4-m active primary system (installation FY 1998)  
Wavefront analysis system for Mayall 4-m active primary system  
Complete major WIYN improvements program  
Major software revision of the TCSs for the Year 2000 Project

2000  
Construction of 2.4-m telescope  
Commissioning of WIYN tip-tilt system  
Relocation of coudé spectrograph to Mayall 4-m and installation of fiber-feed  
Install mirror surface heating system at Mayall 4-m if feasible  
Completion of other projects to improve image quality at the 4-m  
Completion of the Year 2000 Project well before New Year’s Eve 2000

2001  
Install and commission new 2.4-m telescope

2002  
Install new telescope control system at Mayall 4-m  
Install Mayall f/15 tip/tilt secondary system

2003  
Consolidate telescope operations in single control center  
Propagate new telescope control system to other telescopes

- Mayall 4-m
  The primary goal of the work planned for the Mayall 4-m telescope is to achieve nearly site-limited image quality as much of the time as possible with this 25-year-old telescope. Smaller average image size makes it possible to detect fainter objects, to observe equal brightness objects in shorter exposure times, and to achieve better angular resolution. There are three reasons to believe that consistently better image quality is attainable. First, the performance of WIYN and contemporary site testing have convincingly demonstrated that Kitt Peak is a much better astronomical site than previously thought. Second, the Blanco 4-m at CTIO, which has nearly the same design as the Mayall, now routinely averages sub-arcsecond images. And third, 0.5 arcsec images have been recorded upon occasion at the Mayall 4-m when a detector of sufficient pixel scale was used.

A major project to improve image quality at the Mayall was initiated four years ago, and will require an additional two years to complete. The goal is to achieve a median delivered image quality of 0.9 arcsec. (This should be compared with the WIYN, which has a median delivered image quality of 0.8 arcsec, with 25% of the time better than 0.7 arcsec and 10% better than 0.6 arcsec.) We know that excellent imaging is possible because 0.6-0.7 arcsec images have been obtained when the conditions at the 4-m—particularly, the thermal characteristics of the mirror and enclosure—were just right. Initial experience with the dome vents indicates that we have increased the number of nights when optimum conditions are achieved.
The next major tasks in improving the DIQ will be commissioning the Mayall 4-m active primary (FY 1999), construction of a wavefront analysis system (FY 1999), and other relatively smaller projects, e.g. improvements to the mirror cooling capacity and ventilation of the volume above the primary (FY 1999-2000). We continue to follow the development of the mirror heating system by Gemini, and, if found feasible for the 4-m mirror, a similar system will be installed in FY 2000.

- **WIYN 3.5-m**
  NOAO's goal for WIYN is to ensure that it continues to achieve high image quality and reliable operation. Our experience during the first three years of science operations (FY 1996-1998) identified areas where the safety of the telescope and of personnel working in the telescope environment could be improved and where the performance of the telescope and observing efficiency could be enhanced. The four partners of the WIYN Observatory have approved a two-year special assessment totaling $400K to address these issues; this work will be completed in FY 1999.

  The next steps in ensuring the continued competitive edge of WIYN are the completion of the tip-tilt imaging system (FY 1999-2000) and development of a strategic plan and a long-range instrumentation program.

- **2.1-m**
  No improvement projects are planned at the 2.1-m. This telescope will continue to be operated as a general purpose research instrument supporting low to moderate resolution optical spectroscopy (upgrade to the GoldCam spectrograph camera to be completed in FY 1999), optical imaging with a 1K x 1K CCD, IR imaging and spectroscopy. In particular, the 2.1-m has become the principal test-bed for IR instrumentation with the closure of the 50-inch.

- **0.9-m**
  The lifetime of the 0.9-m will determine whether any improvements are made to it. The 0.9-m will be closed in FY 1999 if funding is available for the 2.4-m telescope project; the site of the 0.9-m will be used for the new 2.4-m telescope.

  If it appears that this telescope will remain in operation for more than three additional years, a new telescope control system will be required in order to improve reliability and lower maintenance costs. The current system makes use of FORTH and very old DEC computers. It is likely that we would purchase a commercial TCS rather than attempt to build one in-house.

- **Coudé Feed**
  No improvements are planned for this telescope. We have begun a design study of moving the optics of the coudé spectrograph to the 4-m telescope to enable spectroscopy at resolution greater than 200,000 to fainter limiting magnitudes (~ two magnitudes) than are now possible. If we proceed with this project, it will be carried out in FY 2000.

**Projects Impacting Scientific Operations at All Telescopes**

- **Modern software architecture Telescope Control System for Mayall 4-m and other telescopes**
  The TCS at the Mayall 4-m is a derivative of the original KPNO FORTH-based telescope control code and has neither the modern message passing system of the WIYN TCS or the data-base TCS of Gemini. A new TCS should be based on a software design which includes many of the aspects of the Gemini control system. This design will be employed at the 4-m and other telescopes in operation on
the mountain so that we maintain compatibility of TCS throughout the mountain for ease of maintenance and upgrades. The anticipated time scale is to initiate planning and design in FY 2000, with completion in FY 2002.

- **Replacement of telescope guider electronics**
  The leaky memory guide electronics—integrators with time-weighted history to feed correction pulses to the telescope servo control—are based on commercial circuit-boards which are no longer available and cannot be readily repaired at the component level. The guider at the 4-m or 2.1-m will be replaced in FY 1999 with a commercial frame-grabber unit similar to that at WIYN. Other operating telescopes will be reviewed at that time, and their leaky memories will be replaced if the projected lifetime of the telescope warrants it.

- **Year 2000 software issues**
  The year 2000 has significant consequences for the computer systems on the mountain. So that operations do not grind to a halt on midnight of 1 January 2000 or put us back to 1900, we plan in FY 1998 to determine all of the century dependencies in our software and to complete changes in FY 1999 before the millennium arrives. The night of 31 December 1999-1 January 2000 will be designated “testing & engineering” with appropriate software personnel on site when the telescopes are first used for science after this date.

- **Investigation of consolidation of all control rooms and technical shops in one building**
  A modern multi-telescope observatory where telescopes are designed for remote operation could have a single control facility to consolidate operations and technical staff with the astronomers as they observe and reduce their observations. As the older telescopes on Kitt Peak are closed and replaced with modern facilities, such consolidation may be feasible. In conjunction with the design of the new 2.4-m, we plan to investigate this operations philosophy. We must understand what this style would entail for the Mayall 4-m and WIYN. Design study will proceed in concert with that of the 2.4-m (FY 1998 and beyond).

- **Update of data computers to multi-processor units**
  The generation of computers used currently for data acquisition was installed in 1991. While we have upgraded them with increased memory, disk space, and in some cases, faster processors, we must provide significantly increased computing capacity for the Mosaic CCD imager and other future high data-rate instruments. In addition, we must provide computers at the telescope which are at least as powerful as astronomers have on their desktops at their home institutions. Current computer technology uses multi-processors to provide increased computing power. Because device drivers would have to be re-written for the operating systems provided with the multi-processor machines, this upgrade is not a simple replacement. Investigation of the scope of this improvement will begin in FY 1999 with implementation in the years to follow.

3. **Plans for Observing Facilities at CTIO**

Observing facilities at CTIO are being developed as a complementary system of larger telescopes open to the community on a competitive basis alongside individual smaller facilities, the latter being set up and financed by US university groups and others. Gemini South and these smaller facilities contribute to, and benefit from, the overall AURA/NSF infrastructure in Chile. The following sections summarize the status of the telescopes on Cerro Tololo and Cerro Pachon.
• **Gemini South 8-m Telescope**

The primary focus in Chile is accommodating Gemini South. Although operated by the International Gemini Project and not by CTIO, Gemini South will make maximum use of the existing infrastructure. In order to gain the economies associated with sharing of infrastructure, AURA has established a new unit in Chile, which reports directly to the President of AURA, serves as the sole interface to Chilean authorities, and provides administrative, logistic, and other common services to all of the telescopes operating on AURA property in Chile, including those operated on behalf of CTIO, Gemini, SOAR, and such other organizations as may subsequently wish to make use of the site. The interim head of this AURA unit will be Malcolm Smith, who will continue to serve as Director of CTIO as well. A document describing the roles of the AURA head and the various site directors in Chile has been developed by Gemini, NOAO, and AURA and will form the basis for determining how services are to be shared and charged for. The goal is to establish an administrative structure that preserves the autonomy of the operators of the individual telescopes with respect to scientific programs and priorities but to have a single business unit that supports all of the telescopes on Cerro Tololo and Cerro Pachon.

Gemini Project team members are already involved in significant discussions with CTIO staff at all levels. The following examples of work for and with Gemini involving CTIO staff in the first years of this long range plan are given below for illustrative purposes:

- Logistics and administrative support for completion of the Gemini South Building and Dome.
- Assistance with the transfer of AURA Chilean engineering and technical staff from CTIO to work on commissioning of Gemini North in Hawaii and their return to work in Chile.
- Scientific, technical, and logistical assistance with characterization of the atmosphere over Cerro Pachon.
- Publishing SCIDAR measurements made using the 1.5-m telescope on Cerro Tololo.
- Scientific work on numerous Gemini committees at US and international level.
- Representation of AURA (including Gemini) in Chile.
- Support for safety training and inspections on Cerro Pachon.
- Support for operations of Gemini South.

• **SOAR 4-m Telescope**

A general description of the SOAR project has been provided elsewhere in this document. CTIO staff are involved in many activities in support of this project similar to those listed above for Gemini. CTIO staff serve on the scientific and operations committees of SOAR. Unlike the case of Gemini, CTIO will itself operate the SOAR telescope for the consortium. It is expected that the construction and commissioning of SOAR will be completed during the period of this long range plan.

• **The Blanco 4-m Telescope**

At the beginning of the planning period, this telescope will still be the largest operating routinely in the Southern Hemisphere. By the end of the period, at least nine significantly larger telescopes will be in operation in Chile, along with others on US soil (principally Mauna Kea). Because of this changing environment, we plan to specialize the Blanco instrumentation in order to exploit fully its wide-field imaging capabilities and permit some deep survey work in preparation for the arrival of Gemini South.
Initial emphasis at CTIO will be to complete the installation and commissioning/recommissioning of the various instruments being built in Tucson for use on the Blanco Telescope, in particular the MOSAIC 8K x 8K CCD imager, the Hydra multifiber spectrograph and the Phoenix high-resolution IR spectrometer.

- The 2.4-m IR and Optical Survey Telescopes

NOAO’s plans for 2.4-m telescopes north and south are described elsewhere in this document. The goal for CTIO is to provide access to the equivalent of one full telescope of this aperture for the community. It is our best judgment, based on discussions with the NSF, that we are unlikely to obtain full funding for one telescope through a single proposal. Therefore, our plans are to try to accomplish the construction incrementally by finding partners for halves of two telescopes. Ultimately one could be dedicated to optical imaging and the other to infrared imaging, thereby minimizing instrument changes, downtime, and operations costs. One option under active exploration is a collaboration in which the primary partners are the NSF and the UK’s PPARC; instrumentation would be provided for the optical by the MACHO collaboration (a large CCD mosaic) and for the infrared by a group in the UK (possibly an IR array mosaic developed by the University of Cambridge). The second 2.4-m for CTIO may involve contributions by US universities and Brazil. Discussions are at a very preliminary stage, but our goal is to submit a proposal to the NSF later in 1998.

- The Older, Smaller Telescopes

The smaller CTIO telescopes will be replaced by the 2.4-m survey telescopes. In the meantime, because CTIO offers unique access to the southern hemisphere for most of the US community, we are endeavoring to find creative ways to operate those telescopes no longer supported by the NSF. All telescopes smaller than 1.5-m on Cerro Tololo are operated now with only one fixed instrument. Fifteen percent of the 0.9-m is used for MACHO follow-up studies, financed through the MACHO program. This funding allowed the performance of the 0.9-m to be improved substantially.

The 1-m telescope (which was closed to general users in January 1997 and is currently being upgraded with funds from consortium members) will be operated for the first three years of the long range plan period by a consortium of Yale University (30%), Ohio State University (30%), The University of Lisbon, Portugal (30%) and NOAO (10%). This telescope will be operated in service mode, exclusively for synoptic programs—a new venture in operations strategy at CTIO. The small access retained for NOAO will provide most NOAO users with their only opportunity for this kind of work in the southern hemisphere.

- New Small Telescopes

CTIO does not itself intend to build new small telescopes. However, there is increasing pressure from the community for access to such facilities in the southern hemisphere. CTIO is therefore responding to this demand by offering to facilitate, at full cost recovery, the installation and operation of smaller facilities by high quality user consortia led by US universities and other institutions. Some examples follow:

- 2MASS

The 2Mass IR survey is now under way. It will provide a census of galaxies and stars in the J, H, and K bands, complete (at high galactic latitudes) down to K = 14.3. The 2MASS telescope on Cerro Tololo complements a northern equivalent on Mount Hopkins in Arizona. Survey observations will be completed by the second year of the plan period. Options for subsequent use of the telescope will be explored once the main survey gets underway.
GONG
This successful, six-station, world-wide robotic network of telescopes to probe the interior of the Sun is described in Section IV. GONG will continue to operate throughout the period of this long range plan. Impact on the rest of CTIO operations is likely to remain very light.

USNO Astrometric Survey
The goal of the United States Naval Observatory's CCD South Astrometric Survey is to produce a high density catalog of reference stars in the Southern Hemisphere with accuracies of about 20 milliarcseconds at epoch for the magnitude range of about 7 to 14 and extending to 16 magnitude with about 70 mas mean error. This survey is expected to be fully underway at the start of the plan period and to continue until late 1999 or early 2000. The strategy for measuring positions is to obtain a two-fold overlap of exposures, make a preliminary reduction with Tycho stars, link directly to Hipparcos stars and then to extragalactic sources. A global block adjustment will be done to develop the final catalog.

The USNO catalog will have about 2000 stars per square degree, positions better than Tycho for 9th magnitude and fainter at epoch. The catalog will bridge the magnitude gap between Hipparcos and faint photographic surveys. It will provide reference stars for faint observations and for IR surveys (such as the 2MASS survey) at the same epoch. Improved proper motions will later be derived for all stars in the catalog when combined with other epoch observations.

The USNO twin 8-inch astrograph will be housed in an existing small dome on the summit platform of Cerro Tololo.

Robotic Networks for Research and Education
As part of an overall effort to improve access to the southern hemisphere skies, CTIO is in very preliminary conversations with two groups that are proposing to set up non-profit global networks of small, optical, robotic telescopes. The GNAT consortium wishes to set up 1-m class telescopes, while Remote Telescopes Inc. is planning a 0.5-m-class network. There would be some advantages to the US user community in having photometric calibration measurements taken each night on Cerro Pachon and Cerro Tololo. Such networks are also likely to prove a valuable resource for education and public outreach. Once the first US-based telescope in each network is functioning successfully, CTIO is prepared to consider hosting the first overseas telescope station in each network, again at full cost recovery.

4. Controlling Light Pollution in Chile

Although Cerro Tololo and Cerro Pachon are still very dark sites, CTIO has become increasingly concerned in recent years with the growing threat of light pollution from neighboring cities and towns. Thus we have begun to collaborate actively with local officials as well as private industry to insure that future lighting installations are as “astronomy-friendly” as possible. This program is being carried out on several different fronts as described below.

• Public Information
When this work began, one of the basic problems facing us was a nearly complete lack of awareness of the damaging impact of light pollution on astronomy. The people of the Fourth Region of Chile are very proud of the presence of Cerro Tololo and the other astronomical observatories in this area—indeed, Cerro Tololo has long been one of the most popular tourist destinations in this part of Chile.
We have found that once the problem of light pollution has been explained, the local officials, merchants, and residents have been quite willing to work with us to improve lighting standards. In order to reach more people, we have provided information and interviews to local and national newspapers and television stations and given talks to various civic groups to publicize the problem. As a result of this work, the local population is clearly more sensitized to the problem, although there is still much to do.

**Street Lighting Installations in Local Towns**
As part of a nationwide program sponsored by Chile's National Energy Commission, the cities of Vicuña, La Serena, and Ovalle have replaced their old, energy-wasteful mercury vapor street lights with more efficient high-pressure sodium lighting. Although we would have preferred that the local towns adopt low-pressure sodium lights, this is not practical due to the lack of suppliers in Chile. However, much can still be gained by replacing the old mercury vapor fixtures with fully-shielded high-pressure sodium lights. Vicuña (pop. 15,000) is the closest (12 miles) town to Tololo, and therefore potentially one of the most serious concerns for the Observatory. Fortunately, the town leaders showed considerable interest in working with CTIO to improve existing street lighting, and to ensure that future lighting installations are "astronomy-friendly." On their own, they contacted CTIO to seek advice on how best to ensure that the new street lights would not significantly affect the telescopes on Tololo. CTIO provided the necessary technical assistance to the Vicuña city officials to ensure that the change-over from mercury vapor to high-pressure sodium lights was carried out in a cost-effective manner which, on the one hand, produced better street lighting for Vicuña, while on the other resulted in an actual decrease in the light pollution affecting Tololo and Pachon. The successful completion of this project has served as an important example to the other neighboring communities; indeed, as a result of the publicity surrounding the Vicuña project, the city of La Serena (pop. 120,000) opted to install "astronomy-friendly" lighting; they also replaced their old mercury vapor lights with high-pressure sodium. In this case as well, CTIO worked directly with city officials to ensure that they had the necessary technical assistance to achieve this goal.

**Lighting for Andacollo Mines**
During the last three years, two modern mines (Dayton and Carmen) have gone into operation in Andacollo. Due to the proximity of these mines (only 17 miles from Tololo), considerable effort was made to work with the mine owners to minimize the effect of the nighttime illumination of the mines, both of which operate on a 24 hour schedule. CTIO was able to persuade the mines to go with low-pressure sodium lights. These are the first cases in Chile where low-pressure sodium lamps have been adopted exclusively for industrial lighting, providing an important precedent for any future mining installations near Tololo, Pachon, and the other observatories.

**Light Pollution Norm**
When we first began to talk with city officials about light pollution, we were told that it would be easier for them to adopt lighting ordinances if there were a national or regional norm which dealt specifically with the problem. Consulting with members of both the executive and legislative branches of the Chilean government, we were advised that the best approach would be to work through the newly-created Comision Nacional del Medio Ambiente (CONAMA), which had been charged with creating and monitoring environmental law in Chile. We have devoted considerable effort during the last three years to working with the CONAMA on the formulation and passage of an environmental norm aimed at controlling light pollution in the vicinity of the existing astronomical observatories in Chile. Two years ago, we submitted a proposal for this norm which received strong support from the Governors of both the Fourth and Third Regions; this proposal was ultimately accepted for inclusion in the CONAMA's official work program. This norm, which is modeled after
outdoor lighting standards in Hawaii and the Canary Islands, came very close to being enacted last year but has since been delayed due to technicalities having to do with its enforcement. We are working hard to overcome these difficulties, and are optimistic that a light pollution norm will be in place before the end of 1998. Once approved, the next step will be to work with the individual cities to create lighting ordinances that are consistent with the general specifications of the CONAMA norm.

C. Center for High Angular Resolution (CHARA)

It is widely believed that the next major initiative in groundbased astronomy may be in the area of optical interferometry. Several prototype systems, developed in the university and DOD communities, have demonstrated the capability of optical interferometry to deliver high angular resolution. Optical interferometry was ranked highly by the Astronomy and Astrophysics Survey Committee (AASC), and two moderate scale interferometric facilities are now funded and under development in the US.

The NOAO staff has a long record of participation in the development of high angular resolution techniques, including visible and infrared wavelength speckle interferometry, double Fourier interferometry, and other more recent multi-telescope interferometry. In recent years NOAO staff members and long-term visitors have collaborated with astronomers at the University of Wyoming, University of Paris, and the Harvard-Smithsonian Center for Astrophysics in design, construction, and operation of several prototype interferometer systems, including the Infrared Michelson Array (IRMA) and the Infrared Optical Telescope Array (IOTA). The FLUOR program, carried out at Kitt Peak with NOAO support, resulted in the first interferometric linkage of telescopes with optical fibers. More recently, the classical and fiber infrared beam combiner systems, which NOAO developed for IRMA and FLUOR, have been moved to IOTA. The fiber system has recently obtained the most accurate stellar angular diameters yet recorded with optical interferometry, and the system is now in regular use for scientific observations.

During FY 1997, NOAO completed the third year of a contract with the Georgia State University Center for High Angular Resolution (CHARA) to support the design of the telescopes for the CHARA interferometric array. The design was completed in FY 1996 and the five 1-m aperture telescopes are now under assembly and integration. Installation at Mt. Wilson is scheduled for 1998. The contract also includes work on additional areas including the telescope enclosures, the optical delay system, and the beam transport system. Steve Ridgway will continue to serve as project scientist for CHARA through the commissioning phase.

The AASC Interferometry Panel working papers recommended work in this decade leading to the development of a plan for a large interferometric optical array, with construction possibly starting towards the beginning of the next decade. With several prototype and permanent interferometric facilities operational or in progress, discussion in the interferometry community is now turning toward the possibility of preparing a plan for a major facility. NOAO will be prepared to join in these discussions, to support the planning process, and to collaborate in the construction and operation of a major interferometric array.
D. NOAO Nighttime Instrumentation

Milestones for Instrument Completion

1999  
- Gemini Near IR Spectrograph
- GMOS and HROS Gemini CCD Systems
- CCD Mosaic 2
- COB Upgrade
- SQIID Upgrade
- OSIRIS Upgrade

2000  
- WIYN Tip/Tilt Imager
- WIYN Hydra Upgrade
- FLAMINGOS (IR Imager Mode)
- Prototype Micro-Mirror IR Multi-Object Spectrograph

2001  
- Wide-field Near-IR Imager for KPNO
- FLAMINGOS (IR Multi-Object Spectrograph Mode)
- WIYN Near-IR Spectrograph Detector
- Mayall 4-m f/15 Tip/Tilt
- Gemini Near-IR Spectrograph Clone

2002  
- SOAR Mini-Mosaic
- Mayall 4-m Coudé Spectrograph
- Wide-field Near-IR Imager for CTIO

2003  
- High-Throughput Optical Spectrograph
- SOAR Instrumentation/Adaptive Optics

1. Scientific Planning for Instrumentation Development

NOAO must provide the national community of users with facilities that enable them to carry out observations competitive on an international level. That charge alone is sufficient to compel a substantial ongoing investment in new and upgraded focal plane instrumentation. Advances in detector performance, delivered image quality, and in user expectations all drive the development of new capabilities. The international competition also forces an extremely focused investment. Large instruments produced recently by NOAO have required some 20 FTE (work-years) of effort and the order of $500K in capital. A recent survey by ESO showed that the typical instrument for an 8-meter class telescope requires some 45 FTE and $1M capital.

A focused program of investment in instrumentation therefore demands that we play to the strengths of the telescopes and sites, exploit new detector and optical technology to maximum advantage, and manage resources with extreme diligence.

The existing facilities at CTIO and KPNO will provide observations that support and complement observations with the Gemini telescopes. We intend to exploit the one-degree fields of view of the 4-m telescopes for deep optical imaging and fiber-coupled spectroscopy. The new technology telescopes, WIYN and SOAR, will deliver image quality nearly undegraded from that provided by the atmosphere. These telescopes can support rapid image compensation systems through upgrades to adaptive optics and spectroscopy with higher angular resolution than offered by the older 4-m telescopes. The problems of
star formation and evolution of galaxies at intermediate and high redshifts demand supporting data in the near-IR. Both 4-m telescopes and SOAR will be equipped with imagers and spectrographs to tackle these challenging IR investigations. We also plan to construct a 2.4-m telescope for each site. Those telescopes will provide the imaging surveys in the optical and near-infrared required to isolate samples suitable for study with 8-m and 10-m class telescopes.

Rapid advances in both optical and near-IR detector technology have created opportunities and strong user demand for new instrumentation. NOAO will continue to exploit the revolution in near-IR indium antimonide arrays that it has helped create by deploying a suite of new and upgraded instruments designed around 1K × 1K and larger formats. These will include multi-color and wide-field imagers and three new spectrographs. The development of 2K × 4K, three-side buttable CCDs, driven in part by NOAO and its Gemini partners, enables very large format optical imaging. Mosaic imagers with 8K square format will be deployed for the prime foci of both 4-m telescopes, and mini-mosaics will be created for WIYN and SOAR. NOAO is developing new array controller hardware and software for Gemini that will be adapted for NOAO instruments as well. The Gemini telescopes will take on the proposals based on multi-object optical spectroscopy of the faintest objects. The niche for the national 4-m telescopes will be fiber-coupled wide-field spectroscopy and very high efficiency limited-field beam-fed spectroscopy. Holographic grating technology holds the promise of offering very high efficiencies for new instruments for SOAR and at Kitt Peak.

The specific instruments included in the current plan, with start and completion dates and total direct costs, are listed below in Table III-1. To estimate a true cost for comparisons with costs of instruments built in universities, an average ETS labor cost rate has been applied to the manpower estimate. For a more direct comparison with any particular institution, an appropriate overhead rate must be applied as well.

The instruments selected for construction are consistent with the priorities outlined in the Executive Summary and elsewhere in this five-year plan. During the early years of the plan, the emphasis is on wide-field imaging to deep limiting magnitudes in both the optical and infrared because we believe this capability is essential for the effective use of the Gemini telescopes. Because of the high priority placed on wide-field imaging, we are not planning to pursue diffraction limited imaging with adaptive optics with laser guide stars until these systems have reached such a degree of maturity that they can be costed with confidence. The first telescope where we would like to install an AO system is SOAR. We will do tip/tilt at WIYN, as we have already at the Blanco 4-m, with the goal of improving image quality over a few arcminutes—again emphasizing programs that require fields of view larger than will be offered by the Gemini telescopes.

In terms of infrared spectroscopy, we have chosen to build instruments based on InSb detectors so that we can work out to 5 microns, rather than confining ourselves to the region accessible with HgCd detectors. However, we have no plans to develop instruments for 10 microns and longer wavelengths.

After completing a fiber spectrograph for CTIO, which covers nearly a one degree field of view, we plan to build a high throughput, single object spectrograph. By emphasizing throughput, we hope to be more sensitive to point sources than the spectrographs that have been designed for the 8-m class telescopes and also to take advantage of the more rapid slewing and set up time of 4-m class telescopes to reduce the overhead for projects such as identifying x-ray sources. We do not plan to build multi-slit optical spectrographs for the 4-m class telescopes since we believe the 8-m telescopes will offer substantial advantages for this type of spectroscopy.
The two technology development efforts are focused on volume phase holographic grating technology, which we hope will allow us to achieve higher throughput and also to develop novel designs for spectrographs, and on multi-object IR spectroscopy, with the goal of evaluating various approaches and incorporating the best option in the next generation Gemini IR spectrograph.

Because of budget limitations, we are not currently investing in the development of the next generation of detectors, although such development is crucial for instruments that are likely to be built early in the next century. Very large format CCD arrays require four-side-buttable CCDs, which exist and show promise but require optimization. Similarly, future instruments for the near-IR will require detector formats larger than 1K square. Buttable architectures could be developed for InSb arrays that would allow access to wavelengths in the 3 to 5 micron range.

In addition, budget restrictions and the need to complete current projects mean that the next generation wide-field-of-view IR imagers will not yet be available for deep imaging support at the time the Gemini telescopes become available for science observations.

| Table III-1 |
|---|---|---|---|---|---|---|
| Major Instruments | Project Scientist | Start Date | Completion Date | Manpower MM | Capital ($K) | Labor ($K) | Total Cost ($K) |
| Mosaic II | Armandroff | 1997 | 1999 | 136 | 139 | 789 | 928 |
| WIYN Hydra Upgrade | Barden | 1999 | 2000 | 18 | KP | 104 | 104 |
| Mayall Coude Spectrograph | Barden | 1999 | 2002 | 68 | KP | 394 | 394 |
| WIYN Tip/Tilt Imager | Claver | 1998 | 2000 | 60 | KP | 348 | 348 |
| High Throughput Spectrograph | Armandroff | 1999 | 2003 | 102 | 125 | 592 | 717 |
| FLAMINGOS | Elias | 1998 | 2000,2001 | 30 | 500 | 174 | 574 |
| WFOV IR Imager | Joyce | 1998 | 2001,2002 | 156 | 520 | 905 | 1,425 |
| Micro-Mirror IR Spectrograph | Green | 1998 | 2000 | 15 | KP | 87 | 87 |
| Adaptive Optics | Green | 2001 | 2003 | 313 | $ 262 | $1,815 | $ 2,077 |

The instrumentation group will also be responsible for the development of arrays for both optical and infrared astronomy and for the associated control electronics. In addition, the staff responsible for instrumentation upgrades and for maintenance of instruments and detectors at Kitt Peak have been assigned to the instrumentation group. The total staffing for upgrades and improvements at KPNO and CTIO is the same. Table III-2 shows the yearly costs of the four components of the instrumentation group program: operations and maintenance of already completed equipment now in use primarily at KPNO; upgrades to KPNO instruments; R&D of detectors; and major instruments.

2. Infrared Instrumentation

A comprehensive approach to the development, upgrading, and deployment of infrared instrumentation for the nighttime telescopes has been defined by CTIO and KPNO. The long-term goal is to provide substantial imaging and spectroscopic capabilities for both sites, based on the anticipated production of large-format InSb arrays. The steps to that goal include upgrades of existing instruments and development of new spectrographs for both sites. A collaboration of Hughes Santa Barbara Research, NOAO, and the US Naval Observatory (USNO), known as the ALADDIN project, has been formed to provide the $1024 \times 1024$ InSb arrays necessary for the next generation of IR instruments and upgrades.
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<td>1563</td>
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<tr>
<td>Capital Recovery - Gemini</td>
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At the present time, the IR instruments deployed at CTIO are an IR Spectrometer (256 x 256 InSb) and an IR Imager (256 x 256 HgCdTe), as well as the Cryogenic Optical Bench (512 x 512 ALADDIN InSb). The IR instruments at KPNO are Phoenix, the high resolution near-IR spectrograph with a 512 x 1024 ALADDIN InSb array, CRSP (256 x 256 InSb), IRIM (256 x 256 HgCdTe), and the Ohio State/NOAO Imaging Spectrograph, a shared instrument with a 512 x 1024 ALADDIN InSb array.

By the end of the plan period, most of these instruments will either be replaced or upgraded with better detectors so that both existing observatory sites will have state-of-the-art imaging and spectroscopic capabilities. CTIO will have the clone of the Gemini Near-IR Spectrograph to share between SOAR and Gemini South. KPNO will support imaging with the upgraded SQIID (simultaneous four-color imager). The Cryogenic Optical Bench will be in use to commission the SOAR telescope after its use as the commissioning imager for Gemini South. Both CTIO and KPNO will have a wide field of view near-IR imager for their new 2.4-m telescopes. Both sites have aggressively pursued partnerships for near-IR spectroscopic capability. This complement of advanced facility IR instruments has been selected in order to provide powerful and balanced capabilities to users of our nationally supported facilities in both hemispheres.

In addition to instruments for CTIO and KPNO, the IR instrument team is responsible for the production of the near-infrared arrays and controllers for the two initial Gemini near-IR instruments, the imager and spectrograph. The arrays are based on the ALADDIN development program. NOAO’s responsibility is to manage Gemini’s foundry production at SBRC. The development of the new array controller presents both hardware and software challenges. The first controller is being delivered to the imager project at the University of Hawaii in spring 1998. The second controller will be provided for the spectrograph in FY 1999. The Gemini controller design will be used as the basis for all the planned NOAO near-IR instruments, allowing uniformity in support of Gemini operations in the South and both NOAO sites.

The major instrument under production for Gemini at NOAO is the Near-IR Spectrograph (GNIRS). This project is the largest IR instrument ever undertaken by NOAO. The dewar will be 2 meters in length, and the instrument weighs some 2000 kg. It will provide long-slit capabilities with a range of dispersions through selectable gratings, and two pixel scales, covering the wavelength region from 1 to 5 microns with a design for four cameras addressing a single 1024 square ALADDIN-type InSb detector. Fabrication began in FY 1998, with delivery to the Mauna Kea site planned for late calendar 1999.

Spectroscopy at CTIO will be carried out on the new long-slit and cross-dispersed IR Spectrograph to be built later in the plan period. The CTIO spectrograph will be a customized version of the GNIRS. The compatibility of the CTIO spectrograph with Gemini protocols will allow it to be shared with Gemini South, and it has the strong endorsement of the Gemini IR Instrument Science Working Group and the Gemini Instrument Forum. This IRS will be accommodated on the new SOAR telescope, since its weight and volume exceed the capacity of the Blanco 4-m. The Cryogenic Optical Bench serves as a high-resolution imager, with 0.1 arcsec pixels matched to the image quality of the Blanco 4-m with tip/tilt correction. COB will be upgraded (with partial support from Gemini) to an InSb detector with more than one working quadrant and a Gemini-style controller in FY 1999. NOAO has arranged with Gemini that COB will be available for somewhat more than one year as the commissioning imager for Gemini South, starting in mid calendar 2000. At that point, CTIO will require a replacement imager for its users.

Three new infrared instruments will be developed for imaging at CTIO and imaging and spectroscopy at KPNO. The scientific staff is currently exploring concept designs and formulating the details of the integrated plan. The development path presented in Table III-2 is the best projection for the second half of the plan period, but may be modified on further consideration. A high priority for the users, as
expressed through the Users’ Committee, is wide field near-IR imaging. The first realization of that capability will be in the upgrade of SQIID, the four-color imager. The 256 × 256 PtSi arrays will be upgraded to 512 × 512 InSb arrays with a customized NOAO/Gemini Controller. The plan is for commissioning on Kitt Peak in late 1998.

Both sites have sought partnerships with instrumentation groups in the community to offer users capabilities faster than the IPG budget envelope alone would allow. CTIO resources are going toward an upgrade of the Ohio State imager/spectrograph OSIRIS to a 1024 × 1024 HgCdTe array. The newly configured instrument will be available to CTIO users on an ongoing basis. OSU is currently sharing an imager/spectrograph, ONIS, with KPNO. NOAO is collaborating with the University of Florida in their production of FLAMINGOS, a wide-field near-IR imager/spectrograph with cooled multiple object spectroscopic slit masks for low-dispersion grism spectroscopy. The instrument will be used at f/8 or f/15 on the Mayall 4-m and the 2.1-m on Kitt Peak. KPNO is exploring a partnership with Space Telescope Science Institute and Goddard Space Flight Center to produce a near-IR medium resolution spectrograph with a cold programmable digital micro-mirror array for multiple object spectroscopy. The instrument is planned with an ALADDIN InSb array and NOAO controller.

To meet the needs for wider field imaging, the major instrument produced within the IPG will be a pair of imagers that will ultimately address 2K × 2K near-IR detectors. Those imagers will be used on both the new 2.4-m imaging telescopes. They are listed in Table III-2 as WFOV IR imager, and are scheduled to be commissioned in FY 2001 and 2002. The deployment of those imagers is part of the integrated plan in supporting both observatories and Gemini.

The last IR instrument in queue will expand the capabilities of the WIYN multi-object spectrograph. The long-term plan is to provide near-IR recording capability for the multi-fiber output of the WIYN Hydra positioner. Such a configuration would be unique in covering a large area of sky spectroscopically at wavelengths between 1 and 2 microns. The surface densities of objects discovered in the 2MASS and Sloan Digital Sky Surveys will be an appropriate match for such an instrument.

3. Optical/UV Instrumentation

The driving principle of the O/UV program is to develop capabilities for CTIO and KPNO that will complement the strengths of optical observing on the Gemini telescopes. Current plans concentrate on exploiting the wide-field of the 4-m telescopes. Individual instruments are described below.

- Mosaic Imager 2

The major instrument currently in commissioning is the CCD mosaic imager, to be deployed at KPNO, then cloned for CTIO. IPG has produced an imager with 8096 × 8096 format that has an active imaging area of over 12-cm on a side. The Mosaic currently contains eight 2K × 4K three-side buttable CCDs from STe, but they are engineering grade. Scientific grade CCDs have been ordered for two Mosaic imagers, through a consortium purchase with Carnegie Observatories, and are currently being delivered at the rate of about two a month. The controller is a multiplexed quadruple version of the ARCON, developed and produced at CTIO. The first Mosaic Imager is scheduled for test with the science-grade thin CCDs on KPNO telescopes in July 1998. The second Mosaic is scheduled for completion in FY 1999, with full deployment at both sites completed in the first half of the calendar year.
• **Tip/Tilt Imager**
  An extremely high priority for the entire WIYN partnership is the implementation of a tip/tilt imager for the WIYN telescope. A proposal was submitted by the WIYN Consortium to the NSF MRI Program for significant upgrade to the capability of the basic system supported in the base program, including a near-IR imager. Only NOAO's contribution to the project is listed in Table III-2 under instrument upgrades.

• **New spectrographs**
  Long-term studies are currently underway to define a new generation spectrograph for the 4-m telescopes. Scientific performance tradeoffs are being investigated to identify the most effective combination of field of view, spectral dispersion, and wavelength coverage. A key goal is to use the new generation of large-format CCDs with smaller slits and adequate pixel sampling, in order to exploit the expected improvement in delivered image quality. In addition, the use of holographic volume phase gratings may allow a significant increase in throughput. Brazil has expressed interest in collaborating with CTIO in exploring a spectrograph design for use on SOAR, which could also build on this technology. The spectrograph that results from these considerations is planned as the next major instrument to follow the WIYN imager upgrade to a mini-Mosaic of two 2K x 4K SITe CCDs.

• **4-m Coudé Spectrograph**
  To maintain the capability for very high resolution stellar spectroscopy, KPNO must find a way to continue use of the coudé spectrograph, currently at the 2.1-m/Feed. To reduce operations stress because of the long-term reduction in personnel, the 0.9-m Feed telescope itself is planned for closure. To open a significantly larger volume of space for observation, fainter limiting magnitudes could be achieved by moving the coudé spectrograph to the 4-m. It could be fed by a simple addressable fiber, to achieve high stability as well as high resolution. A new image slicer must be designed to realize high signal to noise with respect to the narrow physical slit required for the highest resolutions. This project is currently under study and will be implemented through the portion of the IPG that is committed to support of KPNO instrument upgrades.

E. **US Gemini Program and NOAO Science Operations (SCoPe)**

Milestones for USGP

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>December 1998</td>
<td>First light on Gemini North</td>
</tr>
<tr>
<td>February 1999</td>
<td>Schedule open access nights at HET, upgraded MMT</td>
</tr>
<tr>
<td>January 2000</td>
<td>Deliver near-IR spectrograph to Gemini North</td>
</tr>
<tr>
<td>March 2000</td>
<td>Science operations begin at Gemini North</td>
</tr>
<tr>
<td>June 2000</td>
<td>First light on Gemini South</td>
</tr>
<tr>
<td>June 2001</td>
<td>Science operations begin at Gemini South</td>
</tr>
</tbody>
</table>

1. **Roles of the USGP**

The US Gemini Program (USGP), which was established in 1993, is the fourth and newest division of NOAO. Its initial role was to serve as the interface between the international Gemini Project and the US community. Recently this division has begun to take on the role of providing the interface to users of the NOAO nighttime telescopes.

During the period of time covered by this long range plan, the Gemini telescopes will make the transition from construction to operation, and the activities of the USGP will evolve as well. In the construction
phase, the primary role of the USGP and the national project offices in the other partner countries is to assist in the management of work packages within their countries. Specifically, the USGP has taken on the responsibility for management oversight of the entire infrared instrumentation program for the international Gemini Project, including work being carried out at both NOAO and other institutions. The USGP is also managing the effort to provide CCDs and CCD controllers for the Gemini optical instruments. In addition, the USGP is responsible for obtaining input on scientific requirements and goals from the US community, and disseminating information about the project. The USGP supports design reviews and other project activities, identifies US representatives for international Gemini committees and working groups, and otherwise assists the project.

In the operations phase, the national project offices will retain the above roles but also will be responsible for supporting the national access to the Gemini telescopes. In general terms, the USGP will be required to support all activities before and after the observing run itself. We have decided that the US user community will be better served if we unify the interface to the other northern hemisphere telescopes to which NOAO provides access. The USGP will therefore also support national access to KPNO, the independent observatories that supply national access time in exchange for NSF instrumentation funding, as well as to the Gemini telescopes. The CTIO telescopes will be added later after the lessons from adding the KPNO telescopes have been learned. Specific responsibilities for Gemini and northern hemisphere telescopes include the following:

- Distribute information to the US community about telescopes and instrumentation.
- Supply or coordinate expert advice and support for observing proposal preparation.
- Solicit observing proposals and perform or coordinate initial technical evaluation.
- Evaluate proposals through Time Allocation Committees (peer-review) and organize representative participation in TACs run by the non-NOAO organizations providing access to the US community.
- Establish and support a Users’ Committee structure that provides effective feedback on the entire suite of facilities to which national access is provided, and organize participation or input to the non-NOAO organizations providing this access.
- Supply data reduction software and data reduction support to the US community for all instruments (NOAO, Gemini, independent observatories) for which packages in the IRAF environment are desirable.
- Coordinate support for observing programs through instrument specialists drawn from all the NOAO sites.
- Establish and maintain whatever type of data archive is cost-effective. Provide or facilitate US community access to this database.
- Investigate the feasibility and desirability of operating remote observing stations and support this type of access.
- Coordinate assistance to the community for queue-scheduled observations.
- Carry out public relations and outreach activities aimed at the astronomical community.

The following are additional responsibilities that are uniquely aimed at support of the Gemini facilities:
• Coordinate and manage the US-allocated Gemini instruments. This includes supporting community participation in defining new instrumental capabilities.

• Coordinate the maintenance support for systems provided by the US to Gemini.

2. **Gemini Instruments: Construction Phase**

The international Gemini agreement is designed to ensure that all the partner countries maintain full intellectual participation in the project. In general terms, this goal has been achieved by assigning specific responsibilities to each of the partner countries, as described above. Active participation in the definition and implementation of the instrumentation program is a particularly important component of the responsibilities assigned to the partner countries. According to the terms of the international agreement, work on the design and fabrication of the instruments will be allocated to the partner countries approximately in proportion to their financial participation in the project.

In accordance with the international agreement, responsibility for approximately half of the initial complement of instruments has been allocated to the US. These US-allocated instruments are:

- Near-IR (1- to 5-micron) Imager
- Near-IR Spectrometer
- Mid-IR (8- to 30-micron) Imager
- Optical detector arrays and array controllers
- Near-IR Arrays
- Near-IR Array Controllers

• **Near IR Imager**
  This instrument was allocated by the NSF to the University of Hawaii. A contract between Gemini (AURA) and the University of Hawaii for design and fabrication has been negotiated. The USGP has assumed responsibility for an assessment of performance against schedule and budget and is making regular reports to the international Gemini project.

• **Near-IR Spectrometer**
  This instrument was the subject of an open competition, based on an RFP. NOAO won this competition, and the proposal design has been refined in preparation for fabrication. The critical design review was held in November 1997.

• **Mid-IR Imager**
  Interest in designing and building this instrument was expressed by a number of university groups. The USGP ran a competition and selected two groups for partial funding of conceptual design efforts. These and two unfunded design studies were submitted for review. A second competition selected a group at the University of Florida to complete a detailed design and fabricate the instrument. Work on this instrument is just beginning.

• **Optical Detector Arrays and Array Controllers**
  This work package consists of three parts, the acquisition of CCDs, the design/fabrication of CCD controllers, and the integration of these two items into the cameras of the Gemini optical spectrographs. The USGP organized an international consortium of CCD experts to study various approaches
toward acquiring the $2048 \times 4096$ CCDs. Based on the evaluation of proposals from three potential vendors by this consortium and another committee of Gemini instrument scientists, EEV was chosen to supply the optical detectors.

Based on the evaluation of an external committee, which is part of the Albuquerque Process, the USGP adopted the following approach for providing CCD controllers to Gemini:

- The required hardware has been purchased from San Diego State University (SDSU). This choice follows directly the recommendation of the evaluation committee.

- The Royal Observatories will provide the low-level software (where their expertise is most relevant). NOAO will be responsible for the high-level software, which is a modification of the software already written for the IR controllers. This approach is consistent with the evaluation committee's identification of the strong points of the various software efforts.

- NOAO has assumed overall management responsibility for integrating the software and the hardware. NOAO has already been assigned the responsibility for integrating the detectors with the controllers.

**Near-IR Arrays**

The Gemini near-IR instruments are designed around $1024 \times 1024$ InSb arrays. The only such device is the ALADDIN array, currently being developed at SBRC under a contract funded jointly by NOAO and USNO. The USGP has initiated a foundry run at SBRC aimed at fabricating a sufficient number of arrays to assure two high-quality detectors for the Gemini imager and spectrograph. NOAO will characterize the arrays. Several of these arrays have been received and characterized, and one acceptable for the Near-LR Imager has been identified.

**Near-IR Array Controllers**

NOAO and Gemini requirements for controllers are similar because both observatories plan to use $1024 \times 1024$ InSb arrays. Because of the advantages of commonality, including the possibility of sharing IR instruments built by NOAO for its own telescopes, the international Gemini project indicated that it wishes to use the same array controllers as NOAO. The two builders of near-IR instruments (the University of Hawaii and NOAO) have agreed that the NOAO controllers will meet their requirements. An assessment by the USGP of other alternatives for the IR array controllers indicated that no other single vendor could provide an end-to-end system that meets the Gemini specifications, and development of a new controller is inconsistent with the Gemini schedule. Therefore, NOAO is building array controllers for the two Gemini Near-IR instruments. In order to facilitate the integration of the controller with the Near-IR imager at the University of Hawaii, NOAO will integrate the controller with an engineering-grade ALADDIN array in a test dewar and ship this assembly to Hawaii.

3. **Gemini Instruments: Operations Phase**

During the construction phase of the Gemini project, instrumentation planning has emphasized providing a suite of basic instruments for spectroscopy in both the optical and infrared and for infrared imaging. With the completion of this initial complement, there should be more opportunities to provide innovative and special purpose instruments. There must also be an evolution of the basic capabilities in order to ensure that the Gemini facilities remain competitive with other large telescopes. In order to encourage input from the US community to the ongoing process of Gemini instrument planning, the USGP organ-
ized a workshop in 1996 to discuss priorities of future capabilities. This US workshop fed into an international workshop with the same format organized by the international Gemini project. It is planned to hold similar workshops to review and extend the ongoing instrumentation program every two years.

The new high-priority instruments identified by these discussions include a laser guide star adaptive optics system for Gemini South; two Near-IR multi-object spectrographs, one optimized for a small AO-corrected field, and one for as wide a field as can be easily accommodated; and a Near-IR imager/coronagraph, optimized for use with the AO system.

4. Gemini Instruments: Procurement Plan

As the first generation of Gemini instruments are well into final design or fabrication, it has become obvious that some substantial issues should be resolved concerning the process that the international project uses to procure future instruments for Gemini. In particular, it is agreed that there should be a uniform and consistent method of establishing the constraints on instruments, the performance, the cost, and the schedule. In order to address this and other procurement issues and to converge on an actual program for the ongoing instrumentation, Gemini recently began meetings of the Gemini instrumentation forum. This group includes the national project managers and national project scientists as well as the Gemini personnel associated with the instrumentation program. The recommendations for the procurement process that came out of the forum meetings include:

• The procurement process will begin with a very rough estimate of the cost for an instrument with a given set of scientific capabilities, generated by the Gemini project or by one or more of the national project offices. These estimates and the assumptions used will be presented to and discussed by the forum.

• National project office representatives will poll their communities to determine interest in providing any of the instruments currently on the table. They will then advocate those interests to the forum. There will also be opportunities for the national project offices to propose to the forum existing instruments that could be shared with Gemini as well as programs aimed at instrument-oriented technology development.

• One or more conceptual designs for each instrument will be commissioned and at least partially funded by Gemini. Selection of the groups to perform this design work will be through an open, informal discussion involving all interested parties, in the presence of the instrumentation forum members, supplemented by unbiased experts from the partner communities. Additional groups may elect to develop unfunded conceptual designs in parallel with the selected groups.

• Following presentation of the conceptual design studies, the instrumentation forum will decide which, if any, of the groups it would like to fund to complete the detailed design and fabrication. The desire is to negotiate one or two fixed-price phases, based on the conceptual design work already done.

• Over the long run, instrument allocation should approximate the relative financial participation of the partners. However, it is recognized that in the short-term, departures from this will be necessary. It is also recognized that collaborative efforts are desirable both because the smaller partners may not have the national infrastructure allowing them to build entire instruments and because of the intellectual benefits of such collaborations.
The two significant differences from current Gemini procedures are that instruments are not first assigned to countries and that the members of the forum itself have put themselves in the role of recommending the selection from among the interested groups. The potential involvement of all countries is seen as desirable in order not to force the assignment of an instrument to a particular partner on the basis of equity as opposed to technical expertise. The recommendation of the forum members will be forwarded to the Gemini Board.

The USGP’s role in this new instrument assignment and procurement process will be much the same as if instruments were assigned to the US at the start. The USGP will solicit input and expressions of interest from the community for each of the instruments that the instrumentation forum considers. Assistance in the development of cost estimates will be requested from groups with relevant experience. The USGP may run pre-forum discussions (particularly in cases where both NOAO and outside groups have expressed interest) to identify the few best groups and help them refine their presentations to maximize their opportunities. After instrument design and fabrication work is assigned, the USGP will maintain its management role for Gemini. It may also be desirable for the USGP through NOAO to act as an integrator in order to maximize participation by smaller groups in the community, or to supply special pieces of Gemini instruments, such as the software, in cases where other existing groups do not have that expertise.

The second meeting of the forum concentrated on merging the scientific priorities for instruments established by the national and international workshops with realistic constraints of budgets and other resources. A ten year plan for Gemini instrumentation was developed, the initial elements of which are laser guide star adaptive optics and the addition of a polarization modulation capability for the acquisition and guide units. These will be procured using the process outlined above.

5. National Access to Gemini and Other Telescopes

Just as the design and construction of the Gemini telescopes rely on assistance from the national project offices, the Gemini operations plan assumes that the partner countries will be actively involved in providing user support. Given this requirement, it seems most useful for planning purposes to consider the US share of the international Gemini project as simply the newest of the NOAO telescopes. If NOAO integrates the US support of Gemini with support of access to the independent observatories who will provide national access in exchange for NSF instrumentation funding, and with the analogous parts of the KPNO, and ultimately the CTIO operations, then it will be possible to carry out this broader set of responsibilities with limited impact on existing programs. Accordingly, the USGP is now moving toward supporting all the pre- and post-observing run activities for all the nighttime telescopes to which NOAO provides access. A few Gemini-specific responsibilities (primarily concerning the ongoing Gemini instrumentation) will also remain within this NOAO-wide science operations division.

The operations-phase activities were summarized in the introduction to this section and are detailed below.

- **Instrumentation Program**
  
  The USGP will be expected to continue to manage the development of those Gemini instruments that are assigned to the US. Through the Gemini instrumentation forum and the Gemini science advisory structure, the requirements and estimated costs for elements of the ongoing instrumentation program will be defined. The USGP will be responsible for identifying US interests in designing and fabricating the approved instruments.
• **The Proposal/TAC Process**
  The USGP will develop an efficient and uniform method by which the community can propose to use any of the facilities to which NOAO supplies access. The process will facilitate the approval and execution of scientific programs, rather than differentiating among different telescopes. The information in submitted and approved proposals will transfer into the various databases by which the different facilities manage their operations, and into a database that allows NOAO to track its success at facilitating the community’s science. The USGP will also integrate the TAC process for all these telescopes, so that uniform, consistent, and appropriate criteria are used to ensure that the best scientific programs are executed successfully. One idea being investigated is the restructuring of the current site-based TACs into discipline-based TACs that each consider proposals for all the telescopes to which NOAO supplies access. The USGP will explore means to increase the efficiency of the entire process, including investigation of computer-aided scheduling of the NOAO telescopes. Initial experiments will involve northern hemisphere telescopes only.

• **Scientific Support**
  The USGP will assemble and unify the information that proposers and observers need to use the facilities effectively. This includes making general information about telescopes, instruments, and techniques available electronically, providing software such as exposure time estimators, and documentation such as instrument manuals. This also includes the identification of astronomers at each of the sites who will provide pre- and post-observing run support and who can answer questions about specific programs, instruments, telescopes, or data reduction capabilities.

• **Data Reduction**
  The USGP will ensure that software is available to reduce data from instruments to which NOAO supports access by the community. This will involve the production of IRAF applications in some cases (such as the Gemini instruments) and will involve the distribution of software produced by outside groups in other cases (such as the independent observatories). The effort to be put into new software should be appropriate to the expected demand.

• **Alternate Modes of Observing**
  The efficient use of telescope facilities of the future may well require a change in the way that astronomers obtain their observational data. With space-based and radio ground-based observatories we have seen the advent and the initial development of practical remote observing and queue scheduling. These types of observing and scheduling may be essential elements of the national facilities in order to optimize both the science and the operational efficiency of those facilities. The international Gemini project science and management teams have already established that the Gemini telescopes will be queue-scheduled at least 50% of the time. The Hobby-Eberly Telescope, to which the community will get some access, will be entirely queue-scheduled. The USGP will explore alternate modes of observing 1) in order to ensure that the US community can get maximum benefit from those programs that are not scheduled in the classical way, and 2) to understand whether the scientific and operational benefits are substantial enough to warrant implementing such modes for additional facilities. Such implementation might include a remote observing station with high-bandwidth links to Cerro Tololo or the Gemini telescopes, with eventual support for remote observing from the observer's home site.

• **Archiving**
  Although Gemini maintains the requirement that instruments write data into an archive, no support is provided for access by the astronomers of the partner country communities. Similarly, KPNO
currently writes all data frames into a save-the-bits archive, but no access is provided other than to recover data that are lost or damaged. The USGP will investigate the feasibility, the cost, and the anticipated benefits of supporting general access to the data obtained on the various telescopes. If such access seems warranted and feasible, USGP will develop a plan for providing it. As an associated issue, it may be desirable to identify certain datasets as being of general scientific interest and to support acquisition of, and access to, these datasets.

• **Scientific Outreach**
  The USGP has a specific responsibility to act as the liaison between the international Gemini project and the US community. It satisfies that obligation by providing information about the project and the facility capabilities through newsletters, displays, and talks, by convening workshops on special topics relevant to Gemini and of interest to the US community, and by soliciting input, both through its advisory committee, the US SAC, and informally. In its new, broadened role, the USGP will have responsibility for NOAO scientific outreach. Information will be broadcast through newsletters, displays, talks, and electronic media. Sessions at AAS meetings and workshops will be organized so that the community can provide input to guide the NOAO program. Users' committees will meet annually to discuss issues of current concern. In 1997, the USGP organized a community-wide workshop to understand the requirements for supporting capabilities in order that the community will be able to use very large telescopes effectively. The USGP will initiate additional community discussions about technical, scientific, and programmatic issues of interest to the entire community.
IV. SOLAR ASTRONOMY

The study of our nearest star continues to yield important results about its structure and evolution that are widely applicable to astrophysics and solar-terrestrial physics. The five-year plan for NSO contains two parallel and interdependent thrusts: (1) research on the Sun by the NSO scientific staff and (2) the development of instruments and facilities to support solar research by both staff and the user community. In contrast to the nighttime NOAO program, where most of the telescope time goes to the user community, which in turn carries out most of the research, the NSO scientific staff is directly engaged in a large fraction of the research conducted with the facilities provided by NSO. Accordingly, in the sections that follow, we summarize first some of the primary research directions for the next five years and then describe the program for building new facilities and instruments.

A. Science at NSO

1. Understanding the Solar Activity Cycle

- Local Helioseismology

NSO has played a key leadership role in the emerging field of local helioseismology. In this field, the solar oscillations are analyzed in a variety of ways to infer conditions in localized volumes, rather than globally averaged over the entire Sun. NSO staff members have been instrumental in developing four major methods of local helioseismology: p-mode absorption, acoustic holography, time-distance, and ring diagrams.

Observations obtained at the Vacuum Telescope on Kitt Peak have shown that sunspots and active regions absorb a significant fraction of incident p-mode acoustic wave energy. This has provided a new diagnostic tool for understanding the structure and dynamics of magnetic regions. The scattering and absorption of acoustic waves by sunspots offer the prospect of studying the subsurface structure and evolution of sunspots and active regions by a form of acoustic holography. Indeed, analysis carried out on the South Pole data as well as High-l Helioseismograph (HLH) data may have already detected the presence of subsurface magnetic fields before their appearance at the surface. Acoustic power maps from South Pole observations show enhanced power in the form of "halos" surrounding active regions as well as occasional "finger"-like features, which extend outward from active regions. Theoretical work has been carried out to understand the physical mechanism responsible for the absorption and to explain the observed scattering properties of active regions by wave and geometric acoustics.

Time-distance helioseismology, developed at NSO, provides another excellent tool for local helioseismology. Directly analogous to classical terrestrial seismology, this method measures the time it takes a wave to travel over a certain distance. It is now known that sunspots produce a measurable signature in time-distance plots, and a secondary reflection of the acoustic waves from a layer in the solar atmosphere is detectable. Theoretical work done at NSO has reproduced the time-distance observations and studied the forward problem of deciphering the subsurface structure of sunspots through time-distance helioseismology.

A three-dimensional analysis of oscillation data has been developed in which the signature of the oscillations is a set of trumpet-shaped surfaces in the \( k_x-k_y-\omega \) volume. When the surfaces are sliced at a constant temporal frequency (\( \omega \)), a set of rings appears. The central positions of these rings are proportional to an average over depth of the horizontal components of the velocity of the solar plasma. By analyzing rings from data obtained at different heliocentric positions, three-dimensional
maps of the horizontal flows can be determined. All of the results to date indicate the presence of a horizontal flow field whose direction spirals with depth at a given location. This pattern could be a consequence of a set of oppositely-directed shear layers associated with the ionization zones in the outer convection zone, and is consistent with the production of helicity in magnetic fields observed at the surface. The magnitudes of the flows are also consistent with the velocities of thermal winds that could be the consequence of large-scale thermal variations also observed as changes in the shape of the solar limb. Synoptic observations obtained with the HLH over the course of a solar cycle are now being analyzed to study the temporal evolution of the flows in the outer solar convection zone, as well as flows associated with magnetic helicity and active longitudes. The possibility that the formation of active regions is presaged by a recognizable flow pattern in the convection zone holds out the hope that a long-range forecast for specific solar activity may eventually be available. Theoretical work is also underway to develop methods to infer sub-surface magnetic fields from the ring diagrams. Here, the shapes of the ring (rather than the positions) are altered by the presence of magnetic field.

Using this arsenal of analysis techniques, NSO plans to interpret local helioseismic observations over the next five years, during the declining, minimum, and ascending phases of the solar activity cycle. The observations will be obtained from GONG, the Spectromagnetograph, and the HLH at the Kitt Peak Vacuum Telescope, the Universal Birefringent Filter at the Sac Peak Vacuum Telescope, and through the NSO-NASA-Bartol South Pole project.

**Large-Scale Fields**

Helioseismology is helping to map the internal flow fields that are central to the solar cycle, but the interaction of these flows with (as yet undetected) strong magnetic flux tubes remains obscure. Three-dimensional simulations of the rise of magnetic flux tubes from the base of the convection zone are used to understand the formation of sunspots, plages, and ephemeral regions. The properties of these active regions—such as rotation, meridional circulation, growth, and decay—can be determined by studying the dynamics of flux tubes. This should shed light on the underlying mechanism that drives the solar cycle.

The newly-commissioned spectromagnetograph at the Kitt Peak Vacuum Telescope is now providing vital data for the study of the solar cycle. Full-disk digital magnetograms, Dopplergrams, and intensity maps in the 1080-nm line of helium are now produced daily and distributed to the solar-terrestrial community. These data, along with the 20 years of nearly daily full-disk magnetograms acquired with the now-retired 512-channel magnetograph, are currently being used to study the emergence patterns of active regions over a size scale extending from the smallest ephemeral regions to large complexes of activity. These studies have already led to important and new information about the solar cycle. We now know, for example, that the new solar cycle begins with the emergence of reverse-polarity, high-latitude ephemeral regions approximately two years before the first appearance of a new-cycle sunspot region and three years before sunspot minimum. The diachronic observations at NSO and the research investigations using these data by the NSO staff and visitors will yield further clues and constraints to the modeling of the solar cycle.

Sunspots are perhaps the most obvious manifestation of solar activity. A long-term program is underway at NSO, in collaboration with colleagues at the Indian Institute of Astrophysics in Bangalore, India, to study the daily positions and sizes of sunspots. The photographic archives at Mount Wilson and Kodaikanal (India), which date back to the early 1900's, have been measured for this information, and the analysis of these datasets in terms of detailed regularities in sunspot motions is nearing completion. These results will bear on the problem of the solar cycle.
A new observational tool for mapping large-scale horizontal flows in the photosphere has been developed at NSO: local correlation tracking of granules for many hours per day. The granules, which live for 10-15 minutes, serve as tracers of persistent flows that interact with active region magnetic fields. In combination with other tools, this technique allows close study of the forces that build flare energy. Similarly, proper motions of supergranulation cells over longer periods are giving information for the first time on the so-called giant cells which are thought to penetrate the entire depth of the solar convection zone.

The GONG network is providing coarse full-disk maps (16-arcsec resolution) of the surface magnetic field and Doppler velocity every 20 minutes for three years beginning in 1995. From these data the large-scale surface horizontal flows (e.g., differential rotation, torsional oscillation, meridional circulation) can be derived, as well as non-axisymmetric flows at least as large as supergranulation. Simultaneous observations from the Solar Oscillations Imager aboard SOHO will complement the GONG observations, at 4-arcsec resolution, and will be used to track the fine-scale flows (vortices, sources, and sinks smaller than supergranules).

**Solar-Stellar Physics**

The principal objectives of the NSO and NOAO program in solar-stellar physics are: (1) to advance solar physics by testing theories developed in a solar context through observations of stars that, in total, represent a range in physical parameter space unavailable using the Sun alone; and (2) to advance stellar physics through the application of the methods and results of solar physics to the study of solar-type phenomena observed in other stars.

The McMath-Pierce solar-stellar program has made important contributions in the general area of the magnetic field properties of solar-type stars. These include the delineation of magnetic field characteristics such as strength and filling factor, and their empirical dependence on stellar properties that include rotation, fractional convection zone depth, and photospheric gas pressure. The results serve as critical constraints for the development of dynamo theory. This effort relied on high-resolution spectroscopic techniques often carried out in a synoptic mode that produced data on time scales ranging from that of the stellar rotation period to actual magnetic cycle periods.

The solar-stellar program relies increasingly on the utilization of NOAO nighttime telescopes and instrumentation, in part because of their greater aperture and sensitivity and in part because of reductions for this type of research within the NSO budget. A collaboration of KPNO and NSO scientific staff in SONG—Stellar Oscillations Network Group—is exploring techniques for the detection of p-mode oscillations in solar-type stars. Experiments are being conducted at both the McMath-Pierce telescope (solar data) and the Coudé Feed (stellar data) on Kitt Peak. In addition, the WIYN telescope with its multi-object spectrograph (HYDRA) is being utilized to investigate the chromospheric and cycle properties of the numerous solar-type stars in M67. The many "Suns" in this solar-age and metallicity cluster are counterparts of our own Sun, thus serving as representative examples of the Sun at all possible, or potentially possible, phases of its activity cycle. Such data would require centuries to obtain if we were to rely on observations of the Sun alone. Both NSO and KPNO staff are utilizing the new cryogenic echelle PHOENIX for sensitive, high-resolution observations of infrared spectral diagnostics of magnetic fields in solar-type stars. The infrared is a particularly powerful region for magnetic field studies because of the wavelength sensitivity of Zeeman splitting. The NSO also maintains contact with developments in the area of small telescope networks, such as GNAT (the Global Network of Automated Telescopes). Photometric data from small telescopes provide a potentially valuable augmentation to spectroscopic studies that include,
for example, Doppler imaging and the joint behavior of magnetic field properties and luminosity variability on short and long time scales in solar-type stars.

2. Understanding the Coupling of the Interior and the Surface: Irradiance Variations

Overview
Measuring and understanding the Sun’s variable outputs poses one of the most important problems in solar research. Not only is this problem linked to fundamental questions concerning the structure of the interior of the Sun and to the unknown mechanisms of the activity cycle, but it also has an impact on climate and atmospheric chemistry. In recent years much has been learned about variations in the solar radiative output, but much is still lacking in our knowledge of this important field.

Investigators now believe there are at least three, and possibly four, contributors to solar irradiance variations: active regions (sunspots and plage), strong magnetic network elements, weak magnetic network elements, and possibly the centers of supergranular cells. The relative importance of these components as a function of time in the short- and long-term variations in solar irradiance is not well established.

In a cool star like the Sun, energy is transported by convection in a thick shell that lies just below the visible surface, the photosphere. Convective motions also generate and amplify solar magnetic fields, which rise buoyantly to the photosphere and expand into the outer solar atmosphere. The interaction of these motions and fields is responsible for all the detailed structure that we observe (sunspots, coronal streamers, active regions) as well as the great variety of non-thermal phenomena that comprise solar activity. Convective motions also generate sound waves, gravity waves, and MHD waves, which can propagate outward and heat the solar atmosphere.

The interaction of magnetic fields and convective motions (“magneto-convection”) occurs on a broad range of temporal scales (seconds to months) and spatial scales (arcseconds to the solar radius). Such phenomena as solar flares, the solar wind, and many other solar cycle manifestations are products of this interaction. This broad subject forms one of the major research areas in solar physics and is a central concern in NSO’s long range plan.

Over the last two decades, NSO instruments have acquired a set of observations that provides a strong foundation for studies of the evolution of the surface features on time scales of minutes to that of a solar cycle and on spatial scales of around 2 arcsec to the full disk (the Sun as a star). These data are now being used to study with moderate spatial resolution, the detailed spatial and temporal comparison of photospheric magnetic fields and the corresponding absorption and emission structures observed in the photosphere and chromosphere. Work at NSO now involves the separation of several different components of magnetic activity (e.g., active regions, decaying active regions, and network), using masks derived from the NSO full-disk magnetograms, to determine the contributions of these different components to variations in solar irradiance and how these vary with time.

The continuation of synoptic observations at NSO in the future, especially when SOLIS is operational, will play a central role in developing an understanding of the physical mechanisms that drive solar activity and the resulting variations in solar irradiance, and in determining the effect of solar variability on the Earth’s environment.

The diachronic magnetogram data from the KPVT are an important existing tool for understanding how the irradiance signal is distributed across the surface of the Sun. Such groundbased data may help to settle a long-standing controversy about whether all irradiance variations arise from localized magneti-
cally associated features or whether other more global changes are involved. Since April 1992, additional thermodynamic information, strictly co-spatial and co-temporal with the magnetograms, has been obtained. The analysis of both archival and current data by NSO scientists (including NASA and SPRC staff) will be a major effort during the next decade.

• RISE/PSPT
High-precision measurements of continuum images yield important data on the diminution of the total irradiance by sunspots as well as the enhancement of this irradiance by faculae. Similar measurements in the core of the Ca II K line yield equally important data on the distribution and strength of plages and network in the chromosphere. These bright plages and weaker network contribute directly to the Sun's output in the UV and EUV regions of the spectrum. In large part these measurements describe the effects of emergence and evolution of magnetic flux in the solar photosphere on the Sun's irradiance. NSO, in collaboration with a consortium of scientists, has begun the RISE program (Radiative Inputs from the Sun to the Earth) to increase our knowledge in this important area. RISE has attracted—and depends on—separately-identified, incremental funding from the NSF. NSO is currently building two identical instruments (Precision Solar Photometric Telescopes), capable of 0.1% photometry of the continuum irradiance with a one-hour cadence. The instruments are designed around a 15-cm objective, a 2K x 2K pixel CCD, and fast frame-selection electronics. Full-disk surface photometry with 0.1% per pixel accuracy with a one-hour cadence will be obtained. In addition to their role in solving the solar irradiance puzzle, the PSPT data will satisfy a long-standing need for precision photometry in many other areas of solar physics.

• Convection
Two convective eddy sizes have been recognized for decades: the granulation, with typical sizes of 1500 km (2 arcsec), and the supergranulation, with sizes around 30,000 km and lifetimes of around a day. Only recently, advanced observing and analysis techniques (developed at NSO and at Lockheed Palo Alto Research Labs) have confirmed the existence of a third scale—the mesogranulation, with typical sizes of 7000 km. Theorists in the US and Denmark are engaged in modeling the dynamic behavior of the turbulent, compressible, radiating flows that are involved in stellar convection, using observations obtained at NSO and La Palma to guide their models. Certain numerical studies of convection predict the existence of a fourth scale of convective cells the size of roughly 300,000 km. Recent NSO studies of proper motions of the supergranule cells covering several days appear to confirm the existence of these giant cells with flow velocities of about 20 m/sec. Magnetograms, taken since 1975, have been studied extensively to analyze the surface flow fields, like meridional circulation, torsional oscillations, rotation, diffusion of fields, and the variation of these parameters over the solar cycle.

New data will help to improve kinematic models, which already give realistic representations of the time-evolution of solar granulation. In addition, three-dimensional simulations of solar convection, based on the hydrodynamic equations, have now reached a degree of realism that should allow quantitative comparison between theory and observations. NSO scientists plan to collaborate with scientists involved in the SOI instrument aboard the SOHO satellite in a three-year study of convection. The SOI will be capable of observing the evolution of granulation and its interaction with small-scale magnetic fields for several days with uniform spatial resolution of 1.2 arcseconds.

The interaction of convection and differential rotation in the outer layers of the convection zone generates a variety of vortical and shearing motions of intermediate spatial scales (10 arcseconds), which are relevant to the evolution of active regions but are only now beginning to be studied with the new tool of local correlation, which makes it possible to study flare buildup. In the quiet Sun,
such motions must participate in the redistribution of magnetic flux over the surface. NSO plans further studies of this important process.

Convection in the Sun has two important side effects. First, the turbulent motions produce sonic noise, which propagates into the overlying atmosphere, produces shock waves, and heats the low chromosphere. Gravity waves are also predicted above the convection zone, but their wavelengths are too short to be detected directly, except for their role in broadening photospheric line profiles. Recent work at NSO is directed at estimating the energy flux in such gravity waves from high spatial resolution observations of granulation. Second, convective motions transport magnetic fields that emerge from the solar interior. In the photosphere, these fields have kilogauss strength and occupy only a tiny fraction ($10^{-4}$) of the surface area, mainly between granules.

Hydrodynamic simulations of convection predict the existence of high-speed vortices that lie between emerging granules and that have diameters of 100 km at most. These vortices may play a crucial role in twisting the footpoints of coronal magnetic fields and thus heating the solar corona.

In order to study convective motions and magnetic fields on such small scales, NSO is developing several complementary approaches to enhancing image quality. An adaptive optics system for the Vacuum Tower Telescope at Sunspot is being developed in partnership with the US Air Force. This system is intended to correct the VTT image for distortions produced in the Earth’s atmosphere (“seeing”) and to deliver a diffraction-limited image (0.17 arcsec) for many hours a day. The program is expected to deliver a 20-element system in two to three years. Algorithms for image restoration and speckle are being applied and improved. Image selection techniques now allow diffraction-limited single images. Two-dimensional spectroscopy at video rates is now available and can freeze the solar image in moments of good seeing. In partnership with the Kiepenheuer Institute and Johns Hopkins University, NSO has developed a correlation tracker, which is now available at the VTT at Sunspot. These developments are expected to culminate in a superb facility for imaging and spectroscopy at 0.15 arcsec (100 km) resolution.

- **Small-Scale Magnetic Fields**
  In the quiet Sun, magnetic fields cluster at the borders of supergranule cells. Small bipoles constantly emerge inside the cells and drift to the borders, where they disappear or merge and reconnect with opposite polarities. This continuous dynamic process is basic to the dispersion of magnetic flux from active regions to high latitudes and ultimately controls the evolution of the large-scale fields, which impose structure on the corona. This process will continue to be a focus of studies by NSO scientists and visitors during the next five years.

  The interaction of small-scale magnetic fields in the quiet Sun sometimes produces He I 1083-nm dark points and X-ray bright points. Such events are most often associated with the removal of magnetic flux and the disappearance of small-scale (10-30 arcsec) bipolar magnetic structures. Research is now being conducted, in a collaborative study of X-ray bright points observed with the Yohkoh Soft X-ray Telescope, of He I 1083-nm dark points and the underlying photospheric magnetic field in order to understand the conditions and processes leading to the chromospheric and coronal response to changes in the photospheric magnetic field.

  The Advanced Stokes Polarimeter, a collaborative effort by the High Altitude Observatory and NSO, has been operating at the VTT at Sunspot for several years. It provides high-precision measurements of small-scale vector magnetic fields. During the next few years, it will be used for
studies of the structure of sunspots, the dynamics of spicules, MHD wave phenomena, and many other research programs.

The image-quality enhancement techniques described above (adaptive optics, correlation tracking, image selection and restoration) are vital for studying fundamental magnetic processes on their intrinsic physical scales. Another important component of NSO’s effort is the collaboration with space-based observations from the SOHO, TRACE (Transition Region and Coronal Explorer), and Solar-B missions. SOHO, launched in 1995, is a major European/US spacecraft that brings a powerful array of instruments to bear on the structure of the solar corona and its connections both inward to the photosphere and outward to the heliosphere and the Earth. TRACE (1997-1998) is a NASA mission that will overlap and augment SOHO by exploring the connections between fine-scale magnetic fields and hot plasma structures. Solar-B is a Japanese mission expected to fly around 2001. It will feature visible and soft X-ray imaging with high angular resolution.

The infrared portion of the solar spectrum offers important advantages for magnetic field measurements. To exploit these advantages, NSO (with support from NASA) has built a Near Infrared Magnetograph (NIM), which has been available to staff and visiting scientists at the McMath-Pierce telescope. The NIM has enabled us to study for the first time the spatial distribution of kilogauss flux tubes in solar plages. A second-generation NIM-2 is now complete (also with NASA support). The VTT at Sac Peak transmits infrared radiation to 2.5 microns, a range that includes the Zeeman-sensitive iron line at 1.56 microns. Recent studies by NSO scientists at the VTT have demonstrated the power of combining the high-resolution of the telescope with the sensitivity of the infrared line. NSO’s infrared magnetometers will become even more powerful over the next five years as infrared array technology advances.

- **Weak Magnetic Fields**
  The solar photosphere is penetrated by a turbulent magnetic field. The largest of these magnetic field elements are probably the so-called intra-network magnetic fields, whose morphology has been studied in the last two decades. As turbulent fields may be of considerable importance for the solar cycle, the physical parameters of these fields (field strength, temperature, etc.) need to be determined. The Zürich Imaging Stokes Polarimeter (ZIMPOL I) has been used at the McMath-Pierce facility to record spectra in circular and linear polarization of these weak fields. Measurements indicate that the strength of these fields is less than 500 Gauss. Investigations of the depolarizing properties of the Hanle effect suggest the field strength is even weaker, on the order of 50 Gauss. The temperature is significantly cooler than in plages and the network at the level of line formation.

  The role of these weak magnetic fields in the solar cycle is still unexplored because of the difficulty in observing them; however, theoretical studies at NSO and elsewhere have emphasized that they may play a key role in the magnetic cycle.

3. **Understanding the Coupling of the Surface and the Envelope: Transient Events**

Solar active regions are composed of low-lying magnetic arches and arcades in the vicinity of sunspots. These fields have their roots in the photosphere and are distorted by a variety of convective motions and horizontal shearing flows. The free energy stored in the field by these motions can ultimately discharge in a violent solar flare and coronal mass ejection, with major terrestrial effects. One of the major goals of solar physics is to understand, in detail, how this process of energy storage and release occurs. The
problem has many facets, ranging from the study of sub-arcsecond field footpoints to the study of persistent large-scale horizontal flows. NSO is bringing on-line new tools for this major effort.

A new instrument for high spatial and temporal resolution imaging of solar active regions and flares in the 1083-nm line of He I has been developed jointly by NSO and NASA/GSFC for use at the KPVT. The instrument is built around a conventional but cleverly packaged five-element Lyot filter. Ferroelectric liquid crystals modulate bandpass response and polarization at video rates. Subtracting accumulated observations in three possible pairs of filter transmission modes provides active-region imagery of 1083-nm equivalent width, line-of-sight velocity, or longitudinal magnetic field with time cadence of a few seconds. Nearly two decades of full-disk observations in the 1083-nm line at the KPVT show a wide range of solar phenomena such as coronal holes, filament channels associated with coronal mass ejections, long-duration flares, and analogues to X-ray bright points, which are otherwise viewed on the disk only from spacecraft. The filtergraph will provide a new view of transient phenomena in solar active regions with temporal and spatial resolution that cannot be obtained from the spectromagnetograph, where data images are built by scanning the telescope's solar image across a long entrance slit. The new data are particularly timely for comparisons with observations from the SOHO spacecraft which, in combination with recent developments in modeling the formation of neutral helium, promise to resolve long-standing controversies on how the formation of the line depends upon external EUV radiation from the corona and low-temperature transition region.

The solar corona is coupled to the photosphere by its magnetic field. According to current ideas, the power necessary to balance coronal radiative losses (and losses in the solar wind) originates in convective motions in and below the photosphere. A major goal in solar research is to understand how convection heats and shapes the corona via the magnetic field.

The earlier idea of acoustic heating by waves propagating from the photosphere has now been substantially discarded since propagation of these waves is inefficient and observed upper limits are insufficient to heat the corona. Processes related to the electric current dissipation or MHD wave generation and damping are now receiving more attention, but observations of small-scale dynamical phenomena are needed to support and offer further development of these ideas.

The horizontal convective motions and interactions of the small-scale magnetic fields in the photosphere twist and braid the magnetic field loops that extend into the corona. According to a plausible theory, the complex coronal field develops current sheets, in which free magnetic energy is released to heat the corona. One of the prime objectives for observational solar astronomers at this time is to test this idea. We might expect to observe transient, high-temperature fluctuations in the active-region corona, accompanied by turbulent high-speed flows. The initial volumes of these transient "nanoflares," may be very small, however, and difficult to detect. Vector magnetic field measurements in the photosphere, at subarcsecond spatial resolution, and fast imaging spectroscopy of the solar corona will be required. NSO is developing the equipment needed to pursue these crucial investigations.

Flow and condensation of the coronal plasma are known to exist above active regions and around prominences. Flows are particularly impressive in the case of post-flare loops, where rapid evolution is seen. Recent studies with the NSO coronagraph provide evidence for the reconnection of post-flare loops with the release of small quantities of energy. If this is a common phenomenon in the quiescent corona, as two staff scientists suggest, it may give support to the nanoflare heating process. Further studies of this important question will be performed.

High-speed solar wind streams originate in coronal "holes" (regions of depleted density). The mechanisms that accelerate coronal plasma to speeds as high as 800 km s\(^{-1}\) are not well understood. Some form
of MHD wave, generated low in the corona by convective motions in the photosphere, may be responsi-
able. To date, little convincing evidence for such waves has been found. Recently, however, the source of
coronal heating and wind acceleration has received attention by two of NSO's visiting scientists. They
have used the 40-cm coronagraph at the Evans facility to measure the height-dependence of the two
strongest forbidden coronal lines and find linewidth changes consistent with the deposition of Alfven
wave heating. They expect to continue these studies to sort out the various complications during the next
few years.

Small-scale explosive or impulsive events are believed to produce fast ejections that propagate along the
open magnetic field lines of a corona hole, producing the fast solar wind. At the 1991 total eclipse of the
Sun, such an event was detected for the first time with the 3.6-m Canada-France-Hawaii Telescope on
Mauna Kea by a team of NSO and French astronomers. Further searches for such minute ejections will
continue.

Of more practical relevance are the large-scale eruptions called coronal mass ejections (CMEs). These
occur once or twice per day at all phases of the solar cycle and involve the ejection, by magnetic forces,
of perhaps $10^{16}$ grams of plasma into interplanetary space. When such ejections interact with the Earth's
magnetic field, violent geomagnetic storms can occur, sometimes with devastating effects on power grids
and communications. NSO, in collaboration with the High Altitude Observatory, will continue to investi-
gate the origin of such events and the instability of the solar corona, with the ultimate aim of being able
to predict CMEs.

The high-resolution NSO magnetograms and He I 1083-nm spectroheliograms provide important data
related to the study of CMEs. The KPVT observations provide information about magnetic field configu-
rations and the evolution of the magnetic field that eventually leads to the occurrence of a CME.

One important type of event, the two-ribbon event, defines the large-scale, long-duration end of a wide
spectrum of flares and is more easily seen in He I 1083-nm, as a pair of dark ribbons, than in H-alpha.
Most of these events are located outside active regions, though the strongest occur in active regions, and
all follow the eruption of a filament or of a filament channel. Because of their high association with
CMEs (96%), our ability to identify these events provides an important tool in locating the probable
occurrence of CMEs that are likely to affect the Earth. The transient formation or expansion of adjacent
coronal holes is observed with many of these events, indicating a significant alteration of the magnetic
field configuration in the vicinity of these flares. Collaborative studies of the two-ribbon events seen in
He I 1083-nm with X-ray images from Yohkoh are currently being undertaken to investigate coronal
activity and changes in magnetic connections and configurations inferred from these data.

It is clear that better coronal and chromospheric observations are needed to attack many of the major
problems connected with the coupling of the surface and the envelope. Most of the physics seems to
reside in small volumes. To carry out detailed spectroscopic studies at high temporal and spatial resolu-
tion, observers will certainly need more photon flux. Conventional coronagraphs have been limited in
aperture by the difficulty of making near-perfect lenses. A new era in coronal studies has been opened by
the advent of super-polished mirrors. Now meter-class coronagraphs are feasible, providing more photons
in fully achromatic images, which can be used to investigate the fundamental physical processes. NSO, in
collaboration with the Institute of Astrophysics in Paris, is engaged in building such mirror coronagraphs
with USAF funding. Two prototypes have been completed successfully, and a third 55-cm instrument is
under consideration. When completed, it will produce a fast series of monochromatic images in the
principal optical spectrum lines of the corona. The spatial resolution of the 55-cm aperture instrument
will be limited only by the seeing and should be sufficient to permit studies of coronal fine structure at 2
arcsec scales.
The temperature and density structure of the solar corona varies systematically throughout the solar cycle as its magnetic topology changes. NSO scientists are using new IR detectors to examine several forbidden line ratios that are sensitive to electron density, at different temperature regimes. This diagnostic work is important for an understanding of the coupling of the solar surface and interior.

4. Exploring the Unknown

• The Infrared Frontier

Infrared observations offer unique advantages for probing the magnetic and thermal structure of the solar atmosphere. For example, because the ratio of the Zeeman splitting of a spectral line to its Doppler linewidth increases linearly with wavelength, it is possible in the infrared to measure the intrinsic strength and orientation of solar magnetic fields with a sensitivity that is difficult or impossible to achieve in the visible region. The discovery at NSO of Zeeman-sensitive emission lines near 12 micron and a sensitive Fe I absorption line near 1565 nm has made this possibility a reality.

Results from the Near Infrared Magnetograph (NIM) have demonstrated the existence of spatially coherent and correlated variations of field strength and area filling factor in plage regions. A collaboration with NASA Goddard Space Flight Center has been initiated to study the three-dimensional variation of field strength within individual magnetic structures by making simultaneous and co-spatial measurements with NIM and the GSFC Athena imaging 12-micron magnetograph.

Infrared observations at wavelengths shorter than 2.3 micron are being pursued at the Sac Peak VTT and ESF, including 1565-nm magnetometry with high angular resolution and imaging spectropolarimetry of the He I 1083-nm line. The 1083-nm line is also studied at the Kitt Peak Vacuum Telescope, where the spectromagnetograph recently discovered evidence for chromospheric outflows in coronal holes.

Other major diagnostic resources of the infrared spectrum include molecular band systems and the infrared continuum. For example, the vibration-rotation bands of carbon monoxide (CO) at 2.3 and 4.7 micron are a sensitive thermometer that is being used to probe temperature inhomogeneities in the upper photosphere and to test the validity of widely-used atmospheric models. The published results of this program are substantial and growing. A coordinated observing program with the ESA/NASA SOHO spacecraft has been accepted under the SOHO guest investigator program to study the relationship between temperature inhomogeneities revealed by CO and activity higher in the atmosphere revealed by ultraviolet emission lines.

The McMath-Pierce Telescope is particularly well-suited to infrared observations on the solar disk beyond 2.3 micron. Its all-reflecting optics provide high transmission, low scattering, and low instrumental polarization at all infrared wavelengths accessible to ground-based observation. Its large aperture is a major advantage both for potential angular resolution (0.25 arcsec at 1.6 micron) and for light-gathering power (the number of solar photons per Doppler linewidth is some 20 times smaller at 10 micron than at 0.5 micron). The scientific potential and emerging technical capabilities have stimulated broad interest in an enhanced solar infrared facility. A comprehensive approach to pushing back the infrared frontier is embodied in NSO's goal of a "flagship" large-aperture visible/IR telescope.
B. Instrumentation and Facilities Development at NSO

Milestones:

1999
• Continue construction of SOLIS
• Complete construction of and install GONG high-resolution camera
• Integrate 20 Zernike AO system in Sac Peak VTT. Start tests
• Operate RISE/PSPT network
• Possible redeployment of Sac Peak PSPT to Learmonth, Australia
• Complete phase A study of Flagship Solar Telescope
• Prepare proposal for Flagship Solar Telescope
• Explore national and international partnership(s) for Flagship Solar Telescope
• Review of Flagship Solar Telescope by NAS/NRC decade astronomy study

2000
• Complete SOLIS construction
• First light SOLIS
• Start observations with GONG high-resolution cameras
• Service runs and design of full-up AO system
• Go-ahead for construction of Flagship Solar Telescope
• Phase B study of Flagship Solar Telescope
• Select site for Flagship Solar Telescope

2001
• Regular SOLIS operations
• Propose for continued operation of RISE/PSPT network

2002
• Continue construction of Flagship Solar Telescope
• Complete phase C study of Flagship Solar Telescope. Start phase D (construction)

2003
• Continue construction of Flagship Solar Telescope

2006
• GONG observations of first eleven-year solar cycle completed

2007
• GONG data reduction first eleven-year solar cycle completed
• Full operation of the new NSO site, including Flagship Telescope and SOLIS

1. NSO’s Plans and Visions for the Future

NSO’s facilities and instrumentation plan for FY 1999-FY 2003 is part of an even broader plan that aims at a major renewal of the National Solar Observatory and a reinvigoration of groundbased solar research
in the US. This broader plan has been presented and discussed with the Space Studies Board Task Group on Groundbased Solar Research (the “Parker Committee”), which will view NSO’s plans in the context of the general health and needs of solar physics in the US. Its report and recommendations are expected to be available shortly (April/May 1998).

In its broader plan NSO aims at replacing its current quite old and somewhat outdated facilities with a few major, modern facilities which will incorporate major new scientific capabilities. NSO’s current vision of its future includes:

- The identification of an optimum observatory site for its future telescopes. Major criteria for its quality include low cloud cover, excellent seeing, and low sky scattering.

- The construction at that site of a large optical/infrared telescope referred to here as the “Flagship Telescope.” As minimum parameters for that telescope the NSO scientific staff sees a 300 cm aperture, full access to wavelengths in the range 0.3-30 microns, capable of coronal observations if technically and budgetarily feasible, and equipped with adaptive optics (initially built for 1.6 micron wavelength, later for visible wavelengths). Following the implementation of that facility at that new site, NSO would close down its operations at Kitt Peak and Sac Peak.

- The construction and operation of a suite of instruments enabling the study of the long-term variability of the Sun from its core to the outer solar atmosphere. With the acceptance and funding of the SOLIS proposal, the extension of the GONG operation to at least one solar cycle, and the deployment of the RISE/Precision Solar Photometric Telescope, this part of the vision is well underway toward becoming a reality. Although initially SOLIS will be located at NSO’s Kitt Peak site, it will be constructed to be movable with minimal effort to NSO’s new future site.

Many of the current efforts at NSO are directed at the pursuit of this vision. Among these are: (1) the development of a low-order, 20 Zernike adaptive optics program anticipated to be ready for tests at the end of FY 1999; (2) construction of the SOLIS facility to be in operation by FY 2001; (3) the identification and testing of premium solar observatory site(s); (4) the development of a camera to upgrade the GONG capabilities to allow local helioseismology; (5) the continuing development of NSO’s data archives; and (6) studies of the design and technologies of the large O/IR telescope. Details of these efforts are given below.

The realization of this vision will result in major changes to the present NSO environment. Most of these cannot be fully foreseen until both the new site and the properties of the new O/IR facility are defined. But obvious issues to be considered are: (1) What to do with the existing NSO sites and facilities? Restructuring towards public, educational, “science-recreational” use may be an option. (2) Where to locate the scientific and managerial offices of the “new NSO”? This is clearly directly dependent on site choice. Most consider easy access to the new site to be important. There appears to be general agreement that the resulting co-location of all NSO’s scientific staff is a major bonus of the new NSO implementation.

2. Planning the Flagship Solar Telescope(s)

NSO is planning a major solar observing facility with the goal of having a phase A definition study in hand to present to the next astronomy decade review. At that time we will be celebrating the 28th, 31st, 39th, and 46th anniversaries of NSO’s large facilities! They still have a lot of life in them, but if we are to solve many of the outstanding questions in solar physics and open up new areas in the observational...
parameter space so essential for new discoveries, NSO will need a state-of-the-art, broadly capable solar facility. The contrast with nighttime astronomy, which will see the construction of about 15 modern 8-m class telescopes in the 1990's, is startling.

A concept for a 4-meter aperture, all wavelength, low-scattered-light solar telescope is currently in a phase A class study by NSO. The acronym for this telescope is CLEAR, which stands for Coronagraph and Low Emissivity Astronomical Reflector, but the telescope would also provide high angular resolution, broad wavelength coverage, and high polarimetric accuracy. This technical and budgetary feasibility study is nearing completion. Parallel with this study, NSO is engaging in a dialogue with the solar physics community to explore the scientific opportunities which such a telescope presents. After community input is obtained, priorities will be set and choices will be made on the characteristics of the telescope, especially angular resolution/diameter, wavelength coverage, polarimetric characteristics, and coronagraphic/scattered light properties.

Parallel to the planning for this large O/IR solar facility, NSO is involved in a number of relevant technology development programs: (1) development of adaptive optics for solar applications; (2) testing of reflecting coronagraphs (USAF-supported program resulting in two completed prototypes and another one underway); and (3) evaluation of the observing qualities at potential solar observing sites. The latter program emphasizes seeing testing. Evaluation of daytime seeing conditions is underway for a number of existing observing sites (Big Bear, Kitt Peak, La Palma, Mauna Loa, Sac Peak, various lake sites). First results show that under appropriate observing conditions seeing can be as good at daytime observatories near lake sites as it is at the best nighttime observatories (like Mauna Kea), with the excellent image quality lasting most of the day.

3. SOLIS

SOLIS (Synoptic Optical Long-term Investigations of the Sun) is a project to make optical measurements of processes on the Sun, the study of which requires well calibrated, sustained observations over a long time period. Conceived in 1995, the project started in earnest in late January 1998 when initial funding was received. The design and construction effort will take three years with a 25-year operational phase scheduled to start at the end of 2000. A significant reduction in the scope of the project occurred when funding for SOLIS fell short of the proposal request. Presented with several unpleasant options, the SOLIS Science Advisory Group recommended eliminating the proposed Solar Coronal Imager. As a result, the coronal emission line program at NSO will continue using existing equipment and practices into the future. As part of the SOLIS proposal, NSO/NOAO committed itself to supporting approximately 10% of the SOLIS construction costs from its existing budget. Part of this commitment can be met by restructuring staff assignments and part by reducing maintenance of existing synoptic observing facilities (in anticipation of replacement by SOLIS), but other NSO projects will also be significantly constrained through FY 2000. When SOLIS becomes operational, NSO's superseded synoptic facilities will be retired.

The three instruments comprising the SOLIS measurement capability are: a vector spectromagnetograph for high-sensitivity full-disk measurements of the Sun's magnetic field, a full-disk imager for high-fidelity spectral images of solar disk activity, and a solar spectrometer for accurate measurements of spectral line profiles of the Sun as a star. These measurements will be processed by state-of-the-art data handling systems and reduced results will be promptly available over the Internet. Off-site users will be able to schedule particular observations to support their research programs. The major scientific result of SOLIS will be an improved understanding of how and why stars like the Sun produce activity, and how this activity affects human endeavors. SOLIS will operate in concert with other observational projects, both
in space and on the ground. In particular, NASA's future High Energy Solar Spectroscopic Imager project (to be launched at about the time of SOLIS first light) is counting on SOLIS measurements.

A proposal from the High Altitude Observatory of NCAR has recently been submitted to NSF that includes funding for two additional vector spectromagnetographs. These would be located at widely different longitudes to obtain nearly continuous time coverage. One well known European solar site has tentatively offered its services. If the NCAR proposal is successful, NSO would help build and install the additional instruments on a cost recovery basis.

4. Global Oscillation Network Group (GONG) Project

The Global Oscillation Network Group (GONG) is a community-based international project studying the internal structure and dynamics of the closest star by measuring resonating waves that penetrate throughout the solar interior—a technique known as helioseismology. To overcome the limitations imposed by the day-night cycle at a single observatory, GONG has constructed a six-station network of sensitive and stable solar velocity mappers located around the Earth that is obtaining nearly continuous observations of the "five-minute" oscillations, as well as direct measurements of the "steady" motions of the solar surface itself. GONG has also established a distributed data reduction and analysis system to facilitate coordinated analysis of these data by the community. The primary analysis is being carried out by half a dozen science teams, each focusing on a specific category of problems. Membership in these teams is open to all qualified researchers; there are currently 163 members, representing 70 different institutions.

The full GONG network became operational in October 1995, and the performance has met the project's objectives both operationally and scientifically. Processing of the data and its distribution to the community have been able to keep up with the data flow, and refinement of the algorithms is proceeding now that the network data are available.

It has now been established, beyond a shadow of a doubt, that the solar resonant oscillations which GONG has undertaken to study vary significantly over the solar cycle. These solar activity-related frequency variations contribute both noise and signal. On one hand, the influence of the variations must be removed to achieve the ultimate potential of the solar interior inversions. On the other, these variations represent one of the largest potential advances for understanding the time-variable Sun. We plan to operate the GONG network for a solar cycle to achieve its full potential and to advance our understanding of the mechanism of the solar variability.

In order to achieve the scientific potential of the network for studies of time-distance helioseismology, as well as probing closer to the visible surface, we plan to replace the existing 256 × 256 cameras with 1024 × 1024 cameras as quickly as possible. This can be accomplished by changing only the camera and its associated electronics, without any significant optical or mechanical modifications. This detector upgrade will support the systematic study of the variation of the solar interior over the solar cycle. This development will also provide continuous surface velocity and magnetic field measurements, which will support other important scientific objectives. NSO will continue to involve the scientific community in all of the technical and scientific decisions in the development of the replacement detector system.

The cost of continued operation of the GONG network is included within the current NOAO budget. Support for the new cameras will be requested from the NSF through a special proposal. The cost of these two activities is shown separately in the following table.
Table IV-1
Camera Upgrade
($ in Millions)

<table>
<thead>
<tr>
<th>Plan Year</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
<th>2001</th>
<th>2003</th>
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<tr>
<td>Base Budget</td>
<td>1.85</td>
<td>1.90</td>
<td>2.22</td>
<td>2.29</td>
<td>2.36</td>
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<tr>
<td>New Cameras</td>
<td>1.01</td>
<td>.62</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Annual Total</td>
<td>$2.86</td>
<td>$2.52</td>
<td>$2.22</td>
<td>$2.29</td>
<td>$2.36</td>
</tr>
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</table>

The increase in operating costs after the new camera is completed reflects the factor of 16 increase in the data flow. We believe that with continuing improvements in the price/performance of modern computing systems, we can keep the increase in annual operating costs to $300K. The increase is largely in the area of data storage media and in processing, with some additional operating costs for sparing and maintenance of the increased on-site image storage electronics.

5. Image Quality Improvement Program for NSO Telescopes

Major progress has been made in the last few years in improving the image quality of NSO’s highest angular resolution telescope, the Sac Peak Vacuum Tower telescope. This is a result of a systematic program aimed at achieving diffraction-limited imaging with that telescope. This program has successfully completed a number of components:

- Improving the optical quality of the telescope’s entrance window by active thermal control.
- Improving the optical quality of the alt-azimuth flat mirrors.
- Installing a rapid tip/tilt system relying on correlation tracking to locate the solar image with the required accuracy.
- Applying image selection techniques in combination with the correlation tracker to select the moments of best atmospheric seeing for the observations.
- Developing a wavefront sensing system and applying it initially with a low temporal bandwidth to an adaptive mirror to correct the residual telescope aberrations (so-called “active optics”).
- Speeding this system up, using parallel processing, to achieve a full-up adaptive optics system capable of correcting atmospheric seeing.

At this moment all steps of this program have been successfully implemented except for the speeding up to achieve full adaptive optics performance. Doing the latter is one of our highest priority programs for the next year. Hardware has been purchased and is currently being integrated into a system to accomplish that. Given sufficient funding, we expect a full-up 20 Zernike adaptive optics system to be functioning in two years.

Because of the improvements already achieved, NSO has now obtained the highest angular resolution images of the Sun ever achieved.

Adaptive Optics is, of course, a central component of our plans for a large O/IR solar facility, so that this program is essential technology development towards that telescope.
This program is supported as part of the NSO annual budget with significant additional financial and personnel support by the USAF Phillips Lab branch residing at Sac Peak.

6. Radiative Inputs of the Sun to Earth (RISE/PSPT)

Measuring and understanding the Sun's variability constitutes one of the most important problems in solar and solar-terrestrial research. Proposed in 1990, RISE is a systematic program of research to increase our knowledge of solar irradiance variations and their effect on global change.

An important part of the overall RISE plan calls for the design, construction, deployment, and operation of precision solar photometric telescopes (PSPTs) that will work together to provide a reliable daily (and higher cadence, as weather permits) record of solar surface-brightness variations. These telescopes will define state-of-the-art precision for groundbased solar differential photometry. A proposal by NSO and the RISE Scientific Advisory Committee to construct two PSPTs was accepted by the NSF (ATM) in 1992. The scientific objectives of the RISE program call for this PSPT network to be operational for at least three years.

Each PSPT will be a small, low-scattered-light refracting telescope consisting of a 15-cm doublet, a fast guider, a 0.3-nm Call K-line filter (and several additional filters for continuum observations at other wavelengths), and a 2048 x 2048 CCD camera. The enclosed telescope package will be equatorially mounted and computer controlled. Each instrument will achieve photometric precision approaching 0.1% per pixel across the full 2048 x 2048 pixel array in continuum wavelength bands extending from the green to near IR wavelengths. Image data of this quality will elucidate the cause of the small irradiance variations that are seen in satellite observations of integrated sunlight. The daily observations and occasional campaigns of higher-cadence time-series data will allow new studies of the transport properties of the upper convection zone in the presence of photospheric magnetic fields.

The Rome PSPT telescope now generates full-disk photometric data on a daily basis. A second PSPT has recently begun operation from Mauna Loa and is jointly operated by the National Solar Observatory and the High Altitude Observatory. These instruments, plus a developmental telescope at NSO/SP, will provide the RISE community with the highest precision high-resolution solar photometric data.

The PSPT is jointly funded by the MPS/AST and GEO/ATM division of NSF.

C. Instrumentation

Milestones for the Active and Adaptive Optics Program:


FY 1999: System integration [SH-WFS, reconstructor (Phillips Lab), Xinetics DM] and tests at VTT/SP.

FY 2000: Science runs and design of full-up AO system.

The instrumentation program given in this section and the planned upgrades in the next section assume level funding over the next five years. Some of the programs are therefore very limited in scope. Table IV-2 summarizes the instrumentation and upgrades program.
<table>
<thead>
<tr>
<th>Table IV-2</th>
<th>NSO FIVE-YEAR INSTRUMENTATION PLAN SUMMARY</th>
</tr>
</thead>
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<tr>
<td></td>
<td>(months)</td>
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<tr>
<td>Image Quality Improvement, Sac Peak</td>
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</tr>
<tr>
<td>Adaptive Optics*</td>
<td>Dunn/Rimmele</td>
</tr>
<tr>
<td>Detector Improvement, Sac Peak</td>
<td></td>
</tr>
<tr>
<td>CCD Upgrade</td>
<td>Hegwer/Stauffer</td>
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<tr>
<td>SOLIS, Sac Peak</td>
<td>Harvey/Keil</td>
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<tr>
<td>Instrumentation Strategic Plan, Sac Peak</td>
<td>TBD</td>
</tr>
<tr>
<td>Sac Peak Subtotal</td>
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</tr>
<tr>
<td>Infrared Program, Kitt Peak</td>
<td></td>
</tr>
<tr>
<td>Large-format array and controller</td>
<td>Rabin</td>
</tr>
<tr>
<td>8-12 um array*</td>
<td>Rabin</td>
</tr>
<tr>
<td>Telescope Improvement, Kitt Peak</td>
<td></td>
</tr>
<tr>
<td>SOLIS</td>
<td>Harvey</td>
</tr>
<tr>
<td>McMath-Pierce Telescope Control</td>
<td>Keller/Keil</td>
</tr>
<tr>
<td>Image Quality Improvement, Kitt Peak</td>
<td></td>
</tr>
<tr>
<td>McMath-Pierce Seeing</td>
<td>Keller</td>
</tr>
<tr>
<td>McMath-Pierce Guider</td>
<td>Keller</td>
</tr>
<tr>
<td>Correlation Tracker</td>
<td>Rabin/Rimmele</td>
</tr>
<tr>
<td>Detector Improvement, Kitt Peak</td>
<td></td>
</tr>
<tr>
<td>Fast CCD Imager</td>
<td>Keller</td>
</tr>
<tr>
<td>Spectral Hole-Burning Device*</td>
<td>Keller</td>
</tr>
<tr>
<td>Imaging FTS*, Kitt Peak</td>
<td>Hill</td>
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<tr>
<td>Kitt Peak Subtotal</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
</tr>
</tbody>
</table>

*Supported in part by NSO partners
+Requires additional incremental funding (NSF, USAF, NASA, etc.)
1. Active and Adaptive Optics

Observations of highest resolution are extremely important to address fundamental scientific questions in solar astronomy [e.g., coronal heating, the physics of fundamental magnetic elements (flux tubes), and magnetoconvection]. Substantial progress could be made in these areas if existing telescopes like the VTT/SP were equipped with an adaptive optics (AO) system providing diffraction-limited resolution over an extended period of time. It is also widely acknowledged that any new large aperture, ground-based telescope will need AO to be an effective tool for high-resolution solar astronomy.

NSO/SP is developing an AO system to be deployed as a user system at the VTT/SP. An AO system consists of three major components: a wavefront sensor that measures the wavefront aberrations introduced by atmospheric turbulence, a reconstructor that converts the wavefront measurements into drive signals for the deformable mirror, which is the third component and compensates the wavefront errors. Deformable mirrors and reconstructors are now commercially available or can be cloned from nighttime AO systems.

The critical challenge facing the Adaptive Optics program at NSO/SP is developing a solar wavefront sensor. Solar wavefront sensing is difficult because point source sensing targets are never available everywhere on the solar disk. Most nighttime AO systems use Shack-Hartmann wavefront sensors (SH-WFS), in which a point source target (natural or laser beacon) is imaged through an array of subapertures. The displacement of each subaperture image with respect to a reference is proportional to the wavefront slope within that subaperture. Displacements can be measured by simple center-of-gravity algorithms or quad-cell devices. However, tractable sensing targets such as small sunspots or pores are scarce on the Sun, and laser beacons are not bright enough to provide practical substitutes.

In general, solar wavefront sensing has to be performed using the granulation, an extended, low contrast and evolving structure, as its sensing target.

Two wavefront sensing approaches are currently under consideration at NSO/SP: (1) a modified Shack-Hartmann wavefront sensor that employs cross-correlation techniques to measure the displacements of granulation images formed by a subaperture array; and (2) a spatial filtering approach that uses a mask placed in an image plane to modify the light in a way that makes wavefront gradients visible as intensity fluctuations in a pupil plane.

The latter technique can be understood as a generalization of the classic Foucault knife edge test, in which the “mask” is a straight edge placed over image of a point source. Typically the partial derivatives of the target structure are mapped in binary form on a transmissive liquid crystal screen, which is placed in an image plane. A small, fast CCD records the wavefront information in a pupil plane.

There are advantages and disadvantages to both approaches. Shack-Hartmann wavefront sensors are widely used in nighttime AO, and are comparatively well understood. The low (order 2%) contrast of the granulation image formed by a small subaperture is not a problem. The Mark II correlation tracker recently completed at Sac Peak has successfully demonstrated its ability to stabilize the granulation image formed by a 7-cm subaperture—i.e., a single channel of a correlating solar SH-WFS has been implemented in hardware. To gain a more detailed understanding of the SH-WFS approach, we have also recorded simultaneous SH-WFS data and granulation images. The measured instantaneous wavefronts are being used to deconvolve a time sequence of granulation images. Results show that the SH-WFS provides phase information with the required accuracy.
We also have used a SH-WFS to test the concept of an active optics system operating at the VTT/SP. The active optics system is intended to correct aberrations in the VTT optics and also serves as a stepping stone towards a full AO system. A Xinetics 97 actuator deformable mirror (DM) was purchased using year-end funds provided by the Air Force Phillips Lab and NSO. The 97-channel DM, which has sufficient bandwidth to be used in an atmospheric compensation system, was implemented in the active optics system and tested at the VTT. The loop was closed and the capability of the system to measure and correct optical aberrations introduced, for example, by the entrance window of the VTT was successfully demonstrated.

In principle, the “LCD Knife-Edge” approach offers an elegant and inexpensive solution to wavefront sensing, since much of processing is performed optically rather than digitally. However, several engineering runs at the VTT/SP showed that the Signal-to-Noise ratios achieved by the “LCD Knife-Edge” wavefront sensor are insufficient and prevent its use in practice. Given our vast experience with the SH-WFS approach, we decided to implement an AO system based on the SH-WFS.

A SH-WFS for a solar AO system operating on granulation requires the implementation of high-speed cross-correlation algorithms. Although the hardware needed to do this is now commercially available, the bandwidth requirements point to a massively parallel system. We estimate the cost of a full-up AO system with 80-100 channels to be of order $1M+. At this point, we are confident enough to contemplate proposing to the NSF and other sponsors implementation of a full-up AO system. In the meantime, we will pursue the implementation of a low order AO system as the logical next stepping stone toward the full-up AO. A low order system would significantly improve the capabilities of VTT, produce new science, and thus support the proposal for the full-up AO system.

Provided the low order system has sufficient bandwidth (> 100 Hz) to correct on the order of 20 Zernike modes, the Strehl ratio will be as follows:

\[
\begin{align*}
\text{~0.6 for } r_0 = 15 \text{ cm (good-excellent seeing); } \\
\text{~0.5 for } r_0 = 10 \text{ cm (good seeing); } \\
\text{~0.1 for } r_0 = 5 \text{ cm (medium-bad seeing).}
\end{align*}
\]

This means the system will deliver satisfactory results only in good seeing conditions in the visible. However, in the near infrared the system will deliver diffraction-limited imagery at the VTT/SP with even unexceptional seeing.

2. Mark II Correlation Tracker

The development of the Mark II correlation tracker has been completed, and the system is now operational at the VTT/SP. Compared to the Mark I CT, the Mark II CT has improved performance, in particular a higher servo bandwidth (60 Hz) and a capability to track low contrast granulation images during moments of bad seeing. We are considering cloning the CT system to provide tip/tilt correction at the McMath telescope. Also the Big Bear Solar Observatory has expressed interest in getting a copy of the Mark II CT.

3. CCD Cameras

For over a decade, NSO/SP has been relying on the Multiple Diode Array (MDA) system as its main data acquisition system. The MDA system was custom developed at NSO/SP. Although state-of-the-art at the time, this RCA CCD-based system is now outdated. NSO/SP is upgrading its CCD detectors with the goal of replacing the MDAs by state-of-the-art, large format, fast-readout CCD systems. Where possible,
commercially available systems will be implemented. In-house development efforts will be kept to the necessary minimum.

New CCD systems currently available to the users are:

- Thomson 1K x 1K, fast read-out (10 Mpix/sec), 10-bit resolution, 4-5 frames/sec.
- Kodak Megaplus 1500 x 1024 pixels, fast read-out (10Mhz), 10-bit resolution, 5 frames/sec.
- XEDAR 2K x 2K (developed by XEDAR INC. for the RISE project). Fast read-out [8 Mpix/sec (multiplexed mode), 16Mpix/sec max, 4-quadrant], 2 frames/sec, high dynamic range (30e read noise, 12-bit resolution), low dark current [thermoelectric cooling (-30C)], MPP mode, Lumigen coated.
- 512K x 512K, back-illuminated, blue-sensitive CCD (40-50% QE @ Ca-K) for K-line.

Features of the new CCD systems include frame selection and on-the-fly co-adding of images. Each CCD detector has its own data acquisition, i.e., parallel datastream from multiple cameras.

NSO/SP received nine 1K x 1K Photometries cameras from the Air Force. The cameras have back-illuminated CCD chips with high QE and are read out at 1Mhz. The cameras need minor modifications but will be very useful for many solar applications.

Driven by user requests, in the near future we plan to add the following CCD systems:

- One to two additional XEDAR 2K x 2K cameras.
- Two to three 1024 x 300 spectroscopic CCDs, for Horizontal and Echelle spectrograph observations.

4. Infrared Cameras

To realize their full potential for infrared solar astronomy, NSO's major telescopes must be mated to modern infrared cameras and data systems. NSO will participate in an NOAO-wide initiative to incorporate 512 x 512 or larger infrared arrays in astronomical instruments.

In typical solar applications, low-noise infrared arrays saturate in a fraction of a second. To build up the signal-to-noise ratios that will often be required, it is necessary to average many frames of data at each spectral/spatial location. Thus, NSO needs data systems with real time processing. There is a similar requirement in nighttime work, so the effort is again NOAO-wide.

Because much of the infrared work at the McMath-Pierce Telescope is at wavelengths longer than 2.5 microns, NSO/KP has asked NOAO to supply one or more ALADDIN (1-5 microns) arrays from the joint NOAO/USNO development effort, and NSO/KP has reserved internal funds for an NOAO-developed ALADDIN array controller.

At NSO/SP, IR observing accounts for approximately 25% of all allocated telescope time at the ESF and VTT. It is necessary to develop a better infrastructure to satisfy the needs of the unique aspects of its IR capabilities. Resources required are a liquid crystal polarizer, leak detector system, new detectors, and a tunable filter. These will provide the basic tools for coronal spectroscopy and high-resolution magnetometry out to 2.5 microns. Our long range goals include the development of new IR arrays based on HgCdTe materials. Continued progress in upgrading the existing near-IR camera systems with larger format array detectors will be needed. The current SP/IR program has been limited by the availability of
our shared cameras. The HgCdTe arrays were jointly developed with MSU and the Wyoming Infrared Observatory and are available to the NSO/SP user community for only a fraction of the year.

D. Facilities/Infrastructure Upgrades

1. Evans Solar Facility Instrument Upgrades

The new ESF control system is in place. We now plan to complete the automation started in the 1980’s, which will improve the data quality and allow the observers to make observations with a minimal amount of daily setup and interaction. This is especially important because of the reduced observing staff size. The data quality will improve because, e.g., settable parameters can always be set the same way, and instrument stability will be improved. Also, maintenance will be easier and less time consuming on an upgraded system.

Anticipated upgrades in FY 1998-FY 2000 are as follows:

- Replace the relay racks with solid state relays.
- Upgrade the coronagraph aperture select, coronal lens select, dustcap, and fan control to allow for computer control.
- Upgrade the air lines and air pressure system.
- Add coronagraph fast mirror guider.
- Add sky brightness monitor.
- Add coelostat guider.
- Add linear arrays on the Spectroheliograph to replace film.
- Add linear array detector for the LSG.
- Automate the Littrow Spectrograph.

2. Replacement of KPVT with SOLIS

As described earlier above, SOLIS will replace the aging KPVT with a state-of-the-art automated facility.

3. McMath-Pierce Guider

The McMath-Pierce facility consists of three large telescopes that are used for a variety of observations. Currently, there is no permanent guiding system available at the McMath-Pierce facility. The lack of a permanent guiding system is one of the major drawbacks of the telescope, in particular for collaborative efforts where accurate positions on the solar disk are important. A guiding system that is computer controlled and that is available all the time is an indispensable part of a modern telescope.

4. McMath-Pierce Telescope Control System Upgrade

The McMath-Pierce is the largest solar telescope in the world. Upgrades to the telescope control system are needed to ensure that the facility remains competitive and maintainable. The proposed upgrades will take advantage of existing engineering experience within NOAO, as well as the experience gained in the SOLIS project.
The proposed control system will allow accurate pointing, tracking, guiding, and scanning of the main and East Auxiliary telescopes at any coordinate on the solar disk. This capability is particularly needed for collaborative efforts with other ground- and space-based solar telescopes.
V. SCIENTIFIC STAFF

A. The Role of the Scientific Staff

The quality and capability of the scientific staff is the single most important determinant of the quality of the programs supported by NOAO. It is the scientific staff that takes primary responsibility for defining the future directions of the observatories; the users play a significant role in shaping those directions, but usually by making suggestions to proposed plans rather than developing the plans ab initio. Through internal committees the scientific staff is responsible for ensuring that the priorities within the observatory are consistent with the long-term scientific goals. A scientist is associated with every major program within the observatory, either as line manager or as project, instrument, or telescope scientist, who must co-sign with the manager for any significant expenditures or changes in science performance requirements. The scientific staff have served in effect as systems engineers for instruments and telescope upgrade projects. They are responsible for commissioning instruments, ensuring that the data meet science requirements, and providing manuals. NOAO scientists serve as the interface to the community, giving advice on the best approach toward addressing specific scientific problems with NOAO instruments, assisting with the preparation of observing proposals, and helping to support observing runs.

Because the functional responsibilities are central to their roles, all NOAO scientific staff are required to carry out service to the community.

The staff also carry out scientific research at a very high level. In fact, research and service are inseparable. The quality of service that NOAO has traditionally provided can be maintained only by scientists who are intent on pushing the limits of instrumentation for their own scientific programs.

B. Emeritus Staff

NOAO offers an excellent emeritus program. Astronomers with emeritus status retain the same access to research equipment and support (travel, page charges) as the salaried staff. This policy allows emeritus staff to continue to participate actively in research and the intellectual life of the observatory but allows the directors of the divisions in which the emeritus positions are held to exercise judgment about the allocation of scarce resources. All but two (about 85%) of the most senior staff have accepted some form of emeritus status. All of the “retired” staff still come to work regularly, and most continue not only to conduct research but also to carry out some functional responsibilities.

C. Recruitment

Because the quality of scientific staff is inextricably linked with the quality of the program carried out at NOAO, it is essential that NOAO be able to recruit astronomers of the highest caliber. In the past, NOAO, and most particularly KPNO, has been able to compete effectively with the best university departments. There are clear advantages to being at NOAO. The scientific environment is excellent, with frequent interactions with a large number of astronomers either on the staff or visiting the observatory; the facilities for acquiring and reducing data are competitive with the best in the world; the technical capability for building facility class instruments is outstanding; since staff are ineligible for NSF grants, a minimum amount of time is spent writing proposals for support of research; and some staff truly do enjoy being at an organization where there is an opportunity to enable distinguished research by the user community.

There is evidence, however, that NOAO positions are becoming less attractive relative to those offered by major research universities. Negative factors include:
The increased functional load, which has reduced the time available for research by tenured and tenure track staff to 25% or less. The reasons for the increased functional load include past downsizing (a factor of 2 in the size of the nighttime staff in Tucson, with smaller changes at the other observatories); increased program scope, including Gemini support, WIYN, SOAR, GONG, and SOLIS; and increasing complexity of instrumentation and of data sets. Given the current stresses on the scientific staff, NOAO does not intend further downsizing of the scientific staff and will fill all vacancies when they occur. (An analysis of what size staff is required can be found volume 1 of the recent proposal to renew the cooperative agreement under which NOAO operates.)

Limited support for research. By NSF policy, NOAO staff cannot seek support for individual research projects from the NSF, and the observatory provides support only for page charges, travel, and data reduction facilities. Staff have no post docs, graduate students, or assistants to help with their ground based research.

No guaranteed access to “big glass.”

An uncertain future because of repeated downsizing now coupled with the NSF’s proposed competition for the management of NOAO with no ground rules for how staff will be treated should new management be selected.

Salaries, which surveys show to be 15-20% below the averages at the AURA member institutions.

Most of these problems can be corrected only by a greater investment of funds into staff research. It is essentially impossible, however, to redirect funds in this way at the same time as observing opportunities for the community are being reduced for budgetary reasons. Failing an increase in direct support of in-house research, commitment to a clearly defined and stable future for NOAO on the part of the NSF would be the single biggest asset in recruiting and retaining scientific staff.

D. Post Tenure Review

One of the projects that will be completed during the first two years covered by this five year plan is the implementation of a policy for post tenure review. AURA will shortly adopt a policy calling for such review by each of the centers. The NOAO scientific staff has proposed to the directors a plan for post tenure review, which is designed to “advance institutional and individual effectiveness by creating a shared understanding, between each scientist and NOAO management, of NOAO’s requirements and its peer-developed standards of performance as they apply to a scientist’s individual circumstances.” Implementation of the staff proposal will require development of criteria for satisfactory performance; regular reviews by the directors; creation of professional development plans; procedures for working with staff who receive unsatisfactory reviews; and definition of an appeals procedure.
VI. NOAO SUPPORTING SERVICE

A. Computer Support

Milestones:
- December 1998: Release of Open IRAF, phase 2
- October 1999: Completion of ATM link between La Serena and Cerro Tololo
- December 1999: Release of Open IRAF, phase 3
- January 2000: 100 Mbps Fast Ethernet extended to every NOAO-Tucson scientist's desktop
- October 2000: Extension of ATM link to Cerro Pachon
- October 2002: Establishment of ATM link between CTIO and Tucson

1. Save-the-Bits

The Save-the-Bits Project provides a mechanism to archive all data from the NOAO nighttime telescopes. The system has been in use at KPNO for several years, and was recently implemented at CTIO as well. Data from the McMath nighttime program and from the WIYN Observatory have also been routinely archived as part of Save-the-Bits. The WIYN Telescope Board recently approved and funded a CD-ROM-based upgrade that will serve as the primary data distribution mechanism for the telescope, in addition to its archival functions. Save-the-Bits has also been adopted by other observatories, including Keck, Lick, and the CFHT.

At NOAO, Save-the-Bits data are currently stored on Exabyte tapes. Two copies of all data are written and stored at different locations. The Save-the-Bits archive provides the primary back-up for observers' data. The volume of NOAO data archived is now 3.4 terabytes, and more than 1.3 million science images have been saved. In addition to providing new copies of data lost to media failures, the Save-the-Bits Archive is also used to collect data obtained by different observers monitoring particular objects. For example, an astronomer in Hawaii is conducting a long-term campaign to study comets and asteroids. Save-the-Bits is also used for special, intensive observing programs such as the SONG observations of Procyon.

During the five-year plan period, we expect that Digital Versatile Disk (DVD) technology will become mature enough to replace Exabyte tapes as the storage medium for Save-the-Bits data. A project to copy the existing collection of data on Exabyte tapes to DVDs would then be undertaken. DVDs are preferable to Exabyte tapes because DVD media have a longer lifetime than Exabyte tapes and DVDs are random accessible which vastly speeds access to the date.

In the long term, an archive's real value is only achieved when its data are accessible for new scientific programs. It is the goal of Save-the-Bits to adapt existing and successful user interfaces, such as those demonstrated by STScI and by the CADC, to make the NOAO data available to the community. Data from the existing NOAO nighttime programs will provide a path for the development of NOAO services for the archive of Gemini data for the US community.

2. Downtown Tucson Computer Support

The computer facilities run by CCS in the Tucson office complex serve three general needs for NOAO-Tucson: data reduction and analysis for the scientific staff and visitors, general computing for all staff members, and IRAF development and support. Our distributed computing strategy for Tucson implements a combination of central, shared facilities and a variety of desktop facilities, including workstations, X-
terminals, and personal computers. Computing systems are linked with a set of Ethernets transmitted by wire in Tucson, optical fiber on Kitt Peak, and leased-line between Tucson and Kitt Peak. (Work stations for individual staff members are funded by the division or unit to which they are assigned.)

In FY 1999 we will continue an extensive improvement program to our central computing facilities, replacing older high-maintenance systems with modern low-maintenance ones, concurrently achieving a major upgrade of capabilities. In subsequent years, we will continue our program of upgrades for increased performance with reduced maintenance and operating costs. In general, the lifetime of a computer or peripheral is four to five years.

Thus, in FY 1999 we plan to replace our general timesharing machine, Orion, and our printer control machine, Solitaire. In FY 2000 and FY 2001 we will replace the server for the Science Workstation Network, Gemini and the X-terminal server, BigX. In FY 2001 and FY 2002 we will restart the cycle and replace our “fast” machine, Ursa (which was replaced in FY 1996) and in FY 2002 we will replace our IRAF development machine, Tucana, our Web server, WWW, and our Email server, NOAO, which were all replaced in FY 1997.

We also plan to continue our ongoing projects to restructure the network infrastructure in the downtown NOAO office complex to provide multiple 100 Mbps network connections in each office, tie all these connections into an efficient building network, provide effective facilities for staff members to utilize our computer systems from home or while traveling, and provide adequate connectivity to the worldwide Internet.

A staff of approximately five FTE maintains the downtown computer facilities (approximately 100 machines including desktop workstations and approximately 200 personal computers), supports the network, and provides support to users (both staff and visitors).

3. IRAF

IRAF (the NOAO Image Reduction and Analysis Facility) is a portable software system used for astronomical data reduction and analysis, general image processing and graphics, and astronomical software development. The IRAF software, first released over a decade ago, is now in constant use within the NOAO observatories, at over a thousand sites in the world astronomical community, and within the NASA astrophysics community.

Approximately seven FTE programmers work on IRAF systems software and scientific applications and on providing support to the IRAF community. Continuing effort is required to keep IRAF current with the ever-changing world of computing and to accommodate the ever-changing data acquisition, reduction, and analysis needs of NOAO (current projects include a new data handling system for large CCD and IR arrays such as the NOAO mosaic-CCD imager, a real-time image display system for use with the Mosaic and other instruments, and a new IRAF release which includes expanded support for running IRAF on Personal Computers).

The IRAF group has begun a large new effort, supported with funds from NASA's Astrophysics Data Program, in collaboration with STScI, SAO and EUVE. Called “Open IRAF,” the goals of this effort are to:

- Make it easier for non-experts to develop applications in the IRAF environment
- Make it easier to use pieces of IRAF independently, outside of the IRAF system
• Make it possible to use pieces of IRAF with non-IRAF software

• Extend support for additional, popular image formats

• Make it easier for others to enhance or extend the IRAF system software

An additional effort funded by NASA's Applied Information Systems Research program will improve the IRAF data visualization facilities and graphics user interface (GUI). This effort is a collaboration with SAO.

The objective of these efforts is to bring the system framework of the 10 year old IRAF system up to date, while preserving our large investment in IRAF-based science applications software and expertise (currently estimated at well over 100 man-years). The new system framework will be based on modern distributed object technology and will be highly modular, allowing outside groups and scientists to more easily extend the system. The existing IRAF science applications will be migrated to this new framework with what we hope are minor changes. We are working with the NRAO AIPS++ group, IDL users, the FITS committees, and others in the community to develop standards to increase interoperability and potentially allow some parts of the new system to be shared. The scope of this effort is 5-7 years, although much of the framework is expected to be developed within the next several years.

Plans for acquisition of new computer systems are summarized below. Only the funds for the NOAO/Tucson portion of the program are funded out of CCS. The other portions are funded from the divisional budgets. In addition, individual workstations are purchased as required. To meet the needs for wider field imaging, the major instrument produced within the IPG will be a pair of imagers that will ultimately address 2K × 2K near-IR detectors. Those imagers will be used on both the new 2.4-m imaging telescopes. They are listed in Table III-1 as WFOV IR imager, and are scheduled to be commissioned in FY 2001 and 2002. The deployment of those imagers is part of the integrated plan in supporting both observatories and Gemini.

The last IR instrument in queue will expand the capabilities of the WIYN multi-object spectrograph. The long-term plan is to provide near-IR recording capability for the multi-fiber output of the WIYN Hydra positioner. Such a configuration would be unique in covering a large area of sky spectroscopically at wavelengths between 1 and 2 microns. The surface densities of objects discovered in the 2MASS and Sloan Digital Sky Surveys will be an appropriate match for such an instrument.

Table VI-1

<table>
<thead>
<tr>
<th>Item</th>
<th>1998</th>
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</tr>
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</table>

4. KPNO Computer Support

Software for the control of telescopes and instrumentation will continue to evolve during the next five years. An important part of this process is the integration at other telescopes of some portions of the WIYN systems, particularly, the WIYN guider and the network message passing system called “GWC” (which is
being used at both KPNO and CTIO). A tip-tilt experiment at WIYN will be a precursor for tip-tilt systems at the other telescopes.

During the next two years, a concerted effort will be made to inventory and consolidate software systems used throughout KPNO. Although initially motivated by the year 2000 concerns, this effort goes beyond simple concerns about date formats and will result in a solid core of software on which to base instrument and telescope operations for the next decade.

During the plan period, KPNO will continue its evolution into becoming a part of a single seamless NOAO system that provides science capabilities over a range of facilities. Gemini observing procedures and systems will be integrated into the existing KPNO software as a part of this evolution. Gemini control software will be incorporated where it is plausible to do so.

During the next five years, the Internet bandwidth will surely increase, as will the demands on the data line from Tucson to Kitt Peak. As funding permits, we will increase the bandwidth of this link beyond the current level of two T1 lines (1.5 Mbps each) and also improve the bandwidth and robustness of the Kitt Peak mountain network. The overall bandwidth between Kitt Peak and Tucson is limited by the costs and capabilities of the tribal utility company.

<table>
<thead>
<tr>
<th>Table VI-2</th>
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<tbody>
<tr>
<td>KPNO Schedule for Major Computer Capital Expenditures (Amounts in $1,000)</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
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<td>Archiving</td>
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<tr>
<td>Total</td>
<td>$240</td>
<td>$240</td>
<td>$220</td>
<td>$220</td>
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<td>$220</td>
</tr>
</tbody>
</table>

5. CTIO Computer Support

The CTIO computer plan covers both the Cerro Tololo and La Serena sites. The bulk of the expenditures each year will go toward maintaining and gradually upgrading the individual workstations (currently 60) in our network of Sun computers, which are used for data acquisition, data reduction, and laboratory development work. To keep pace with the increasing size of detectors and to avoid falling too far behind the state-of-the-art in computer hardware, we need to replace or substantially upgrade our machines on approximately a four-year cycle at an annual cost of at least $70K.

During FY 1998 there was a substantial upgrade of the data acquisition computers at the 4-m telescope in order to support the CCD mosaic imagers (BTC in service now, and the NOAO mosaic scheduled for deployment at CTIO in early-1999). During FY 1999 the acquisition computer at the 1.5-m telescope will undergo a similar upgrade and the downtown data reduction facilities will be enhanced as funding allows.

During FY 1999 we expect to complete the process of partitioning the Cerro Tololo mountain network into separate sub-nets, one for each telescope. Separate local networks consisting of a smart hub coupled to the mountain backbone were implemented at the 4-m telescope (in FY 1997) and at the 1.5-m (FY 1998). Sub-nets will be established at the remaining telescopes during FY 1999. During FY 1998 the 4-m
The sub-net was upgraded to provide 100 Mbps connectivity between the principal data handling computers. The remaining sub-nets will be upgraded as increasing traffic demands and funding permits. During FY 1998-99 we will also split the La Serena network, establishing a separate 100 Mbps sub-net for the scientific workstations and data reduction machines.

The networks in La Serena and on Cerro Tololo are connected via a commercial microwave link with backup and maintenance provided by the contractor. At present, one of the four available E1 channels (2 Mbps) is used for a network connection and another for voice lines. During FY 1998-1999, we plan to install ATM routers in La Serena and on Cerro Tololo and begin to use ATM on the link between the two sites. The computer networks in both locations will be connected to the switches along with the existing telephone plants. ISDN boards will be installed in both telephone plants along with ATM trunk line equipment.

Changing the link structure in this way incurs a capital cost of approximately $70K for the two ATM switches required. This will immediately increase the maximum speed of data transfer between La Serena and Cerro Tololo from the current 2 Mbps (E1) to 8 Mbps (E2) at no additional recurring cost. This, combined with the installation of boards supporting ISDN lines to external equipment will permit videoconferencing and direct computer connections at up to 128K baud to be made between the two sites. Communication to ISDN-compatible locations worldwide, such as Tucson and Hawaii, will also be possible at the cost of ISDN service from Chile falls to affordable levels.

During FY 2000, we anticipate that the Cerro Tololo ATM switch will be connected to a planned link to Cerro Pachon to meet the needs of Gemini and SOAR, and perhaps also to Las Campanas. To support the resulting increase in traffic, an upgrade of the speed of the CT-LS connection, to at least E3 (34 Mbps), will be necessary. The scalability and flexibility of ATM make network changes of this nature straightforward, relatively low cost, and non-traumatic. Cost sharing arrangements will have to be worked out between the various users (CTIO, Gemini, SOAR, etc.). The budget estimates (Table VI-3) include only CTIO’s share of these costs.

The system connectivity to the outside world is currently throttled by a 56Kbps satellite link to the US, supplied by NASA. A higher speed connection is a prerequisite for remote/queue scheduled observing and will be essential before the turn of the century. Fortunately, we are discussing the possibility of a significant bandwidth upgrade with NASA which may be implemented during FY 1998-99. At the same time, a transition to the use of terrestrial fiber links for telecommunications is taking place in Chile. Fiber connections via Argentina already exist between Santiago, La Serena, and the US, and direct connections from Chile to the US west coast are being installed. As a result, it is likely that a higher speed connection between CTIO and the US will be commercially available, at an affordable cost, within the next few years. The ATM switch in La Serena can be connected directly to such a terrestrial fiber optic link—once it becomes available—to provide a high bandwidth connection to the US Internet. However, it must be recognized that rental and traffic costs for this connection will need to be paid from CTIO’s budget, while the present satellite connection is paid for by NASA. The budget shows these increased recurring costs starting in FY 2000. Again, we will investigate cost sharing arrangements with the other observatories in order to obtain the necessary bandwidth in the most cost-effective way.
Table VI-3
CTIO Schedule for Major Computer Expenditures
(Amounts in $1,000)

<table>
<thead>
<tr>
<th>Item</th>
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<tr>
<td>Spares/Maintenance</td>
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<td>Upgrades</td>
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<tr>
<td>Network Infrastructure (capital costs):</td>
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<td></td>
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<tr>
<td>La Serena - Tololo Link</td>
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</tr>
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<td>Local Networks</td>
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</table>

6. NSO/SP Computer Support

The computer facilities at NSO/SP consist of a campus-style layout with five main areas; Main Lab (ML) building, Evans Solar Facility (ESF) telescope building, Hill Top (HT) telescope building, the Vacuum Tower Telescope (VTT) building, and the administrative offices building. Each building is connected to our central Ethernet switch by a 10BaseF fiber optic link, and is wired or will be wired for 10BaseT (cat5 twisted pair).

The HT, ESF, and VTT computer systems are mainly used for telescope control and data collection with limited data analysis. The ML facility is used for data reduction, analysis, and general computing by both visiting scientists and local staff.

A staff of 1 FTE maintains the NSO/SP computer facilities (approximately 140 nodes including 55 workstation/servers, 17 X-terminals, 25 personal computers), supports the network, and provides support to users (both staff and visitors).

Our main objectives over the next five years (Table VI-4) are as follows:

- Upgrade our old, inefficient, and high maintenance computer systems with new hardware.
- Upgrade the network toward a 100 Mbps plus network. This will include upgrading the Ethernet switch to a high bandwidth switch and high bandwidth links to each building, finishing the upgrade of all buildings to 100BaseT wiring, and adding smaller switches and hubs to segment the network load at each building.
- Purchase a DLT 7000 tape unit for the ML for backups and as a spare to our public unit.
- Move toward a centrally administered network by purchasing software that will allow the 1 FTE to manage the network from a single site.
Table VI-4
NSO/SP Schedule of Major Computer Capital Expenditures **
(Amounts in $1,000)

<table>
<thead>
<tr>
<th></th>
<th>1999</th>
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<td>HW Maintenance/Upgrades</td>
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</table>

** Cost estimates assume level funding over the next five years.

7. NSO/Tucson Computer Support

NSO/Tucson will address five areas:

- **On Kitt Peak**, a continuation of a major modernization of data acquisition, data reduction, and telescope control at the McMath-Pierce Complex. Currently, the Telescope Control System (TCS) is being upgraded to take advantage of the latest developments in real-time operating systems and database management. This, in conjunction with a completely revamped guiding system, will greatly improve the productivity of the facilities.

- **In Tucson**, an ongoing program to provide and upgrade scientific workstations or X-terminals and associated peripheral devices: The ever-increasing size of solar datasets and the further development of sophisticated and numerically intensive analysis algorithms demands additional resources, particularly data storage space, I/O transfer rates, and CPU speed. These demands will be met by acquisition of higher-speed multi-processor SPARC stations, larger capacity disk drives, denser off-line storage media, and optical storage devices. NSO already has both Hyper- and Ultra-SPARC workstations in-house and will continue to upgrade older equipment as funds allow. In addition, better access to commercial software packages has been provided by the installation of IDL on several machines.

- **On-line archival storage for major datasets such as FTS spectra, full-disk synoptic magnetograms and spectroheliograms, and the High-l Helioseismometer**: The archiving of the entire set of transformed FTS spectra onto CD-ROM is complete. Solar FTS spectral atlases are on-line and heavily used by the scientific community. Recent magnetograms and He I 1083-nm Spectroheliograms are available to the user community via anonymous FTP and the World Wide Web. A 300-CD (200 GB) CD-ROM jukebox has been installed on Argo (NSO/Tucson's data server) and now contains 104 disks. The Kitt Peak Vacuum Telescope disk and the untransformed raw FTS data are being migrated onto CD-ROMS. In about two years, the new generation of Digital Video Disk (DVD) technology will be widely available, providing as much as 13 GB of storage on a single 5.25-inch CD-ROM. This increase of a factor of 20 over current capacity will allow NSO to place its entire archive on-line. A user interface to the digital library has been developed using funds from the NSF Space Weather program and will be publicly released soon.
• **Stable access to programming resources sufficient to allow the planning and execution of major software packages:**
  Although this situation was greatly improved with the addition of three assigned programmers to the NSO staff, the subsequent loss of one position to budget cuts eroded the capability of NSO to develop new software. Programming time continues to be the limiting resource in NSO/Tucson project planning.

• **Increased presence on, and use of, the Internet:**
  The NSO Web pages are continually updated. The user interface to the search engine for the digital library is Web-based. NSO/Tucson is also contributing to the development of Web-based educational materials on solar topics. Finally, NSO/Tucson has successfully experimented with the use of the Internet for limited scientific meetings. Potentially, conferencing over the Internet could result in a substantial reduction in travel costs.

The following schedule shows that NSO/Tucson derives the great majority (88%) of its funding for computer-related capital expenditures from outside grants and contributions from its “partner” agencies.

**Table VI-5**

| NSO/Tucson Schedule for Major Computer Capital Expenditures (Amounts in $1,000) |
|---|---|---|---|---|---|
| Item | 1999 | 2000 | 2001 | 2002 | 2003 |
| Distributed Computing | 20 | 5 | 15 | 20 | 45 |
| Equipment Upgrades | 24 | 34 | 25 | 25 | 20 |
| Application Software | 9 | 3 | 10 | 10 | 10 |
| Archives | 10 | 13 | 20 | 25 | 10 |
| Total | $63 | $55 | $70 | $80 | $85 |
| Non-AURA Percentage | 88% | 82% | 85% | 88% | 88% |

**B. Facilities**

**Table VI-6**

| Facilities Maintenance Requirements (Amounts in $1,000) |
|---|---|---|
| Maintenance, Construction and Safety Summary | 1999-2003 |
| CTIO | $870 |
| KPNO | 975 |
| NSO/Kitt Peak | 245 |
| Tucson | 712 |
| NSO/Sacramento Peak | 804 |
| Total | $3,606 |

**1. Cerro Tololo**

**Milestones:**

<table>
<thead>
<tr>
<th>Projects (FY 1999)</th>
<th>Estimated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 4-m telescope: Fire protection system</td>
<td>$40,000</td>
</tr>
<tr>
<td>2. Vehicle fleet renovation</td>
<td>20,000</td>
</tr>
<tr>
<td>3. Main access road to Tololo</td>
<td>75,000</td>
</tr>
<tr>
<td>Total</td>
<td>$135,000</td>
</tr>
</tbody>
</table>
Projects (FY 2000)
1. 4-m telescope: Repainting $20,000
2. Vehicle fleet renovation 20,000
3. Main access road to Tololo $75,000
Total $115,000

Projects (FY 2001)
1. Water system, Tololo (pipeline) $25,000
2. Vehicle fleet renovation 20,000
3. Main access road to Tololo $75,000
Total $120,000

Projects (FY 2002)
1. Power House $25,000
2. Vehicle fleet renovation 20,000
3. Main access road to Tololo $75,000
Total $120,000

Projects (FY 2003)
1. Bus Replacement $150,000
2. Vehicle fleet renovation 20,000
Total $170,000

With the recent closings of the Lowell and Yale telescopes, CTIO now operates four night-time telescopes: the 4-m, 1.5-m, 0.9-m, and the Univ. of Michigan Curtis Schmidt. By the year 2002, we expect to be participating in the commissioning of the SOAR 4-m telescope on Cerro Pachon. In addition to the routine maintenance of the physical plants on Tololo and La Serena, we propose to carry out the following major maintenance and construction activities:

Maintenance

Fire Protection:
A fire occurred in the 4-m building in 1995 which, if not detected in time, could have produced serious damage to the facility. The fire occurred in an area that is out of sight of normal operations personnel but not covered by fire detection devices. Serious fires have occurred recently in astronomical facilities on Mauna Kea, one with fatal consequences. We have recently installed a significantly improved system of fire detection at the 4-m, but our top infrastructure priority at CTIO is to improve significantly the level of fire protection at the 4-m.

Tololo Water System:
The San Carlos water line (CTIO's only water supply) has been in continuous operation for over 20 years and is nearing the end of its expected 25-year useful life. We must replace those sections of pipe that are worn by use or by pitting due to the problems caused by iron-eating bacteria (innocuous to human health) that badly affected the line during the first few years of use. This problem has been dealt with so far by plugging the pipe or removing small stretches where soldering would not be possible because of the extent of the damage. Funds have been found to acquire a stock of pipe tubing. It is necessary now to hire contract personnel to install it.

4-m Telescope Repainting:
The dome and building must be repainted every five years. Delaying this kind of maintenance activity leads to higher costs later.
Vehicle Fleet Renovation:
CTIO maintains a vehicle fleet for transportation of both personnel and goods, especially between La Serena and Cerro Tololo. Heavy equipment is needed to maintain the road and to support access to Cerro Pachon. The vehicle fleet has been replaced only sporadically through special allocations from the NOAO Director, especially including the bus to transport workers to the mountain; the steady state budget for CTIO is inadequate to support regular replacement. Failure to replace vehicles in a timely manner is a financially inefficient policy that adds to maintenance costs in subsequent years.

Cerro Tololo Power House:
During the past four years, CTIO has been carrying out a plan to upgrade the Tololo Power House. The next phase of work involves replacement of obsolete switching and control gear, which has been used for well over 25 years.

Bus Replacement:
The CTIO bus which transports day workers between La Serena and Cerro Tololo every workday will be ten years old in 2002. Careful maintenance should allow the bus to keep operating until then, but it should be replaced at that point. We will, of course, examine leasing or rental options, but currently in Chile it is more economical to purchase a new bus.

Construction

Cerro Tololo Road Improvement:
The greatest safety problem at CTIO continues to be accidents on the access road to Tololo. In recent years CTIO has installed 483 linear meters of guard rails in sectors of the greatest potential danger. In order to continue offering greater protection to people using the road, an estimate of a further 10,200 m of guard rail are needed, at a cost of US $27.50/linear meter ($44,155 per mile, total $300,000).

2. Kitt Peak

Milestones:

<table>
<thead>
<tr>
<th>Projects (FY 1999)</th>
<th>Estimated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Water catchment repair</td>
<td>$ 30,000</td>
</tr>
<tr>
<td>2. Energy management</td>
<td>20,000</td>
</tr>
<tr>
<td>3. Propane system</td>
<td>5,000</td>
</tr>
<tr>
<td>4. Replacement of water, sewer, and telephone lines</td>
<td>20,000</td>
</tr>
<tr>
<td>5. 4-m aluminizing tank enclosure</td>
<td>40,000</td>
</tr>
<tr>
<td>6. Road repairs</td>
<td>10,000</td>
</tr>
<tr>
<td>7. General building and dome repairs</td>
<td>25,000</td>
</tr>
<tr>
<td>8. Lightning abatement</td>
<td>25,000</td>
</tr>
<tr>
<td>9. Telescope systems support</td>
<td>15,000</td>
</tr>
<tr>
<td>Total</td>
<td>$ 190,000</td>
</tr>
</tbody>
</table>
### Projects (FY 2000)

<table>
<thead>
<tr>
<th>Project Description</th>
<th>Estimated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upgrade water treatment plant</td>
<td>$50,000</td>
</tr>
<tr>
<td>Replacement of water, sewer, and telephone lines</td>
<td>$20,000</td>
</tr>
<tr>
<td>Energy management</td>
<td>$20,000</td>
</tr>
<tr>
<td>General building and dome repairs</td>
<td>$70,000</td>
</tr>
<tr>
<td>Road repairs</td>
<td>$20,000</td>
</tr>
<tr>
<td>Vehicle replacement</td>
<td>$15,000</td>
</tr>
<tr>
<td>Telescope systems support</td>
<td>$15,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$210,000</strong></td>
</tr>
</tbody>
</table>

### Projects (FY 2001)

<table>
<thead>
<tr>
<th>Project Description</th>
<th>Estimated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>General building and dome repairs</td>
<td>$45,000</td>
</tr>
<tr>
<td>Replacement of water, sewer, and telephone lines</td>
<td>$20,000</td>
</tr>
<tr>
<td>ADA compliance for dormitory</td>
<td>$30,000</td>
</tr>
<tr>
<td>Energy management</td>
<td>$20,000</td>
</tr>
<tr>
<td>Replacement of underground power lines</td>
<td>$25,000</td>
</tr>
<tr>
<td>Heavy equipment repair/replacement</td>
<td>$30,000</td>
</tr>
<tr>
<td>Telescope systems support</td>
<td>$15,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$185,000</strong></td>
</tr>
</tbody>
</table>

### Projects (FY 2002)

<table>
<thead>
<tr>
<th>Project Description</th>
<th>Estimated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>General building and dome repairs</td>
<td>$45,000</td>
</tr>
<tr>
<td>Energy management</td>
<td>$10,000</td>
</tr>
<tr>
<td>Improvements to administration building</td>
<td>$50,000</td>
</tr>
<tr>
<td>Telescope systems support</td>
<td>$25,000</td>
</tr>
<tr>
<td>Septic system</td>
<td>$30,000</td>
</tr>
<tr>
<td>Alternate fuel storage facilities</td>
<td>$20,000</td>
</tr>
<tr>
<td>Replacement of underground power lines</td>
<td>$25,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$205,000</strong></td>
</tr>
</tbody>
</table>

### Projects (FY 2003)

<table>
<thead>
<tr>
<th>Project Description</th>
<th>Estimated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telecommunications upgrade</td>
<td>$35,000</td>
</tr>
<tr>
<td>General building and dome repairs</td>
<td>$45,000</td>
</tr>
<tr>
<td>Vehicle replacement</td>
<td>$20,000</td>
</tr>
<tr>
<td>Telescope systems support</td>
<td>$20,000</td>
</tr>
<tr>
<td>Heavy equipment repair/replacement</td>
<td>$30,000</td>
</tr>
<tr>
<td>Road repairs</td>
<td>$25,000</td>
</tr>
<tr>
<td>Energy management</td>
<td>$10,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$185,000</strong></td>
</tr>
</tbody>
</table>

KPNO mountain-based facilities have been downsized over the past three years. The nighttime facilities, with the equivalent of four telescopes currently operated full-time by NOAO, are near the projected minimum complement of three telescopes. Further major reductions can occur only if the NSO facilities are closed, as they will be if the flagship facility described elsewhere in this plan is funded. However, the savings would be required to operate the new solar site.

For the immediate future, the highest priority for both maintenance and improvements on Kitt Peak will remain with the WIYN telescope. During FY 1997 and FY 1998, $400,000 (40 percent from NOAO) was earmarked by the consortium members to bring the WIYN telescope up to its optimum level of perform-
ance and reliability. It is hoped that additional funding by the consortium will be made available for the next several years to continue this effort.

Due to significant savings as a result of our energy management and combined Tucson and Kitt Peak facilities programs, we have identified resources to support other maintenance projects during this period.

Maintenance

The projects that we feel are essential to the successful operation of KPNO over the next five years are:

Water Catchment:
Water for use on Kitt Peak is obtained primarily from runoff collected in two catchment basins. These basins have leaks and must be repaired. Adequate supplies of water must be maintained not only for human consumption but also for fire fighting. In dry years, runoff is inadequate to meet these requirements, and water must be hauled to the summit for processing. The problem is compounded by leakage. A third catchment site is being evaluated for possible future use. As a conservation measure, existing high water use fixtures are being replaced with no or low water use fixtures to minimize usage.

General Building and Dome Repairs:
Including the telescope enclosures, KPNO has in excess of 130,000 s.f. of building space. We have developed a plan to repair, paint, and roof all facilities, as well as the telescope domes, on a five-to-seven-year rotational basis.

Replacement of Water, Sewer, and Telephone Lines:
Most of the underground utilities were installed in the early 1960's, and are well past their expected lifetimes. The main sewer lines were replaced in FY 1995, and during this five year period, we will selectively clean and replace the small feeder lines. We have experienced leakage with several of our main water lines, and close examination of these lines indicates they need to be replaced now. Due to the age of the pipes, other main lines are suspect. As time allows, sampled evaluation of the entire underground water delivery system will be made and a plan for replacement developed.

Usable telephone cable pairs remain in short supply, especially on the east side of the summit. For now, we have contracted with our telephone service provider to keep as many lines functional as possible, but it is likely that during this period most of the lines will need to be replaced.

Road Repairs:
The roadways at the summit of Kitt Peak, as opposed to the access road, are the Observatory’s responsibility. These roads are subject to weather damage and must periodically be resealed.

Telecommunications System Upgrades:
Although AT&T System 75 telephone switches for Kitt Peak and NOAO Tucson were purchased in 1984, we have been successful in keeping them as state-of-the-art technology through occasional upgrades. We intend to continue with this option until it is no longer cost effective.

Tucson/Kitt Peak Telecommunications:
Our plan to upgrade voice/data communications capability between Tucson and Kitt Peak was drastically altered in FY1997 when the Tohono O‘Odham Utility Authority (TOUA) finally, after years of lobbying on our part, reduced our single T-1 telephone service cost from $3,749/month to $1,575/month, or roughly a 58% decrease. In addition, the TOUA offered to rent us two more T-1 lines for $500/month each. We implemented the rental of a second T-1 line and are considering the need for a third. This
reduction in cost was timely as we were beginning to experience a slowdown in our data flow because of insufficient bandwidth.

As a result of the price reduction by the TOUA, along with the progress they are making on a plan to provide fiber-optic capability to Kitt Peak, we have placed our plan to purchase and install a microwave link between Kitt Peak and Tucson on hold. At the old T-1 line rental rate, the microwave equipment had a payback time of four to five years. At the new rates, we can afford to wait to see whether the fiber link is installed and whether we can use it at a reasonable price.

Although AT&T System 75 telephone switches for Kitt Peak and Tucson were purchased in 1984, we have been successful in keeping them as state-of-the-art technology through occasional upgrades. We intend to continue with this option until it is no longer cost effective.

**Septic System:**
A study of the mountain-wide septic system in 1993 identified a number of serious problem areas. Since then, most of these problems have been corrected. However, it is likely that replacement tanks may be required in several areas within this five-year period.

**Propane System:**
Most of the underground lines connecting our propane storage tanks with structures on Kitt Peak were installed 25-30 years ago, as were the majority of the furnaces and appliances that utilize the propane. A very thorough study was recently made by KPNO staff and our propane distributor to identify problems with the entire delivery system. The extent of the problem was considerably worse than was expected. Due to the seriousness of the problem, work immediately began in late FY 1997 with the majority of the effort to be accomplished in FY 1998. All known problems will be corrected by the end of FY 1999.

**Energy Management:**
With the demonstrated success of our energy management program for the NOAO Tucson headquarters building, we are proceeding with the same strategy on Kitt Peak. Over the next five years we will make energy improvements, starting with the shortest time and largest pay back items.

**Lightning Abatement:**
Each year considerable damage occurs to Kitt Peak telescope and instrument electronic components due to lightning strikes. Our goal is to minimize this damage and resultant cost by increasing our lightning protection at all telescopes.

**Underground Power Line Replacement:**
The majority of the power lines on Kitt Peak were installed over 30 years ago. While they have served us well, we are beginning to notice deterioration of the lines. In addition, the demand for power, due to new construction on a portion of the summit, is expected to exceed power line capability.

**Upgrade Water Treatment Plant:**
After 30 plus years of service, the water treatment plant remains functional, but the total system is in need of upgrading. The State of Arizona water quality department has recently inspected this facility and made recommendations that we maintain it at a higher level. Accordingly, it will receive a top to bottom over-haul along with a cleaning of the two water storage tanks.

**Telescope Systems Support:**
Specialty cryogenic cooling systems, uninterruptible power sources, etc. are an integral part of today’s state-of-the-art instrumentation. It is necessary to continually maintain and replace these very expensive items as needed.
Heavy Equipment and Vehicle Repair/Replacement:
The majority of the heavy equipment in use on Kitt Peak was acquired through GSA surplus. Most of it is old but in reasonable condition. Given the difficulty of securing heavy equipment from GSA surplus now and the major cost of purchasing new equipment, it is our intent to maintain what we have. On occasion, new light use, alternate fuel, or electric vehicles will be purchased for use on Kitt Peak only.

Construction

4-m Aluminizing Tank Enclosure:
The 4-m aluminizing facility is the only large coating chamber that is made routinely available to astronomy-related organizations. More than half of the mirrors coated each year belong to organizations other than NOAO. The tank is built into the ground floor of the 4-m building within a large open space. It is very difficult to keep this area clean enough to prepare mirrors for new coatings. During FY1999, we plan to enclose the tank and mirror preparation area so that the environment approximates that of a semi-clean room.

ADA Compliance for Dormitory:
There are no handicapped-accessible dormitory facilities to accommodate disabled workers or observers. We plan to modify a portion of one of our dormitories to bring the Observatory into compliance with the Americans with Disabilities Act.

Improvements to Administration Building:
The functions of some of our buildings have changed over the years. Facilities Operations is reviewing the use and condition of the various support buildings with centralization and cost savings in mind. One building that will play a prominent role in future operations is the Administration Building. Proposed modifications include a remote observing area, which could eventually serve as the main control room for all nighttime telescopes; office space for WIYN staff members and observers; the addition of telecommunications/video capability to assist with remote engineering evaluation and repair; and improved office space for observing technicians and programming staff.

Alternate Fuel Storage Facilities:
The government mandated requirement that NOAO must purchase an increasing number of alternate fuel vehicles (AFV) requires us to install an additional underground fuel tank.

3. NOAO Tucson

Milestones:

<table>
<thead>
<tr>
<th>Project (FY 1999)</th>
<th>Estimated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correction of headquarters building (HVAC)</td>
<td>$ 10,000</td>
</tr>
<tr>
<td>Fire/security alarm system</td>
<td>35,000</td>
</tr>
<tr>
<td>Asphalt maintenance yard replacement</td>
<td>20,000</td>
</tr>
<tr>
<td>Energy improvements</td>
<td>15,000</td>
</tr>
<tr>
<td>Replace shuttle vehicles</td>
<td>35,000</td>
</tr>
<tr>
<td>Water pipes replacement</td>
<td>20,000</td>
</tr>
<tr>
<td>General building repairs</td>
<td>25,000</td>
</tr>
<tr>
<td>Fuel tank monitoring</td>
<td>7,000</td>
</tr>
<tr>
<td>Total</td>
<td>$ 167,000</td>
</tr>
<tr>
<td>Projects (FY 2000)</td>
<td>Estimated Cost</td>
</tr>
<tr>
<td>------------------------------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>Power distribution</td>
<td>$ 40,000</td>
</tr>
<tr>
<td>Correction of headquarters building (HVAC)</td>
<td>10,000</td>
</tr>
<tr>
<td>Energy improvements</td>
<td>15,000</td>
</tr>
<tr>
<td>Replace shuttle vehicles</td>
<td>30,000</td>
</tr>
<tr>
<td>Alternate fuel storage facilities</td>
<td>20,000</td>
</tr>
<tr>
<td>General building repairs</td>
<td>25,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$ 140,000</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Projects (FY 2001)</th>
<th>Estimated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>General building repairs</td>
<td>$ 25,000</td>
</tr>
<tr>
<td>Correction of headquarters building (HVAC)</td>
<td>10,000</td>
</tr>
<tr>
<td>Energy improvements</td>
<td>15,000</td>
</tr>
<tr>
<td>Replace shuttle vehicles</td>
<td>40,000</td>
</tr>
<tr>
<td>Replace cargo truck</td>
<td>40,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$ 130,000</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Projects (FY 2002)</th>
<th>Estimated Cost</th>
</tr>
</thead>
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<tr>
<td>Repaint exterior of headquarters building</td>
<td>$ 35,000</td>
</tr>
<tr>
<td>Energy improvements</td>
<td>15,000</td>
</tr>
<tr>
<td>Replace shuttle vehicles</td>
<td>35,000</td>
</tr>
<tr>
<td>ADA building upgrades</td>
<td>50,000</td>
</tr>
<tr>
<td>General building repairs</td>
<td>25,000</td>
</tr>
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<td><strong>Total</strong></td>
<td><strong>$ 160,000</strong></td>
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</table>

<table>
<thead>
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<th>Projects (FY 2003)</th>
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</tr>
</thead>
<tbody>
<tr>
<td>1. Telecommunications upgrade</td>
<td>$ 30,000</td>
</tr>
<tr>
<td>2. Replace shuttle vehicles</td>
<td>45,000</td>
</tr>
<tr>
<td>3. General building repairs</td>
<td>25,000</td>
</tr>
<tr>
<td>4. Energy improvements</td>
<td>15,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$115,000</strong></td>
</tr>
</tbody>
</table>

NOAO remains an obstacle to future University of Arizona campus development. However, during this five-year period neither organization is likely to identify sufficient funds for the relocation of the NOAO headquarters. Therefore, NOAO plans to continue to make investments designed to lower the cost of operation of the existing building. At the same time, we recognize that portions of the headquarters building are now more than 35 years old. Accordingly, we must continue a methodical replacement of likely-to-fail building components.

**Maintenance**

**Energy Improvements:**
The Central Facilities Operations staff set a goal of lowering the Tucson facilities’ electric utility costs to $200,000/yr by December 1996. We missed that goal by $19,000 but will meet or exceed it during 1998. Our new goal is $180,000/yr by the year 2000. Since these savings are not one-time events, but instead realized annually, our energy management program remains at the top of our list of maintenance improvements. Our long-term goal is to implement additional savings measures and complete all of them within this five-year period.
**Power Distribution:**
In portions of the headquarters building, the routing of power lines needs to be improved. We have correlated power line electromagnetic interference with computer monitor instability. The extent of effort required and the feasibility of rerouting the power lines remains to be determined.

Telecommunications between Tucson and Kitt Peak are discussed above under *Kitt Peak Telecommunications.* Here we list costs associated with upgrading the Tucson end of the link.

**Asphalt Maintenance Yard Replacement:**
The asphalt surface of our maintenance yard needs to be replaced over the next five-year period. The surface is no longer responding to the sealing procedure used to prevent deterioration. The old material needs to be dug out and replaced with new asphalt.

**Water Pipe Replacement:**
With portions of the headquarters building more than 35 years old, we have been concerned about the condition of the water pipes. Due to a recent failure, portions of our heating/cooling lines have been replaced. We expect that others will need replacement shortly. We also believe that during this five-year period, replacement of portions of the potable water pipes will be required as well.

**Repaint Exterior of Headquarters Building:**
Within the next five years, the stucco exterior surface of the headquarters building will need to be crack sealed and painted.

**Complete Correction of Headquarters Building (HVAC) Problems:**
The headquarters building main boiler was replaced in 1997, but additional work is required on the HVAC system (replacements and upgrades to the air distribution and piping equipment).

**Replace Shuttle Vehicles:**
A shuttle fleet is utilized for transportation of staff and visitors to/from Kitt Peak and for travel to out-of-Tucson destinations. To maintain safe highway vehicles, we have a program in place for annual replacement of high mileage vehicles. Based on GSA guidelines, we replace three vehicles per year on average.

**Replace Cargo Truck:**
The cargo truck used to transport the majority of the supplies and materials between Tucson and Kitt Peak will need to be replaced during this period unless a suitable government surplus vehicle can be located.

**General Building Repairs:**
The Tucson headquarters facility encompasses 135,000 sf. of office, laboratory and service space. We have an ongoing program of routine and preventive facilities maintenance intended to keep the facility current and in good repair.

**Construction**

**Alternate Fuel Storage Facilities:**
The new EPA alternative fuel vehicle (AFV) regulations may prove costly to NOAO. In the current ruling, by the NSF, our fleet size is determined by the number of vehicles located in Tucson and on Kitt Peak. NOAO's position is that vehicles assigned permanently to the mountain, where the mileage is low and air pollution is not a problem, should be excluded from the pool. Unless we receive a waiver, in FY1999, 75% of our new vehicles purchased in FY 1999 must meet AFV standards. AFV options for transportation between the mountain and downtown are propane and methanol-fueled vehicles. These
vehicles cost more to purchase and operate and will require the installation of additional fuel storage facilities in Tucson and on Kitt Peak.

**Fuel Tank Monitoring:**
To meet EPA standards, by the beginning of FY1999, we will need to install automatic fuel tank monitoring equipment on our Central Facilities underground fuel tank.

**Fire/Security Alarm System:**
In FY1996, we replaced the antiquated NOAO headquarters computer room fire alarm system. At that time, the main building fire alarm system was also determined to be obsolete and in need of replacement. The break-in and computer theft at the Central Administration Services building demonstrated to us how vulnerable we are even with guard service protection. The office areas outside the main headquarters building are now fully protected. All that remains to be completed is the main building.

**ADA Building Upgrades:**
The Tucson headquarters building is not in full compliance with Americans with Disabilities Act (ADA) requirements. NOAO has completed initial ADA modifications to the rest rooms as well as to a side entrance. Access to all levels in the building, however, has not yet been provided.

4. **NSO**

NSO’s telescope buildings at both observing sites, and the entire infrastructure at Sacramento Peak, date mainly from the 1950’s and 1960’s. These structures do not meet contemporary standards for energy efficiency, ease of use, or maintainability. Past and continuing budget constraints have precluded an adequate preventative maintenance program: for at least 10 years, “maintenance” has mainly consisted of repairing or replacing equipment that fails.

The following lists itemize what is required to upgrade NSO facilities to the point that regular maintenance and upgrades over the past 10-15 years would have provided. Such an investment would allow the maintenance program at both sites to become proactive and ensure the future viability of the infrastructure.

NSO will maintain its facilities with an eye toward the future NSO sketched in Section IV of this long range plan. As that vision is realized, some of the maintenance categories listed below will become unnecessary. However, until key components of the plan become real, NSO must and will protect the public’s investment in the facilities under our custodianship.

**NSO/Sacramento Peak**

**Milestones**

<table>
<thead>
<tr>
<th>Projects (FY 1999)</th>
<th>Estimated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Painting - telescope buildings</td>
<td>$25,000</td>
</tr>
<tr>
<td>2. Power line replacement</td>
<td>$20,000</td>
</tr>
<tr>
<td>3. Cloudcroft facility/RCA building reroof</td>
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<td><strong>Total</strong></td>
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<thead>
<tr>
<th>Projects (FY 2000)</th>
<th>Estimated Cost</th>
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</thead>
<tbody>
<tr>
<td>1. Painting - commercial buildings</td>
<td>$25,000</td>
</tr>
<tr>
<td>2. Staff vehicle replacement</td>
<td>$20,000</td>
</tr>
<tr>
<td>3. Lighting upgrades</td>
<td>$32,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$77,000</strong></td>
</tr>
</tbody>
</table>
Projects (FY 2001)  
1. Painting - commercial buildings  $25,000  
2. Lighting upgrades  32,000  
3. Storage facility  40,000  
Total  $97,000  

Projects (FY 2002)  
1. ADA compliance  $50,000  
2. Underground utility replacement  35,000  
3. Housing upgrades  25,000  
Total  $110,000  

Projects FY 2003  
1. Road repair/resurfacing  $175,000  
2. Housing upgrades  25,000  
Total  $200,000  

Road Repair/Resurface  
Roads and driveways throughout the housing area are in serious need of repair. Harsh weather conditions and minimal preventive maintenance in past years have led to serious deterioration. A complete removal of existing paving and replacement will be required.

Commercial and Residential Painting  
All the redwood houses, the Vacuum Tower Telescope, Evans Solar Facility dome and several maintenance buildings on the site require painting. The redwood housing was last painted in 1978, many of the maintenance buildings and telescopes prior to that. The paint is peeling on almost all redwood houses with deterioration beginning around foundations. Continued neglect will result in higher repair costs when undertaken.

Cloudcroft Facility Building Reroof (RCA)  
NASA recently spent over $175,000 renovating the main telescope building at the Cloudcroft Telescope Facility. Other buildings, in particular the RCA building, require immediate roof repair to prevent extensive water damage during the upcoming rainy season. Age and deterioration of this building will soon make it unusable. Access to occupants and visitors has been restricted.

Lighting Upgrades  
Lighting upgrades in all commercial buildings to modern fluorescent fixtures with current switching would result in savings in electricity usage and improve the quality of lighting in all areas.

ADA Compliance  
Currently, none of our buildings is in ADA compliance. To assist a disabled summer student who was on site a couple of years ago, we renovated a restroom in the Main Lab. We need to modify access to several buildings, and renovate more restrooms and an apartment in the VOQ to allow handicap access.

Storage  
Current storage requirements are being met with surplus Quonset huts constructed in the 1950’s. Due to their age and condition, these facilities are not weatherproof, nor heated.

Underground Storage Tank Compliance
Two petroleum underground storage tanks will require upgrade to maintain EPA compliance by the end of 1998. Upgrades will include automatic leak detection, spill/overfill protection and cathodic protection. An option that is being explored is replacement instead of upgrade.

**Housing Upgrades**
The houses at the Observatory were constructed in the 1950's and 1960's. Very little has been done to improve or upgrade them since installation. Many have the original plumbing, electrical fixtures, piping, wiring, floor tile, and cabinets.

**Vehicle/Equipment Replacement**
The current fleet of vehicles and equipment is very old and consists of unreliable equipment and vehicles. Many pieces of equipment are 1960's vintage with high mileage or hours. Current staff vehicles are over 10 years old with some over 100,000 miles each. The advanced age of the fleet increases maintenance costs dramatically.

**Power Line Replacement**
Power lines in the housing area were installed in the 1950's and are beginning to show serious deterioration. Many of the installations are sub-standard.

**NSO Kitt Peak**

**Milestones:**

<table>
<thead>
<tr>
<th>Projects (FY 1999)</th>
<th>Estimated Cost</th>
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<tbody>
<tr>
<td>1. McMath-Pierce electrical upgrade</td>
<td>$30,000</td>
</tr>
<tr>
<td>2. McMath-Pierce painting</td>
<td>15,000</td>
</tr>
<tr>
<td>3. Reroofing and sealing</td>
<td>5,000</td>
</tr>
<tr>
<td>4. McMath-Pierce energy management</td>
<td>5,000</td>
</tr>
<tr>
<td>5. McMath-Pierce fall protection</td>
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<tr>
<td><strong>Total</strong></td>
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<td>5,000</td>
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<tr>
<td>4. McMath-Pierce fall protection</td>
<td>5,000</td>
</tr>
<tr>
<td>5. KPVT vacuum line cold-trap</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>$47,500</strong></td>
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<th>Projects (FY 2001)</th>
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<td>2. Reroofing and sealing</td>
<td>5,000</td>
</tr>
<tr>
<td>3. McMath-Pierce energy management</td>
<td>5,000</td>
</tr>
<tr>
<td>4. Extend KPVT loading dock</td>
<td>2,500</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>$42,500</strong></td>
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<th>Projects (FY 2002)</th>
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<tr>
<td>1. McMath-Pierce electrical upgrade</td>
<td>$30,000</td>
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<td>2. Reroofing and sealing</td>
<td>5,000</td>
</tr>
<tr>
<td>3. McMath-Pierce energy management</td>
<td>5,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$40,000</strong></td>
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<tr>
<td>Projects (FY 2003)</td>
<td>Estimated Cost</td>
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<tr>
<td>--------------------------------------------------------</td>
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</tr>
<tr>
<td>1. McMath-Pierce electrical upgrade</td>
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<tr>
<td>4. McMath-Pierce energy management</td>
<td>5,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$55,000</strong></td>
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In addition to the structural maintenance items summarized above and described below, the aging Telescope Control Systems (TCS) at the McMath-Pierce constitutes a serious long-term maintenance issue. The current 20-plus-year-old control systems are increasingly difficult to maintain, resulting in increased downtime. Replacement with modern, lower-maintenance hardware and software is a high priority. The cost of these TCS upgrades, including labor, will exceed $500,000 but is not included in the summary above since the project cannot be carried out within the current operating budget.

**McMath-Pierce Electrical Upgrade:**
Sections of the wiring and electrical components within the main observing room and the telescope structure as a whole require replacement and upgrade to ensure that the facility remain operational and maintainable.

**McMath-Pierce Interior Painting:**
The exterior of the McMath-Pierce was painted in 1991 and has held up reasonably well; some touch up is scheduled for this summer. Maintenance of the interior surfaces and caulking, however, is long overdue. The section of the interior windscreen just below the top of the pier requires extensive work.

**Reroofing and Sealing:**
Due to deferred maintenance, there now exist several rainwater leaks in the McMath-Pierce complex. The two leaks in the main observing room ceiling and FTS stairwell have become serious and require attention.

**McMath-Pierce Energy Management:**
Improved energy management within the McMath-Pierce complex is required. Currently the lower-tunnel cooling and fans are run open loop. When in operation, the cooling system and fans run continuously even if weather conditions change. Upgrading the system to “closed-loop” operation by the addition of a smart controller and sensors will result in significant savings. Also, additional modest savings may be gained by changes in the general building lighting.

**McMath-Pierce Fall Protection:**
Access to the east and west auxiliary heliostat drives is difficult and can, under certain circumstances, present a safety hazard. A redesign of the accessway and rails should eliminate the hazard. Access has been restricted.

**KPVT Vacuum Line Cold Trap:**
Oil backstreaming from the vacuum pump into the Kitt Peak Vacuum Telescope’s vacuum chamber has been a continuing problem. Adding a large cold trap to the vacuum line should eliminate the problem.

**Extend KPVT Loading Dock:**
The Kitt Peak vacuum telescope loading dock does not extend sufficiently far out from under the roof overhang. This has resulted in damage to the roof by cranes unloading equipment onto the dock. Extending the dock will eliminate the problem.
VII. PUBLIC AND EDUCATIONAL OUTREACH

NOAO has traditionally played a major role in education of graduate students, has a growing role in education at the undergraduate and pre-college level, and is in the middle stages of implementing a long range plan for outreach to the general public.

The effort directed toward outreach to people outside the community of professional astronomers has expanded substantially in the past two years. The plan for this development had three components: 1) creation of a better program for visitors to Kitt Peak mountain, which would in turn generate revenue to help support the other two components of the program; 2) work with school teachers to identify ways that astronomy can be introduced effectively into pre-college classrooms to enhance science education; and 3) re-establishment of the capability for distributing press releases and other information to the media and to the general public. These three program components are listed in the time sequence in which they are to be implemented. The order was determined in part for financial reasons; by making the mountain-based visitor activities more self-supporting, we were successful in freeing funds to support the educational activities. The educational effort was selected as the next for development because we had existing staff with both interest and the necessary capabilities. We are just beginning the implementation of a more systematic program of outreach to the general public.

The components of the education and outreach programs are summarized below, beginning with the traditional NOAO role of supporting graduate student research and then describing the plans for the newer initiatives in public outreach.

A. Graduate Education

NOAO has a consistent and sustained record of supporting a large fraction of the observational theses in the US, and this support will continue during the period covered by this five-year plan. Approximately 120 graduate students participate in observing runs annually, and in any given semester, about 25 thesis programs are assigned time through the competitive review process. A recent analysis showed that approximately 1/3 of the Hubble post-doctoral fellows, 1/3 of the Pierce prize winners, and 1/4 of the Trumpler prize winners used NOAO for a major portion of their research. We have also added a program of graduate student residencies at Kitt Peak. Students live on the mountain and assist with observing support, thereby learning observational techniques and becoming familiar with the set up and operation of instruments; NOAO provides support for room and board. NOAO also has played an important role in providing observing opportunities for astronomers early in their careers and for post docs, who are in many cases not allowed to apply for time on the largest telescopes operated by their host institutions.

B. Undergraduate Education

For many years, NOAO has hosted undergraduate summer students, funded by the NSF Research Experience for Undergraduates (REU) program, and we will continue to seek funding for this program during the next five years. The program currently supports approximately six summer students at each of KPNO and NSO and four students at CTIO. Students work closely with a mentor on the NOAO scientific staff on a substantive research project designed to provide practical experience to undergraduates seeking a career in science.

C. Pre-College Education Programs

Over the past two years, NOAO has initiated—and under the leadership of Suzanne Jacoby has developed support for—a major initiative in pre-college education. This program will be brought to maturity during the period of the current five-year plan.
The overall role of the NOAO K-12 Educational Outreach Office is to make the science and scientists of NOAO accessible to the K-12 educational community in a useable way. The goal is to serve as a resource to educators as they strive to implement the NRC National Science Education Standards. We are also a resource to the NOAO staff when they work with the general public and educational communities. A key component of the program is the NOAO Outreach Advisory Board, a group of thirteen local middle and high school science teachers knowledgeable about NOAO and the science done here. The Board contributes considerable advice and occasional labor on a volunteer basis.

The three main program areas—direct classroom involvement, instructional materials development, and teacher enhancement—are further described in the following paragraphs.

1. Direct Classroom Involvement

Project ASTRO, developed by the Astronomical Society of the Pacific, expanded to Tucson in the fall of 1996 with NOAO as the lead institution. An active and cooperative coalition of astronomy resources in Tucson includes representatives from the University of Arizona, Tucson Amateur Astronomy Association, Tucson Unified School District, Pima Community College, and others. Project ASTRO forms ongoing partnerships between astronomers and fourth to ninth grade teachers in Tucson area schools and community organizations, with teachers and astronomers receiving training, materials, and support throughout the year. The second annual Project ASTRO workshop held in Tucson in October of 1997 welcomed an additional fifty participants to the project and brings the total number of trained ASTRO partners in the Tucson area to over one hundred. ASTRO funds (from the NSF Informal Science Education Program, to the ASP, then to NOAO) provide three years of support for a half-time Project Coordinator, after which time NOAO is expected to continue the program without this source of funding.

The National Solar Observatory (NSO) contributes to both the Tucson-based Project ASTRO and the expansion of Project ASTRO in New Mexico. The first New Mexico Project ASTRO training workshop was held in August 1997, at NSO's new Sacramento Peak Visitor Center in Sunspot, New Mexico, and added another 50 participants to the growing national ranks of trained Project ASTRO partners.

2. Instructional Materials

Instructional materials in various formats have been developed based on topics of current astronomical research taking place within the Observatories. Most materials are available on the NOAO EO Home Page on the WWW as well as in printed formats. We expect to continue with materials development as resources allow. These materials have been well received by teachers, are relatively easy to obtain outside funding for, integrate the development, production, and distribution of resources available within NOAO outreach, and are fun and satisfying to produce.

With funds from an Educational Outreach Supplement to a NASA Sun-Earth Connection research grant, NOAO is developing an educational compact disk on the Sun's Magnetic Cycle. The instructional package will include a day-by-day record of an entire magnetic cycle as recorded in magnetograms and He I 1083 nm spectroheliograms at the NSO Kitt Peak Vacuum Tower Telescope. These data, which have been critical to developing our present understanding of the solar cycle and its terrestrial effects, will be available as individual images and as video sequences in a format compatible with most personal computers available in the home or classroom. This effort is especially timely because the next solar maximum is expected to occur in about two years.

Throughout the next five years, we will continue to identify timely topics that can be used as the basis of lesson plans and will continue to seek funding to prepare instructional materials.
3. Teacher Enhancement

The primary teacher enhancement program during the time period covered by the current five year plan is entitled, "Use of Astronomy in Research Based Science Education (RBSE)." This is a four-year program offering research experience to middle and high school teachers during summer workshops at NOAO. Ten teachers from Tucson participated in the Year One Pilot Study during 1997. In 1998 we will accept up to twenty five teachers from around the country. Participants experience how science is practiced and develop strategies for paralleling those techniques in their classrooms. Teachers are expected to increase their knowledge of astronomy and the scientific process, their use of computer-based technologies including image processing and use of the Internet, their classroom use of inquiry-based teaching and learning, and their awareness of career opportunities in science and technology. The research experience extends to the classroom during the academic year with datasets in preselected areas of astronomical research continuously provided over the Internet. Local mentors, drawn from the national user base of NOAO facilities on Kitt Peak, will provide support to participating teachers in their areas after the summer workshop. Suzanne Jacoby (NOAO Education Officer), Jeff Lockwood (Sahuaro High School teacher), and Don McCarthy (UA Astronomer) are co-investigators on this Teacher Enhancement project, funded through the National Science Foundation's Directorate for Education and Human Resources.

When this program is concluded in three years time, we will evaluate the outcome to determine the best strategy for continuing to work with teachers and to develop lesson plans.

D. Visitor Center Programs

The Kitt Peak Visitor Center attracts approximately 50,000 visitors per year. An aggressive business plan has been implemented to introduce new public services and create new revenue centers to subsidize NOAO public outreach activities. This program has developed extremely rapidly, and so the focus during the initial years of the current five year plan will be to consolidate the program, stabilize the staffing, and make sure that the revenue stream that we have projected can be achieved and sustained. Only after this consolidation will we look at options for further growth.

An enhanced product line—combined with renovations in retail space—is now in place with the goal of increasing sales revenues and improving profit margins.

A fee-based Nightly Observing Program for the public has been created to introduce participants to astronomy and basic telescope usage. A limited group of 20 individuals per night is given a tour of the night sky beginning with a constellation orientation, followed by an introduction to stellar classifications and evolution using the 16-inch Visitor Center telescope, and concluding with planet, nebula, and galaxy viewing using binoculars and portable telescopes. A boxed dinner is provided by the Kitt Peak Dining Hall, thereby generating additional revenue to help support the kitchen staff, who also provide meals for visiting astronomers. A fee-based Advanced Observing Program now gives amateur astronomers the experience of observing on-site at the world's largest optical astronomy observatory using state-of-the-art equipment and including access to, and instruction in, CCD imaging equipment. Over 3,000 visitors participated in the Nightly Observing Program in 1997, and the program is normally sold out several weeks in advance. We expect to support only one or two Advanced Observing programs per week, and the opportunity to participate in such sessions has been widely advertised in such publications as *Sky and Telescope* and *Astronomy* magazine.

A Kitt Peak Docent Program has been developed to train volunteers as tour guides and to give specialized science demonstrations and lectures at the Kitt Peak Visitor Center. Docents attend an introductory six-week training program on NOAO history and policy and receive continuing education throughout the
year. In addition, new exhibits and visitor gallery displays are being installed to enhance the Kitt Peak experience for the public.

The Sunspot Astronomy and Visitor Center opened in the summer of 1997 as a springboard for the education and outreach program at Sacramento Peak. The center includes a large meeting room for workshops and colloquia, and we will be developing educational displays over the next several years.

NOAO continues to be an active participant in the Southwestern Consortium of Observatories for Public Education (SCOPE), a consortium of several observatories located in the Southwest which was organized in 1997. The consortium includes the National Solar Observatory/Sacramento Peak, Apache Point Observatory, McDonald Observatory, Very Large Array/ National Radio Astronomy Observatory, Whipple Observatory, Lowell Observatory, and Kitt Peak National Observatory. SCOPE is working on the development of promotional materials and plans to coordinate visitor center displays. A mutually beneficial partnership with *Astronomy Magazine* is developing.

In the early years of the current five year plan, we expect to inaugurate a fee-based automated tour program at Kitt Peak featuring recorded information via individual headphones. We are looking at the feasibility of creating a new Image Publishing unit to reproduce and market NOAO images in the form of postcards, notecards, posters, and slide packages. Additionally, we are exploring the possibility of creating a wholesale sales catalog to market NOAO products to museums, bookstores, planetariums, and through professional societies such as the Astronomical Society of the Pacific.

**E. Media Relations**

NOAO is in the process of developing a plan for using the media more effectively to disseminate to the general public reports on the science that we do. It has been more than a decade since we have made a significant effort in this area; the programs that did exist were eliminated as a response to declining budgets and the fact that public outreach was not at that time deemed, by the community or by the NSF, to be as high a priority as the scientific programs. Circumstances have changed. Even the KPNO/CTIO users committee now favors a stronger effort in this area.

In planning this initiative, we wish to avoid the problems of earlier programs. Specifically, we want the office to be closely integrated with the scientific programs of NOAO so that the material that is published is consistent with our organizational goals and is characterized by scientific integrity. That is, the results that are highlighted through press releases should be significant, thoroughly vetted by the refereeing process, and appear credible to our professional colleagues. Bruce Bohannan is working with Suzanne Jacoby to develop an overall plan for this component of the outreach program. It is likely that we will target three different audiences: the readers of major publications such as the *New York Times* and the *Washington Post*; the readers of magazines such as *Sky and Telescope* and *Astronomy*; and the local Tucson community. We have already begun to learn how to gain attention for stories through collaborative press releases with other more experienced organizations, as was the case for the story on proto-planetary disks, which made the front page of the *New York Times* and the *Washington Post* and the cover of *Newsweek*. The success of the program that we undertake will be measured by the quality of the material published, not by the frequency of press releases. The goal is to develop long term relationships with major media, provide them with articulate and authoritative scientific contacts, and become such a reliable provider of information that the press releases that we do issue receive attention.

In addition, we will develop some Web-distributed material for the general public. The WWW pages of NOAO (http://www.noao.edu), which describe the programs and facilities, have been redesigned to make the information more accessible to non-professional as well as professional audiences. We are planning to make the NOAO Image Collection, which is a resource common to all outreach programs, available
through the Web. There will be a Web-based pictorial index with thumbnail sketches and brief captions of every available image, as well as downloadable digital versions at different resolutions. Once this database is complete, the NOAO Image Collection will be more widely available, more accurately captioned, and more current. This increased efficiency will make the collection more useful to professional scientists, textbook authors, and the public.

We are also looking at the feasibility of providing specific data sets to the general public. One option is to become an authoritative source for information on activity on the Sun as we approach the next solar maximum. The task here is to select the type of information that will be made available and to develop routine processes for making images available in a timely way without unduly burdening an already overstretched staff.

The overall goal of our newly re-organized public information effort is to integrate our various outreach programs and resources to present a unified message to the many audiences (professional, educational, general public, and internal staff) who come to us for information.
VIII. BUDGET

The budget for this five year plan (Appendix E) is presented in three parts: (1) the core budget, which funds the ongoing telescope operations, instrumentation program, and scientific staff (Table E-1); we have assumed this budget will be maintained at a constant level of effort over the next five years; (2) increments to the program that are properly a part of the base budget but are not covered at the current level of effort (Table E-2); and (3) new projects for which we either have submitted proposals or plan to submit proposals during the time interval 1999-2003 (Table E-3). A summary of the base budget, increments to the operating budget, and proposed initiatives is provided in Table E-4.

A. Operations Budget

Current staffing levels and the rate of investment in instrumentation required to support the core program were justified in the proposal submitted to the NSF to renew the cooperative agreement under which AURA manages NOAO; these numbers will be updated in the forthcoming program plan for FY 1999. These documents make the argument through benchmarking that current staffing is at the minimum level required to operate the program as defined, and the budget plan presented here assumes that this level will be maintained throughout the time period 1999-2003.

In order to estimate the funds needed to maintain the current level of effort, we have matched the budget level in FY 1999 to the request submitted by the President to Congress, and for FY 2000-2003 we have inflated funding at the rate of 3% per year both in Chile and in the US. This represents a change from the past several years when Chilean inflation exceeded the US rate, after allowances for the change in exchange rate, by about 5%. The recent strength of the dollar has served to slow cost increases in Chile, and we are estimating that the current favorable situation of comparable inflation rates in the US and Chile will continue. While US inflation is currently lower than the 3% figure built into this plan, recent financial analyses indicate that salaries in the service sector are rising at a rate faster than inflation, and we believe that salary freezes are not a viable option.

This budget follows the pattern of the previous five year plan in showing a shift of resources away from KPNO and into USGP/SCOPE. USGP/SCOPE will be responsible for implementing the “one-stop shopping” approach to handling applications for observing time and supporting the community in their use of Gemini and the telescopes at the independent observatories, as well as the facilities at KPNO. We have also assigned to USGP/SCOPE those internal functions that serve the scientific staff of more than one NOAO division. Included are the photo lab, the library, Central Computing Services, which supports the scientific computing system and network access, and the IRAF group. Several scientific staff positions (Caty Piłachowski, Buell Jannuzi, Tod Lauer, Dave DeYoung, and one vacant position) have also been transferred from KPNO to USGP/SCOPE.

All major instrumentation for CTIO and KPNO is now being built in Tucson, as is that portion of the instrumentation for Gemini that is being developed at NOAO. Five scientific staff are devoting nearly all of their service to the instrumentation program and are now budgeted within it. These staff are Taft Armandroff, who is head of the optical instrumentation program; Sam Barden, who is project scientist for Hydra/CTIO and for the Gemini CCD controllers; Ken Hinkle, who is project scientist for Phoenix; Mike Merrill, who is project scientist for the IR array controllers for both NOAO and Gemini and also for the Aladdin array program; and Jay Elias, who is project scientist for the Gemini near infrared spectrometer.

Note that a salary adjustment—the first in 18 months—of 3% was made on 1 February 1998 before the final budget figure was known for NOAO. With this adjustment, the cost of maintaining the current level of effort is $28.13M dollars per year. Providing a salary adjustment of 3% on 1 February 1999 would raise this cost to $28.74M dollars per year since 75% of the budget is currently devoted to salaries and...
benefits. If a 3% adjustment is also made in the non-payroll accounts effective 1 October 1998, then the annual cost of the current level of effort becomes $28.8M. The President's request is too low to accommodate increases at this level, and accordingly the plan has been prepared with a 1.5% increase in the salaries of US staff only, effective February 1. No inflation adjustment has been made in either non-payroll or the salaries of Chilean staff.

While SOLIS funding in FY 1998 was provided as an increment to the operations budget, funding in FY 1999 of $1.4M was included in the President's request of $29.72M for NOAO.

NOAO expects to provide $2M toward funding of the construction of SOAR. About $150,000 of these funds, which were identified earlier through a combination of restructuring funds from the NSF and internal reprogramming, have been spent to date.

Our priorities for the operating budget are:

- Maintain the current level of operations, including paying a salary adjustment on 1 February 1999
- Complete SOLIS in a timely manner

B. Increments to the Operations Budget

1. Technical Salaries

The salaries for scientific and technical staff are no longer competitive. Scientific staff salaries remain about 15% below those of AURA member institutions. The problem for engineering and technical staff is even more acute. A severe shortage of engineers and programmers now exists nationwide; salaries for technical personnel are increasing at rates that are estimated in engineering publications to exceed 10% per year, and NOAO's own salaries are no longer competitive—as demonstrated by the fact that we have been unsuccessful in recruiting new staff at salaries that are consistent with our current scales. Some positions have now remained vacant for more than a year, thereby severely impacting our ability to deliver instruments to Gemini, CTIO, and KPNO according to schedule.

Therefore, our priority for an enhancement to the operations budgets is:

- To increment engineering/software/technical salaries by $250,000 in each of the years 2000 and 2001. Given the President's request for FY 1999, it is not possible to provide this increment sooner without reducing the current program of support for telescope operations, and we prefer to delay the instrumentation program, which will be the inevitable consequence of our inability to fill positions through the payment of competitive salaries.

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<tbody>
<tr>
<td>Proposed Increase</td>
<td>—</td>
<td>$250,000</td>
<td>$500,000</td>
<td>$500,000</td>
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</tbody>
</table>

2. Data Reduction and Archiving

The first generation of instruments for the Gemini telescopes includes an optical spectrograph with multi-slit mask capability and an integral field unit, a cross-dispersed high-resolution optical spectrograph, near and mid-IR imagers, and a near-IR spectrograph with three gratings, four cameras, and a cross disperser.
Neither Gemini nor the groups building the instruments will be supplying off-line data reductions software. While IRAF already contains many of the building blocks needed to assemble data reduction packages for these instruments, there are clearly some elements missing. In the near term the effort required is to understand the data reduction requirements of each instrument and the areas in which there are deficiencies in existing IRAF software. Then the existing programs should be pieced together into instrument-specific packages and the required new software written. It is desirable to have initial versions of these packages by the time the instruments are being commissioned, which will begin in mid-1999. The level of effort to accomplish this is one scientific programmer immediately, ramping up to two programmers by mid-1999 to put together the packages for all the initial instruments. This would then ramp back down in the steady-state.

Available expertise in archiving astronomical data now exists to make the initiation of an NOAO data archive a cost-effective operation. An investigation of the cost to establish an archive for the NOAO CCD Mosaic imager produced a quote of $30,000 per year with a start-up cost of $100,000. This would support the input of data as they are obtained and the availability of these data to the astronomical community after the expiration of the proprietary period. The task of ensuring data quality and reduceability of data requires an additional FTE.

![Table VIII-2](image)

**Table VIII-2**

<table>
<thead>
<tr>
<th>USGP/SCOPE</th>
<th>USGP/ScOpe Data Reduction &amp; Archiving</th>
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</thead>
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<tr>
<td>Data Reduction for Gemini Instruments</td>
<td>$75,000</td>
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<tr>
<td>Archive</td>
<td>$175,000</td>
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</table>

3. Detectors

The instrumentation program for nighttime astronomy is fully funded except for the $300,000 that is estimated to be required annually to fund detector purchases. We estimate an additional $100,000 per year will be required for detectors for NSO. No funding is provided within the core operating budget for the purchase of detectors.

![Table VIII-3](image)

**Table VIII-3**

**Increases to Operations Budgets**

<table>
<thead>
<tr>
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<tr>
<td>Detectors</td>
<td>$400,000</td>
<td>$400,000</td>
<td>$400,000</td>
<td>$400,000</td>
<td>$400,000</td>
</tr>
</tbody>
</table>

C. Initiatives

NOAO plans to submit separate proposals for the following projects:

1. 2.4-m Telescope for KPNO

A proposal has been submitted for $2M to the MRI program at the NSF as a partial contribution toward the $6M cost of constructing a 2.4-m telescope on Kitt Peak (Appendix C). Half of the construction,
operations, and, over the lifetime of the telescope, the instrumentation will be funded by the Universities of Colorado and Minnesota.

2. 2.4-m Telescope for CTIO

NOAO is working with the MACHO group to prepare a proposal to build a 2.4-m telescope at CTIO to extend the MACHO survey to determine the nature and location of the dark matter responsible for the lensing events. The telescope would be used for the MACHO survey during dark time when the Magellanic Clouds are above the horizon. The remainder of the telescope time would be available to the NOAO community. The wide-field CCD imager would be provided by the MACHO group. The cost of the telescope is $6M. (The costs of the KPNO and CTIO telescopes are comparable because the first makes use of the Hubble spare, thereby reducing the cost of the optics, but must provide for the full non-recurring engineering costs.)

3. The GONG Upgrade

The GONG project team has built and successfully tested a prototype camera that increases the angular resolution by a factor of four relative to the currently deployed cameras. Installation of this camera at the six GONG stations around the world would provide for continuous surface velocity and magnetic field measurements that can be used to probe changes in the solar interior over the course of the solar cycle. The cost of the new cameras, now that the prototype has been built, is currently estimated to be $1.63M. Operations costs will increase by about $300,000/year after installation of the new cameras, driven in large part by the increased costs of data storage media and processing.

4. Advanced Solar Telescope Technology Studies

A number of technology and other studies are prerequisites for the preparation of a proposal for a 3- to 4-m aperture Advanced Solar Telescope (AST—aka the flagship telescope). These studies include:

- **Adaptive Optics.** NSO expects to have a low-order, 20 Zernike, adaptive optics system in place at the SP Vacuum Tower Telescope (VTT) in 1999. It will demonstrate that fast solar wavefront sensing and wavefront control can be done on a 76-cm aperture solar telescope. It will allow diffraction-limited imaging at the VTT under median seeing conditions at 1 micron wavelength. To do so at visible wavelengths (0.5 micron) at the VTT requires an 80 Zernike system. The same system applied to a 400-cm aperture AST located at a superb seeing location (median Fried parameter of 20 cm) will give diffraction-limited imaging at 1 micron wavelength for median seeing and at significantly shorter wavelengths at 10 percentile good seeing. An 80 Zernike system therefore has the complexity and capability needed for the AST. As part of the AST Technology Studies we propose to develop that 80 Zernike system by upgrading the 20 Zernike system, which already has a 97 actuator adaptive mirror and 20 sub-aperture correlation tilt sensors.

- **Site Selection.** The selection of the best solar observing site is essential for the optimum performance of the AST. Important site parameters are low cloud cover, excellent seeing, and low sky brightness. Excellent image quality (seeing) is a dominant requirement both scientifically and technically. With it comes a large isoplanatic patch size and a significant cost reduction in the AST adaptive optics.

- **Control of Telescope Seeing.** The AST will collect over 10 Kwatts of solar energy. Part of that (~10%) heats up the primary mirror, part of that will be intercepted by the prime focus heat stop and elsewhere. In the past vacuum telescopes were used to eliminate the resulting telescope seeing effects
at the cost of the elimination of most of the IR portion of the solar spectrum and of an increase of scattered light. The AST will not use a vacuum and thus has to manage the telescope seeing in another way. Analysis of the CLEAR concept has shown that to be possible. Recent experience with the Dutch Open Telescope (DOT) on La Palma appears to confirm that. Further experimentation is needed, however.

- **Phase B Design Study.** It is necessary to establish a high degree of confidence with respect to the technical feasibility and estimated construction cost of the AST.

NSO intends to involve the solar community closely in these studies. The funding required is estimated to be $6M divided over three years beginning in FY 2000. Included are $3.5M for upgrading the 20 Zernike Adaptive Optics system to the 80 Zernike System; $0.3M for site evaluation, selection and characterization; $0.2M for the telescope seeing control tests; $0.2M for other miscellaneous tests; $0.1M for community participation (e.g. travel); and $1.7M for the Phase B study.

5. **Second 2.4-m Telescope for KPNO**

The long range plan calls for the equivalent of one full 2.4-m telescope to support optical and infrared wide-field imaging at Kitt Peak. In order to jump start this project, we have entered into a partnership with universities, which will result in only one-half a telescope for the NOAO users. We propose to seek funding for the remaining half telescope after the higher priority projects are complete. We are confident that such partners can be found.

<table>
<thead>
<tr>
<th>Table VIII-4</th>
<th>NOAO Initiatives (NSF New Funds Only)</th>
<th>($ in Millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
<td>1999</td>
<td>2000</td>
</tr>
<tr>
<td>1. 2.4-m Telescope (KPNO)</td>
<td>$ 2.00</td>
<td>$ —</td>
</tr>
<tr>
<td>2. 2.4-m Telescope (CTIO)</td>
<td>1.00</td>
<td>3.00</td>
</tr>
<tr>
<td>3. GONG Upgrade</td>
<td>1.01</td>
<td>0.62</td>
</tr>
<tr>
<td>4. AST Technology</td>
<td>—</td>
<td>2.00</td>
</tr>
<tr>
<td>5. 2.4-m Telescope (KPNO)</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$ 4.01</strong></td>
<td><strong>$ 5.62</strong></td>
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</tbody>
</table>
APPENDIX A

The WIYN Queue: Theory Meets Reality


"National Optical Astronomy Observatories, P.O. Box 26732, Tucson, AZ 85726-6732
bEuropean Southern Observatory, Karl Schwarzschild-Str. 2, D85748 Garching, Germany

ABSTRACT

During the past two years NOAO has conducted a queue observing experiment with the 3.5m WIYN telescope on Kitt Peak, Arizona. The WIYN telescope is ideally suited to queue-scheduled operation in terms of its performance and its instrument complement. The queue scheduling experiment on WIYN was designed to test a number of beliefs and hypotheses about gains in efficiency and scientific effectiveness due to queue scheduling. In addition, the experiment was a test of our implementation strategy and management of community expectations. The queue is run according to a set of rules that guide decisions about which observation to do next. In practice, scientific rank, suitability of current conditions, and the desire to complete programs all enter into these decisions. As predicted by Monte Carlo simulations, the queue increases the overall efficiency of the telescope, particularly for observations requiring rare conditions. Together with this improvement for typical programs, the queue enables synoptic, target-of-opportunity, and short programs that could not be scheduled classically. Despite this success, a number of sociological issues determine the community's perception of the WIYN queue.

Keywords: Queue scheduling, WIYN Telescope

1. THE WIYN TELESCOPE

The WIYN telescope is a 3.5-meter alt-az mounted telescope at the southwest end of the summit ridge of Kitt Peak, Arizona. The telescope was built and is operated by a consortium comprising the University of Wisconsin, Indiana University, Yale University, and NOAO. The telescope is notable in the importance placed on image quality in its design. It has a spin-cast borosilicate mirror with a 66-actuator active support system, a primary mirror thermal control system, and a well-vented dome. The result of this effort is excellent delivered image quality; in the two years of operation the median image FWHM is 0.8 arcseconds (measured in 10 second R band exposures, once a night, immediately after optics/wavefront evaluation), and images as small as 0.36 arcseconds FWHM have been achieved.

The f/6.3 beam is fed to one of two Nasmyth ports with a flat tertiary. One port holds a medium-field CCD imager: a 2048 x 2048 pixel CCD with 0.2 arcsecond pixels and a 7 arcminute square field of view. The other port holds a multi-fiber spectrograph feed known as HYDRA. HYDRA uses a robot-gripper to position 96 fibers individually over the one-degree diameter field. Two sets of fibers are available (only one of which can be used at any time), a blue-optimized set in which each fiber has a diameter of 3.1 arcseconds and a red-optimized set in which each fiber has a diameter of 2.0 arcseconds. The robot-gripper takes about 25 minutes to configure an entire set of fibers. The other end of the fibers form a slit in a bench-mounted spectrograph maintained in a thermally controlled and vibrationally isolated environment. This spectrograph can be manually configured with any one of six gratings and two cameras. The two instruments can be held in readiness simultaneously and the beam can be switched from one instrument to the other in a few minutes.

Forty percent of the time on WIYN is available to the astronomical community through NOAO. Almost all of that time is queue scheduled. Proposing astronomers do not come to the telescope. They submit the information that enables staff observers to obtain the observations and the data is sent to them either on magnetic tape or over the Internet. In many ways this telescope is ideally suited to queue scheduling. Because the delivered image quality can be so good, programs that require 0.5 to 0.7 arcsecond seeing can be accepted with some confidence that such conditions will be achieved at some time during the course of a scheduling period. The two instruments are complementary in the sense that the imager can make use of the periods of excellent seeing while HYDRA can still be used efficiently when the seeing is not good.
2. THEORETICAL ADVANTAGES OF QUEUE SCHEDULING

The dynamic scheduling of the WIYN telescope according to the current conditions should permit a number of quantitative gains in telescope efficiency and scientific effectiveness.

- With queue scheduling, the telescope is never sitting idle if the conditions are good enough to execute any program. While observers sometimes have “backup” programs for conditions unsuitable for their primary program, these backup programs are rarely evaluated scientifically by the allocation committee. The queue should allow the execution of a larger fraction of approved programs than a classically scheduled telescope. Also, the ability to change programs reduces the loss of time due to instrument malfunction.

- The most dramatic gains are expected for programs which require rare, unpredictable conditions. The probability of getting three consecutive nights of best quartile seeing is small enough that most TACs would be reluctant to approve a program with such a requirement. Queue scheduling allows an optimum match of the program requirements to the current conditions.

- Many programs do not fit neatly into the usual allocation pattern of several consecutive nights. Programs that require only a fraction of night, synoptic programs, target-of-opportunity programs, programs that have targets extending over a large range of RA, programs that cannot make effective use of entire nights, and those that require observations to be synchronized with more rigidly scheduled observatories are more readily integrated into a queue scheduling system.

- Queue scheduling makes optimum use of conditions that vary in a predictable way also. For example, some programs require dark time to reduce the background to an acceptable level. A scheduling strategy in which the program may change when the moon rises or sets allows the use of the dark ends of bright nights for dark time projects.

A Monte Carlo simulation can be generated to predict the gains in efficiency expected from queue scheduling on the WIYN telescope. Figures 1 and 2 come from a simulation$^1$ that used theoretical distributions of both program requirements and atmospheric conditions. They show, at least in a qualitative sense, the three main drivers for queue scheduling: the overall increase in telescope efficiency, the ability to emphasize programs of high scientific rank, and the greatest gains for programs requiring rare conditions.

Figure 1 shows that a queue can be operated such that the programs executed are primarily those of highest scientific rank. Classical scheduling shows a flat distribution with program grade, since success of these observations depends only on the statistics of weather and other conditions. The queue simulation shows a somewhat artificial and ideally sharp cutoff with program grade because the constraints such as the positions of targets and other predictable factors have been minimized.

Figure 2 demonstrates that the queue produces a net increase in overall efficiency, but a dramatically larger increase in the programs that are distinguished by their requirement for good seeing. Whenever the seeing is good, observations for these programs can be executed. The final category, programs completed, shows the consequence of working on a program until it is completed. What is not shown is that the classical approach gets some data for a larger number of different programs.

3. OPERATION OF THE QUEUE

After a proposal is accepted, the PI is requested to fill out and submit a form that describes the observations and required conditions in enough detail to allow the observer to carry them out. In addition to information about the observations themselves, such as target positions, filters, exposure times, the PI must indicate any special calibration requirements. Any calibration observations that must be done between evening and morning twilights are charged to that program. Requirements for lunar phase, sky clearness, and image quality are entered in tables, but an additional text explanation often proves essential for deciding whether an observation can be executed at any particular time. The PI must state some figure of merit that will allow the observer to determine whether an observation is acceptable, typically some measure of S/N and, for imaging, an image quality figure.

A-ii
Figure 1. Results of a Monte Carlo simulation of the WIYN queue in which the percent of observations completed in a scheduling period is shown as a function of the scientific grade of the proposal. In this model, a grade of 1 is highest. Results are shown for both a queue-scheduled semester and for a classically-scheduled semester.

Figure 2. Results of a Monte Carlo simulation of the WIYN queue in which the percent of observations completed in a scheduling period is shown as a function of the type of program. HYDRA refers to the WIYN multi-fiber spectrograph. LRI refers to imaging that does not require seeing better than median. HRI refers to imaging that requires better than median seeing. Total refers to the total number of observations completed. Results are shown for both a queue-scheduled semester and for a classically-scheduled semester.

The queue is maintained as two separate lists, a “high priority” list and a “best effort” list. Although the principal distinction between these is the scientific grade, consideration of the requirements of the programs also enter. For instance, programs that require dark time and bright time are treated somewhat separately, and bright time proposal with a lower scientific grade may appear on the high priority list if bright time is less subscribed.

The decisions about what observations to make during a queue night depend on a number of factors. These decisions are based on the WIYN queue rules, which define these factors and their relative importance. These rules are published on the World-Wide Web, and are printed below.
1. WIYN Long Program (LP) proposals will be reviewed and graded by the same KPNO TAC that reviews and grades 4m proposals.
2. WIYN Short ("2hr") Program (SP) proposals will be reviewed and graded internally.
3. After the proposals are reviewed by the TAC, WIYN observing programs will either be scheduled classically (i.e., assigned specific nights), placed in the WIYN observing queue, or denied observing time at the discretion of the KPNO Director or the Director's designee.
4. WIYN programs assigned to the WIYN queue will be further divided into two classes by the KPNO Director or the Director's designee. Class 1 (highest TAC grades) programs will be given "highest priority". Class 2 (lower TAC grades) will be given "best effort" status and only scheduled and executed if no Class 1 program can be scheduled or executed. Note that programs with otherwise excellent TAC grades are sometimes assigned to the Class 2 queue due to targeting conflicts with programs with a higher TAC grade.
5. The WIYN observing queues will be managed by "program" not "object".
6. LP programs will be executed primarily by TAC grade and then by:
   - celestial coordinates
   - acceptable lunar phase
   - angular distance from Moon
   - LST
   - delivered image quality ("seeing")
   - sky conditions (photometric/spectroscopic)
   - spectroscopic configuration
   - level of completion (i.e., in general, completing programs or at least providing a scientifically useful dataset has higher weight than initiating a new program, unless the new program has a significantly higher TAC grade)

These secondary ranking criteria will be applied dynamically.
7. Total time allotted to the Class 1 queue will be approximately equal to 60% of the total time made available to NOAO by the WIYN Consortium. This percentage is roughly equivalent to the mean percentage of photometric and spectroscopic nights per semester at KPNO.
8. Total time allotted to the Class 2 queue will be approximately equal to 50% of the total time made available to NOAO by the WIYN Consortium. This overallocation of time allows for uncertainties in the exact mixture of actual observing conditions in the real semester.
9. Objects will only be observed when they are at 1.5 or lower airmasses, unless higher airmasses are acceptable in order to complete the program, as specified by the PI, or a target never satisfies this criterion.
10. LP programs will be initiated as followed:
    
    A = ABSOLUTE number of NOAO hours left in current semester,
    B = number of CLEAR hours that meet the secondary criteria required to complete currently ACTIVE LP program(s),
    C = number of CLEAR hours that meet the secondary criteria required to complete the NEXT LP program in the TAC grade ordered queue,
    if (B+C ≤ A): start next LP program,
    else: do NOT start next LP program.

11. Program allocation time is defined to be the time necessary to complete the scientific objectives of a program as recommended by the TAC and reviewed by the KPNO Director.
12. LP program execution time will be allowed to exceed allocated time only if: (1) the queue observing team elected to observe certain targets under less than optimal conditions (as defined on the approved program WIYN queue form) and further integration time was needed to satisfy the PI specified figure of merit for those targets; or (2) the queue observing team makes a technical error which requires repeating or extending the observation of certain targets.
13. In general, individual LP program execution time will not be allowed to exceed the allocation time. Once program execution time equals allocation time, the program will be terminated as soon as reasonably possible (e.g., programs will not be terminated in mid-exposure). Note that program execution time includes both integration time and all overheads associated with executing the program (e.g., CCD readout time, Hydra configuration time, telescope slew time, etc.)
14. Preference will be given to meeting the PI specified figure of merit per object. If it appears these specified figures of merit are in error, jeopardizing the completion of the entire program within the allocated time, the PI will be informed and asked to re-prioritize their program.

15. Programs initiated and at least 75% completed, but not fully completed, during the current semester may be completed during the next contiguous semester at the discretion of the KPNO Director. Otherwise, all uncompleted programs will be terminated at the end of each semester and will not be re-started until they are again reviewed and graded by the TAC.

16. Programs not initiated by the end of the current semester will NOT be scheduled in any subsequent semester unless the proposal is re-submitted to the TAC for review and grading.

17. When multiple LP programs are active, the LP program with the best TAC grade and which meets the secondary criteria listed above will have highest priority.

18. On nights when the R-band WIYN delivered image quality is 0.8" or better, preference will be given to programs which require these excellent seeing conditions.

19. Night-time Bench Spectrograph configuration changes will be discouraged and only one per night will be allowed. Note that for certain programs the Bench Spectrograph configuration should NOT be changed until the program is completed.

20. Night-time Bench Spectrograph CAMERA changes will NOT be allowed.

21. Once "passed", SP ("2hrQ") programs will be initiated randomly, except as modified below.

22. Class 1 SP programs will be given preference over Class 2 SP programs.

23. When a Hydra LP program is selected, Hydra SP programs will be executed concurrently if there are SP programs which closely match the current Bench configuration subject to the standard secondary criteria.

24. On nights when the DIQ ≤ 0.6", one (1) Imager SP program which requires exceptional DIQ conditions will be executed.

25. Every tenth usable night, up to one (1) night will be spent on Imager SP programs.

These rules could be used as algorithms to be executed by a computer program, but instead, they are used as guidelines for decisions made by personnel. We have chosen not to be very rigid, but to let our system be flexible enough to accommodate different circumstances. In practice, the decisions are usually made as follows: The personnel involved in the queue program meet about one week before the start of a queue block to plan out a general strategy. For each night a high priority (Class 1) program is selected. The time before or after that program can be undertaken is filled with other high priority programs (usually imaging programs). If no high priority programs are suitable, programs are drawn from the best effort queue (Class 2). An effort is made to complete at least logical subsets of programs that are started, but when rare conditions (very good seeing) occur, programs that require those conditions are given priority. Time critical or target-of-opportunity observations are often strong drivers in selecting programs for a night. In a sense, the criteria used are 1) scientific rank, 2) suitability based on predictable conditions (position in sky, lunar phase), 3) matching the program atmospheric requirements to the current conditions, and 4) desire to complete programs or at least subsets of programs. The ultimate responsibility for making these decisions rests with the observer.

Certain operational factors also affect the decisions. Major instrument configuration changes cannot be done in the middle of the night. HYDRA takes 20-25 minutes to position all of its fibers, and so imaging observations are sometimes executed during the setup time for the next HYDRA exposure. At times when the telescope or instrument stability seems less certain, the decision may be made to concentrate on less demanding or shorter programs.

Most data are distributed on Exabyte tapes after some appropriate subset of the program has been executed. In cases where the observations are time-sensitive, the data may be ftp'd to the PI at the end of the night. Occasionally, some sort of interaction with the PI is needed, e.g., confirmation of the data quality or a perceived problem with the information about the program. These interactions are carried out almost exclusively by email.

4. QUANTITATIVE EFFECTIVENESS OF THE QUEUE

In order to judge the effectiveness of the WIYN queue in terms of the predictions of the simulation, we have generated analogous plots showing the success of the queue for the two semesters in 1997. The classical comparison has been modeled by taking the actual programs (excluding the synoptic programs and the 2-hour-queue programs) in the queue and scheduling them on a calendar (limited to the nights that were allocated to the queue), with priority given to the programs of highest scientific rank. The success of the classically scheduled programs was determined by using the actual weather and seeing conditions that had occurred during the nights assigned to each proposal. Figure 3 compares the queue and classical approaches with respect to TAC grade; Figure 4 shows the success of each approach with respect to the type of program.
Figure 3. Comparison of actual queue-scheduled success (2 semesters) with success predicted for the same programs classically scheduled in the same nights.

Figure 4. Comparison of actual queue-scheduled success (2 semesters) with success predicted for the same programs classically scheduled in the same nights. The percent completed are shown against the type of program. HYDRA refers to the WIYN multi-fiber spectrograph. LRI refers to imaging that does not require seeing better than 1 arcsec. HRI refers to imaging that requires better than 1 arcsec seeing. Note that these definitions (LRI and HRI) are slightly different from those in Figure 2.

These figures demonstrate that the queue is remarkably effective in the ways predicted by the simulation. The overall telescope efficiency is increased. The success rate for observations that require rare conditions is increased even more. The rate of success of completing programs is increased significantly. However, the comparison with the simulation is not perfect. Some caveats about the actual programs should be kept in mind:

A significant element of the queue programs is the synoptic programs which could not be classically scheduled. These synoptic programs dominate the statistics for both the programs with grade of 1.0 and the LRI programs. Since these synoptic program could not done at all classically, these bins are empty. It should be noted (as evidenced by the high grades) that the TAC has thought highly of the concept of using the WIYN queue for unusual programs, and so while this is an
impediment to a straightforward comparison between queue and classical, it is clearly viewed as an advantage of the queue. Similarly, the KPNO users committee has been supportive of continuing the WIYN queue experiment because some of the advantages are unequivocal.

Figure 4 shows that, as predicted by the simulation, the fraction of observations completed is about 15% higher with the queue, and that four times as many HRI observations are completed by the queue. Both the completed programs comparison (about 2 1/2 times as many with the queue) and Figure 3 overall show the real difficulties of implementing a queue. In reality, the positions of target objects and the limited number of nights available strongly influence which observations are completed.

5. COMMUNITY EXPECTATIONS AND RESPONSE

The quantitative gain in efficiency due to queue scheduling affects a relatively small number of people. A much more important and visible measure of the success of a program such as this is what the community thinks of it. In general, astronomers would rather take their chances with the weather and other conditions than be allocated a spot in the queue. Much of what we have learned about how to make the queue successful involves what proposers are told to expect, the degree to which we can really do what we have said we will try to do, and our own luck with the weather.

One important area of community perception is how completely the queue is filled. On one hand, there should never be occasions when the conditions are relatively good yet there are no remaining suitable programs. On the other hand, a semester of bad luck with weather or seeing can leave a large number of proposers upset that they got no data despite being told they had high priority. Our solution to this problem is to separate the queue into the “high priority” and “best effort” groups, with the high priority group sized such that we really expect to complete just about all of these programs under typical conditions. Figure 5 shows the relative success of programs in the high priority and best effort lists. It can be seen that a large majority of the high priority programs are completed, while for the best effort programs, a limited amount of data is obtained.

A second concern is how to keep proposers informed about the status of their programs in the queue. During a queue block, queue status information is updated on the World-Wide Web every few days. Except in cases where the observations are time-critical, proposers are not notified that observations for their program were obtained, but they can find this out by inspecting the latest queue reports. The status is presented in three different tables. One table lists the programs in the queue for the entire semester, and shows how much time has so far been expended for each program. A second table shows each night of a

![Number of Programs vs. Percent Completed](image)

**Figure 5.** The number of programs in three semesters of the WIYN queue are shown as a function of the fraction of the program that was completed. The high priority and best effort lists are shown separately.
queue block with a summary of the conditions and problems. It lists the ID numbers of programs for which observations were obtained on a given night. A third table refers to a single night, listing the programs that were worked on during that night, and giving the conditions under which observations were obtained for each of those programs.

Another factor that affects the degree of mismatch between the programs accepted into the queue and those executed is the understanding that the Time Allocation Committee (TAC) has of the operation of the queue. When a TAC considers proposals for a classically scheduled telescope, little attention is paid to where program objects are in the sky or what seeing is required. It is understood that the scheduler will attempt to accommodate the requirements of the highest ranked proposals and everyone else will take their chances. When the queue is filled with proposals that all require better than median seeing, it is guaranteed a high failure rate even before the semester begins. The TAC has to be cognizant not only of the number of nights that will be available to the queue, but also the distributions of lunar phase, expected seeing, and photometric weather. Since these are all more or less independent, only a few observations that require dark, photometric time with the seeing in the best quartile should be accepted into the queue. In some semesters we have seen serious mismatches between the distribution of required conditions and what is expected. We now try to limit the likelihood of a serious mismatch by including consideration of factors other than scientific grade when we construct the queue.

In order to better understand the community's perception of the success of the WIYN queue program, a short questionnaire was circulated in September, 1997. Only 40 out of the 376 WIYN proposers returned the questionnaire. The overwhelming sentiment was that when data were obtained, they were satisfactory for the science that had been proposed. Interactions with the WIYN queue staff were regarded as helpful and sufficient to address problems. At the same time, there was a dominant view that most proposers waited patiently for observations that were never made. Comments returned with the questionnaire indicate that most proposers understand the global benefit of the queue: improved telescope efficiency, ability to "guarantee" a match between the best conditions and the programs that require those conditions. However, a majority would rather take their chances with a classically scheduled run. Most respondents suggested that a mix of queue and classical scheduling would be most effective.

The only group that sees the queue as essential are those whose programs could not be accommodated at all in a classically scheduled operation. In particular, programs involving monitoring or target-of-opportunity observations have benefited tremendously from the queue. Some of the science that has been enabled in this way is monitoring of gravitational lens images to determine H0, follow-up imaging to find optical counterparts to gamma ray bursters, and follow-up photometry of faint, high redshift supernovae.

6. FUTURE EXPERIMENTS AND EVOLUTION OF THE QUEUE

The WIYN queue currently handles about 25 proposals per semester and is being run and managed by 4 people supplying various fractions of their time. Decisions about which programs to run – both on the 'long' timescale of setting up for a run (spectrograph configuration, filter sets, etc.), and on the 'short' timescale of deciding what observations to do during a night are being made by the observers in accordance with the rules given in section 3 and personal familiarity with the entire pool of proposals. A larger queue will be impossible to run in this way, but this human interaction has been invaluable in identifying the practical issues and difficulties.

The natural progression is to quantify the factors by constructing a utility function for each observation that aids decision making on all timescales. Obvious elements of such a function are:

a) The number of opportunities remaining in the semester for making a specific observation (would include ephemerides, lunar phase and position, expectation of clear nights and adequate observing conditions from site-specific statistical data).

b) The optimum time for making a particular observation (again, driven by ephemerides, lunar particulars, and weather profile, but also includes instrumentation setup).

c) The priority of a particular observation in relation to the scientific goals of the program as a whole (investigator supplies priorities).
d) The scientific priority of the proposal as judged by the TAC.

e) The degree of completion of the proposal – i.e., what fraction of the data remains to be obtained.

The utility function will generally change as the semester progresses – and must be designed so that it can be easily recalculated. The various elements of the utility function may contribute differently to the whole, depending on the type of observation. In particular, the utility function for synoptic programs with specific dates or intervals may need to be calculated differently. The idea is that observations with the highest utility functions drive the setups. Given a setup, element b) above could change for other observations, thereby identifying them as candidates to be executed contemporaneously.

The construction of the utility function needs to abide by the paradigms set out in section 3. The WIYN queue provides a natural laboratory for testing such a scheme, and tuning it with human intervention from an experienced team, while the queue is still small enough to be managed without computer aid.

An area in which further development would help both proposers and the queue staff is the maintenance of appropriate documentation – not only those items specifically related to queue operations, but the telescope and instrument capability and performance documentation that proposers will be using to prepare their proposals and observing plans. One aspect of this is the development of tools to assist the proposer in understanding the conditions under which a particular program can be executed. For instance, “lunar phase” should really be replaced by “sky background”, and the proposer must have a means of determining and specifying what the acceptable or optimal limit is.

Despite the limitations and inefficiencies of the current system for running the queue, it is clear that it is the only way to make effective use of the best conditions. As we develop more facilities that achieve site-limited performance, we will see the range of conditions expand toward the extreme that allows unique observations. These conditions will not be limited to seeing, but will include IR background and suitability for adaptive optics as well. Experiments such as this one that explore how to effectively schedule observations will lead to the most effective operations of the telescopes being completed now and all telescopes in the future.

REFERENCES

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The Soar Telescope Project: A Four-Meter Telescope Focused on Image Quality

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Introduction: In the era of 10-meter class optical telescopes, 4-meter apertures still have their strengths. Key among these are: (1) they collect enough light to pursue efficiently many long-term synoptic programs that follow time-variable phenomena. (2) Their image quality can be optimized at tractable cost to maximize the efficiency of background limited imaging and spectroscopy. (3) They can provide a constantly resident suite of well-calibrated, comparatively inexpensive and therefore program-optimized instruments that can be brought quickly to bear on targets of opportunity or those in (1) & (2). Science enabled by the first capability might be spectrophotometry of Cepheid stars in other galaxies or matter transfer in compact binaries. Microlensing by sub-solar masses (including planetary mass) binary companions represents the third class, as do spectral studies of distant supernovae that have been detected with automated photometric surveys. Background limited observations become competitive if the telescope minimally degrades the image quality at an excellent site. A 4-meter with 0."33 images is just as efficient as a 6.5-meter with 0."5 images. Hence there is a strong scientific case for development of very high quality 4-meter class telescopes at superb sites. SOAR is one such effort.

Background: Initiated by the University of North Carolina (UNC) at Chapel Hill in 1990, the SOAR Telescope Project is now a collaboration between UNC, Brazil, Michigan State University, and the National Optical Astronomy Observatories (NOAO). Funded at a level of $28 million, the objectives are to design, construct, and commission a 4-meter optical/IR telescope within 4 years, at Cerro Pachon in Chile. The telescope is to be operated by the Cerro Tololo Interamerican Observatory (CTIO). US astronomers will receive 30% of the time through NOAO in exchange for this support. Instruments will be provided by partner institutions.

Extensive comparison of competing optical designs for SOAR over the past year have resulted in a decision to optimize encircled energy to address the broad scientific objectives of the partnership. A Ritchey-Chretien design has been chosen with extremely challenging specifications. Low-scatter optics and careful attention to baffling, coatings, and other aspects of system design will minimize stray light. Tip/tilt image stabilization will be integrated fully into the telescope.

A Project Office has been established at NOAO, and concept design work is underway in response to established scientific and technical requirements. Contracts for concept development of the SOAR facility, an active optical system, the telescope mount, and for initial leveling of the site have been let. Official ground-breaking ceremonies will be held in 4/98.

Scope: The SOAR Project includes development of the Cerro Pachon site, a rocky promontory approximately 0.4 km northeast of the Gemini site. A compact facility will be constructed, including space for instrument and telescope maintenance. The telescope will feature an active optical system that includes a figure-controlled primary mirror (M1), an actively aligned secondary (M2), fast tip/tilt image stabilization at M2 or the tertiary mirror (M3), an optimization wave-front sensor, and control electronics and software.

The telescope mount, to be developed and tested at the manufacturer’s facility, will include support flanges for Nasmyth and bent-Cassegrain instruments. Initial instrumentation, under consideration as part of the telescope project, includes a 6x4.5K CCD mosaic camera, an IR mosaic camera, bore-sight optical and λλ1-5 μm IR stellar spectrometers, and a moderate-field (up to 19 arc min-diameter) multi-object optical spectrometer (MOS.)

The SOAR Project Team, CTIO, the core Operations Team, and the sub-system manufacturers will support integration, debug, and commissioning. A key goal will be to minimize the duration hence costs of the integration period. First light is planned for the end of 2001.

Philosophy: Several key strategies will optimize performance of the SOAR Telescope:
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1. Seeing at C. Pachon is excellent. It has been documented via studies for Gemini, and is compared to several other sites in Fig. 1. The principal engineering objective is that the image quality of the SOAR telescope degrade the top-quartile seeing FWHM of the site by less than 40%. This is quantified in Fig. 2, which shows both the intrinsic and the delivered image quality for our specifications, as functions of $\lambda$.

![Graph](image1)

Fig. 1 (left) The top panel (from Gemini) compares the distributions of $r_0$ at Cerro Pachon, Cerro Tololo, La Silla and Mauna Kea. The bottom two panels show long-term statistics on $r_0$ as measured with a differential image motion monitor at C. Tololo. The bottom panel shows large nightly variations in $r_0$ at C. Tololo, emphasizing the need for a pre-emptive observing queue for maximum observing efficiency. Fig. 2 (right) Anticipated delivered image quality for the SOAR telescope with and without tip/tilt image stabilization for median (dashed) and top-quartile (solid) seeing at C. Pachon. The tip/tilt curve refers to the center of the isokinetic patch. Two degradations are shown, with the specified maximum 0.18 FWHM emphasized. Degradations for AO are shown smaller, to reflect non-optical benefits.

2. The SOAR partners have decided that the existing 4-meter Blanco telescope at CTIO and the SOAR telescope shall be a complementary pair and that SOAR will not duplicate the capabilities of the Blanco. Hence SOAR does not need a wide field of view or prime focus access because the Blanco offers a 45 arc min field.

3. The SOAR telescope will have a generous instrument payload. The trend in at least the near-term is for instrument mass and moments to grow. New materials and technologies may eventually halt this inflation, but it is all telescopes hit limits, often early in their operations. SOAR’s allocations are generous. In addition, there is the possibility of debugging/commissioning Gemini-class instruments on SOAR or even using them for science if that makes sense. Gemini instrument compatibility implies an f/16 focus and 2300 kg instrument capacity at the Nasmyth foci.

4. The SOAR telescope will be designed to execute an observing queue with high efficiency. This will minimize the intrusion of the synoptic programs. If seeing at C. Pachon does vary significantly during the night (something that the current C. Tololo measurements summarized in the bottom panel of Fig. 1 suggest), we would hope that most of the observing will be done in this fashion. It will still be possible for the observer to “lurk remotely” on the Internet if s/he feels the need to participate.

5. Considerable effort will be made to analyze scattered light within instruments and the telescope, by using Monte Carlo multi-scatter codes. Our aim is to limit telescope performance only by dust and diffractive scatter of light from in- and out-of-field objects off the optics. Dust will be controlled by washing M1 and M3 at regular intervals, and by using CO$_2$.
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snow between washings. Diffractive scatter will be controlled by the polish specification (in an azimuthally averaged sense, so there will still be unavoidable "mirror speckles").

Technical Specifications: The technical requirements for SOAR are derived from the top-level scientific requirements and the philosophical approaches to design. In abbreviated fashion, they are as follows:

Optical Configuration: Ritchey-Chretien at f/16
Telescope Mount: Altitude/Azimuth
Principal Foci: Two Nasmyth, two Bent Cassegrain, preserve space for Cassegrain Instrument
Instrument Support: Instrument Rotators at both Nasmyth Foci
Instrument Payload: Nasmyth: 1500 kg. Bent Cassegrain: 300 kg
Adaptive Optics: Compatible with upgrade to full AO
Environmental: Operation & survival consistent with C. Pachon conditions
Image Quality: 0.18 FWHM telescope and facility degradation (no seeing)
Field: At least 15'-diameter unobstructed & unvignetted
Field Correction: Refractive corrector provided to f/9 instrument focus over flat field
Pointing Accuracy: Blind: <2" rms; offsets <1°: <0.2
Tracking Accuracy: Open-loop drift: <0.1/min; guided: <0.1

The basic design of the SOAR telescope is Ritchey-Chretien at f/16 on an alt-azimuth mount. M1 will have a clear diameter of at least 4.0m. The principal foci will be at the two Nasmyth locations, requiring three reflections. Both foci will have an instrument rotator and acquisition/guide (A/G) unit. Two different instrument modules will be provided: one has a goal to accept the space/mass envelope of a single Gemini instrument, the other will have provisions for mounting up to three less massive instruments in a co-rotating cluster. The telescope is required to support at least 1500 kg of instruments at each rotator flange, with a goal of 2300 kg. The telescope will be bilaterally symmetric up to the two instrument rotator flanges, so at some future time the two modules could be mixed or matched to mount, e.g. either two Gemini instruments or two co-rotating clusters with up to six lighter instruments.

M3 can rotate to index positions to feed the beam to the desired Nasmyth or bent-Cassegrain focus. M4 in the 3-instrument cluster will allow rapid switching between instruments while sharing guide and acquisition functions. Each of the two A/G's will be compatible with an upgrade to an adaptive optics (AO) feed.

Concept Design: The following are current concepts of major subsystems of the SOAR telescope:

Facility & Enclosure: The SOAR site was recently leveled to a height of 2701 m above sea-level. Excavations and separate footings for the telescope pier and enclosure ("dome") will be provided. The facility will be a metal building of approximately 180 m², erected nearby on a grade-level slab. Heat capacity of the building and enclosure exterior coatings will be selected to minimize total solar absorbance and to provide optimum thermal "speed".

We expect to use a rotating hemispherical dome. One current concept employs a pre-fabricated aluminum geodesic. The high conductivity of aluminum and low mass of the dome enables rapid equilibration. Its prefabricated nature would enable rapid and cost-effective integration on site. An alternative is a more conventional gored-steel dome.

Telescope Mount: An altitude/azimuth type mount is specified. Current concepts include both monocoque and space-frame designs. The monocoque design uses welded sheet-steel, and accommodates the substantial instrument payload requirements as torque loads at the Nasmyth mounting flanges. The space-frame uses common structural-steel members and supports instruments in trunions at the Nasmyth locations. Flange mounted Gemini instruments are enclosed in cages to convert the torque loads implied by flange mounting into point loads via a compact strain path.

Active Optical System: This consists of a figure-controlled M1, an actively aligned M2 assembly, an M3 capable of rapidly selecting between the two Nasmyth instrument clusters and two bent Cassegrain instrument locations. The system will also provide rapid tip/tilt image stabilization, a wave-front sensor for calibration and optimization of the system, and all the electronics and software necessary for operation.

M1 will be a thin low-expansion glass or glass/ceramic facesheet between 7 and 10 cm thick for rapid thermal equilibration. The facesheet will be supported on figure actuators either hydraulic or electro-mechanical in operation. A carbon-fiber
mirror cell is specified, which will provide an extremely stiff yet lightweight and low heat-capacity structure. The open structure of this cell will provide excellent airflow and good radiation cooling of M1's rear surface.

Supplemental flushing and selective cooling of M1's front surface will be provided via a computer-controlled tempered air system. This system provides a variable laminar flow of conditioned air from the outer edge of M1 to a low-pressure region between its inner hole and the M3 rotator. All systems will operate under computer control and the contractors will develop algorithms for optimum performance.

Both M2 and M3 will be low-expansion, lightweight cored-glass or glass-ceramic substrates. These optics will be thermally equilibrated via conditioned air, input through the core structure by small-diameter tubing.

M2 will be actively aligned in five degrees of freedom via a hexapod or Stewart platform system. Correction for optical aberrations will be optimally apportioned between M1-figure and M2-positioning by the contractor-supplied active optics control system.

M3 will be elliptical in perimeter shape, and rotate about the telecentric axis to direct the image to the various instrument ports. It will also feature a high bandwidth (>40 Hz) tip/tilt capability to null atmospheric seeing-induced jitter.

The contractor of the active optical system will provide a calibration wavefront-sensor. Wavefront sensor approaches considered include crossed phase grating, knife-edge, and Shack-Hartmann techniques. Dedicated observation of a bright star will permit stepwise optimization of system parameters and revision of look-up table control parameters.

Instrumentation: The SOAR Telescope will provide two Nasmyth instrument positions as well as two bent Cassegrain auxiliary ports. Space will be reserved behind M1 for a small Cassegrain instrument, though in its initial configuration the telescope will not be set up to service that location.

The SOAR Telescope has been configured to provide an image compatible with Gemini instrumentation, and the two Nasmyth instrument locations will be identical and compatible with the interface and loads required to mount these instruments. While it is envisioned that a Gemini instrument will usually occupy one Nasmyth port, the other will sport an instrument adapter which will co-mount some combination of IR and visible wavelength imaging cameras, a stellar spectrometer, and an optical MOS. A facility calibration unit that simulates the telescope beam will also be provided. The instrument adapter will also provide acquisition and guide functions, and imaging elements for the active optical system wavefront sensor. Each instrument is likely to have an integrated tip/tilt/quad-sensor that picks off the light of an adequately bright star close to the center of the isokinetic patch. The centroid signal will be sent to the M3 control unit. Stars in the annular guide field will be monitored for instrument derotation as well as on-line photometry.

The following instruments are under consideration by the SOAR Science Advisory Committee (SAC):

Imagers: The goal for both visible and near-IR imagers is to span the full isokinetic field that can be stabilized by tip/tilt. This diameter is uncertain because of our current poor knowledge of AO-related characteristics of the atmosphere above C. Pachon. However, it is certainly larger than the span of a single detector chip if proper 3-pixel over-sampling is maintained for precise photometry. Therefore, the baseline optical detector is currently a 3x1 mosaic of thinned EEV 2x4.5K CCD's with 13.5 μm pixels. This detector will see the sky through a refractive focal-reducer/corrector/field flattener, which converts the f/16 telescope beam to f/9 (0.08/pixel) thereby providing more efficient sky sampling. An integrated atmospheric dispersion corrector (ADC) will be used. A preliminary design uses a half-dozen spherical lenses to provide good aberration control, high UV transmission, and ADC correction over a 10x10-arcmin field of view. The 3x1 mosaic mentioned above spans 7.9x5.9-arcmin of this field. This camera does not provide a collimated beam, so opportunities for spectral dispersion using conventional techniques are limited. However, work by others with e.g. curved etalon plates for a tunable filter may be useful to us. A goal is to make the camera confocal with f/16, so that the non-ADC elements can be removed from the beam to illuminate the central chip. This configuration would minimize scattered light, at the expense of the field of view. In addition, the pixel scale of 0.04 would then be well matched to the performance expected for a low-order AO system in the red, if it is implemented later with an adaptive M2.

As Fig. 2 shows, with just tip/tilt image stabilization SOAR should see images with FWHM <0.35 out to λ5 μm fairly often. Hence, either HgCdTe or InSb detectors are justified, and will be selected on the basis of cost, performance, and the ease of
fabricating a mosaic. In either case, the near-IR camera must reimage for thermal control, so the output pixel-scale is a free parameter to be settled on later, and a collimated space can be provided for dispersive elements.

**Spectrometers:** The requirement remains to obtain spectral information from targets that are distributed across the tip/tilt stabilized field. Object multiplex is still under discussion, but roughly 50 simultaneous targets seem appropriate. An ADC will be used before the entrance apertures to maintain image quality. SOAR's MOS will complement the Blanco's optical spectrometers: Hydra-S, with a minimum fiber separation of 23" over a 45-arcmin field; and a bore-sight stellar echelle fed by a fiber and small integral field unit (IFU).

![Diagram of SOAR Instrument Ports](image)

Fig. 3 The current concept for the f/16 telescope foci is shown. M4 within the instrument-adapter cube accesses various lighter instruments, while a single Gemini-class instrument is available on the other Nasmyth port. Each port is specified to carry 1500 kg, with a goal of 2300 kg. Either side has an annular guide field of area 40 arc min².

An obvious niche for a SOAR MOS at visible wavelengths would be a single, monolithic IFU to span roughly 10×10" with 0.15 apertures (for 2-pixel Nyquist sampling.) With fiber coupling this would require an f/5 output beam onto a dual 2×4.5K CCD. If this reimaging is done in fore-optics, the fibers can then be used with minimal focal ratio degradation and a compact, highly efficient double-pass Littrow spectrometer is practical. Throughput would be higher using an image slicer, but with fibers one can envision an eventual upgrade to order a dozen distributed IFU's each providing spatial information.
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across the tip/tilt-stabilized field. Fibers are not currently favored for use in the near-IR, but progress is rapid and the small size of IR arrays makes it all the more desirable to exploit the efficient detector packing of spectra that fibers provide.

Control Systems: The Mount, Active Optics, and Facility vendors will also provide control systems. They will be given broad latitude to find the most effective (including downstream) cost solution. The instrument adapter and controller will be contracts to “astronomy shops.” There will also be contracts to develop the Telescope Control System (TCS), and the Instrument and Observatory Control Systems (OCS) that the astronomers interact with. The OCS will have at least the same look and feel as the Gemini counterpart to ensure operator familiarity, and in fact it may be possible to port the Gemini OCS in its entirety. Many parts of their TCS also seem to be quite portable; the Portable TCS under development at the AAO is an alternative. Gemini has designed their highly centralized TCS around the VxWorks real-time OS, EPICS messaging, and VME hardware. Our approach of necessity will be less unified. However, tying together the contractor systems does allow us to upgrade various components that would otherwise be obsolete when SOAR comes on-line in 4 years. For example by using compactPCI and an alternative real-time OS, we can reduce costs and improve performance.

Fig. 4 SOAR control systems. Vendor-supplied subsystems are oval boxes. Links are fast Ethernet unless shown otherwise. The Observatory CS handles data, instrument interface tasks, and observer support like star catalogs.

Concept Design Approach: Technical requirements for the SOAR Telescope have been derived from the range of science programs put forward by the SOAR partner SAC. From this set of requirements, the SOAR project team and the earlier SOAR Science Working Group developed a range of concepts. Analytical work, and review of the project in 7/97 by an External Review Board, resulted in a top-level configuration. More detailed concepts for structure, optical system, facility, and instrumentation were then developed.

Two study contracts have each been let for alternate approaches to the active optical system, and the telescope mount. A study contract has also been let for facility architectural design. The results from these studies will be utilized to make decisions between the competing designs. The content of final reports from these studies become the property of the SOAR project and can be used as the basis for competitive procurement. The results of the design studies, the final concept design, and an extremely detailed cost estimate will be provided at a concept design review in 6/98. Upon approval of the partners, the project will proceed into the construction phase.

Program Plan:
Detailed design of the SOAR facility will be performed by an architect familiar with the requirements of telescope facilities and construction in Chile. These specifications will form the basis for standard construction procurement, administered by
CTIO in Chile. The facility construction will include installation of all necessary utilities, handling equipment, buildings, civil works, and foundations including the telescope base.

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Fig. 5. Project flow. Proceeding from the concept design and with the approval of the SOAR partners, specifications for major subsystems will be developed. Competitive procurements will produce firm fixed-price contracts for construction of the facility, enclosure, telescope mount, active optical system, and instrument adapter packages.

The telescope mount will include all detailed design, steel fabrication and assembly, encoders, motors, instrument rotators, servo-controls, control electronics, and control software. Manufacturers will be required to assemble the complete mount at their facility with mass and space simulators to represent optical assemblies. Final acceptance testing at the manufacturer's facility, ideally under control of the TCS running on a laptop PC, must demonstrate specified pointing and tracking precision and rates. The contractor will then disassemble, pack, and ship the mount to the SOAR site.

The active optical system contract will include detailed design, optical fabrication, and testing of all components. The contractor will be responsible for all actuators, sensors, control electronics and software necessary to operate the system. Final acceptance testing will be performed with the components assembled in a test stand at the appropriate optical conjugates, demonstrating control of M1 figure, active M2 alignment, M3 rotation, and fast tip/tilt image stabilization with loops closed about the wavefront sensor and simulated guider and tip/tilt sensors. Upon acceptance, the contractor will pack and ship the system.

Integration will be performed in two phases

1. The facility will be constructed up to the rotating plane of the enclosure. During the final stages of construction, the enclosure will be assembled on the ground beside the facility. A temporary roof over the telescope portion of the facility will enable completion of interior finishes. This phase completes when the enclosure is prepared for lifting.

2. This phase commences with the coordinated shipping of the major telescope subsystems to the site. Shipping will not be initiated until Phase 1 completion is assured, and the major telescope components are both ready. Integration of the telescope and enclosure is scheduled to take less than 90 days.

The manufacturers of the major subsystems will provide engineers to ensure rapid installation and debug of their systems. It is also intended that key members of the Operations Team be hired and in place during the telescope installation, to ensure familiarity with the procedures and operation of the system. Additional labor will be provided by CTIO and perhaps partner
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institutions. First light will be defined as the ability to routinely acquire and track images with performance that is in substantial compliance with the requirements. The science commissioning team will work with the Project and the Operations Teams to achieve full capability.

Installation of instruments will occur in stepwise fashion upon their completion, with proof masses in place prior to instrument arrival. The Project will end with final acceptance testing in which the performance of the overall system will be validated via test, demonstration, inspection or analysis, and substantial compliance with the specifications is achieved.

Summary: The SOAR Project breaks ground in several important areas (Fig. 6.) First, it will provide the best image quality of any 4-meter class telescope, with acquisition and tracking precision to exploit that quality. It will provide a second, nearly co-located telescope to use existing Gemini instruments as available. Fast tip/tilt will be included initially and the telescope will be designed to be compatible with a later upgrade to full artificial laser guide-star adaptive optics. Multiple instruments can be selected quickly and routinely to support operation in a queue-scheduled mode. All this will be done at a project cost reproducible by a consortium of e.g. US state universities rather than nations.

Key elements of the SOAR Program plan call for development of complete functional-subsystems by contractors, test to specifications at their facilities prior to shipping, and a minimal integration period. Early inclusion of the Operations Team will minimize the lag between construction and operation that is usually experienced by telescope projects. SOAR promises to be a powerful scientific asset to its partners and their collaborators.

Fig. 6 Site preparation activity at C. Pachon, early Feb. 1998, scheduled for completion in mid-March.
APPENDIX C

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE:
GPG, NSF 98-2 01/30/98
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S): (Indicate the most specific unit known, i.e. program, division, etc.)
MAJOR RESEARCH INSTRUMENTATION

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN): 86-013804
SHOW PREVIOUS AWARD NO. IF THIS IS A RENEWAL OR AN ACCOMPLISHMENT-BASED RENEWAL
IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES NO

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE:
AURA/National Optical Astronomy Observatories
AWARDEE ORGANIZATION CODE (IF KNOWN): 4033110000

NAME OF PERFORMING ORGANIZATION, IF DIFFERENT FROM ABOVE:

ADDRESS OF PERFORMING ORGANIZATION, IF DIFFERENT, INCLUDING ZIP CODE:

IS AWARDEE ORGANIZATION (Check All That Apply):
☐ FOR-PROFIT ORGANIZATION ☐ SMALL BUSINESS ☐ MINORITY BUSINESS ☐ WOMAN-OWNED BUSINESS

TITLE OF PROPOSED PROJECT: Kitt Peak 2.4-meter Telescope

REQUESTED AMOUNT $2,000,000
PROPOSED DURATION (1-60 MONTHS): 36 months
REQUESTED STARTING DATE: 08/01/98

CHECK APPROPRIATE BOXES IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW:
☐ BEGINNING INVESTIGATOR (GPG I.A.3)
☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.D.1)
☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG II.D.10)
☐ NATIONAL ENVIRONMENTAL POLICY ACT (GPG II.D.10)
☐ HISTORIC PLACES (GPG II.D.10)
☐ SMALL GRANT FOR EXPLOR. RESEARCH (SGER) (GPG II.D.12)
☐ GROUP PROPOSAL (GPG II.D.12)
☐ VERTEBRATE ANIMALS (GPG II.D.12) IACUC App. Date:
☐ HUMAN SUBJECTS (GPG II.D.12) Exemption Section or IRB App. Date:
☐ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES
☐ FACILITATION FOR SCIENTISTS/ENGINEERS WITH DISABILITIES (GPG V.G.)
☐ RESEARCH OPPORTUNITY AWARD (GPG V.H)

PI/PD DEPARTMENT: Kitt Peak National Observatory
PI/PD POSTAL ADDRESS: 950 N. Cherry Ave.
POB 26732
Tucson, AZ 857266732
United States

PI/PD FAX NUMBER: 520-318-8170

NAMES (TYPED):
Richard F Green
Ph.D., 1977 520-318-8299 rgreen@noao.edu

SOCIAL SECURITY NO.: High Degree, Yr Telephone Number Electronic Mail Address

NOTE: THE FULLY SIGNED CERTIFICATION PAGE MUST BE SUBMITTED IMMEDIATELY FOLLOWING THIS COVER SHEET.

*SUBMISSION OF SOCIAL SECURITY NUMBERS IS VOLUNTARY AND WILL NOT AFFECT THE ORGANIZATION'S ELIGIBILITY FOR AN AWARD. HOWEVER, THEY ARE AN INTEGRAL PART OF THE NSF INFORMATION SYSTEM AND ASSIST IN PROCESSING THE PROPOSAL. SSN SOLICITED UNDER NSF ACT OF 1950, AS AMENDED.

NSF Form 1207 (10/97)
KITT PEAK 2.4-METER IMAGING TELESCOPE

We request funding for 1/3 of the construction cost of a 2.4-m imaging telescope on Kitt Peak. This telescope will support qualitatively different science by enabling wide-field optical and infrared imaging surveys to the deep limiting magnitudes reachable spectroscopically by Gemini-class telescopes. Existing all-sky surveys fall several magnitudes short. The telescope will be built and operated by the University of Colorado, the University of Minnesota, and NOAO, and will also support innovative instrumentation developed by faculty and students at the partner universities.

Two surveys are of immediate interest to the partners in the project: (1) Narrow-band optical/near-IR surveys of star-forming regions will probe the physical conditions in shocks powered by outflows from young stars and in irradiated portions of molecular clouds. Observations of the mid-plane of the Galaxy will identify hundreds of high-mass star forming regions and probe the interconnection between superbubbles, molecular clouds, H II regions, OB associations. (2) High-latitude near-IR broad-band surveys will produce a census of brown dwarfs in the solar neighborhood. They will also provide fundamental catalogs of K-band selected L* galaxies and of galaxy clusters and groups over wide area out to z~1, which will be used to study the epoch during which normal galaxies undergo profound changes in star formation history and to trace the evolution of large-scale structure. Many other types of surveys will be pursued over the long lifetime of the telescope, because NOAO plans to offer peer-reviewed access to community-based teams for targeted surveys. A recent community workshop to identify major observational programs for Gemini-class telescopes found that surveys with a 2.4-m telescope were a prerequisite. Recommended were surveys to discover Kuiper Belt Objects, sub-stellar mass objects in the local neighborhood, and luminous stars in nearby galaxies; and surveys to characterize the initial mass function in nearby star-forming regions, the populations in dwarf spheroidals, and the formation and growth of galaxies.

The proposed telescope will provide a unique combination of consistent high image quality (FWHM=0.34" from the telescope); continuous availability of both wide-field optical imaging at the Cassegrain focus and wide-field near-IR imaging at one tip/tilt fed Nasmyth port; and accommodation at a second Nasmyth port of university-developed instrumentation. The telescope will be designed to be remotely operable, and the NOAO portion will be scheduled flexibly so that it can support studies of variable objects, targets of opportunity, and snapshots of fields in support of Gemini North observations, as well as surveys. The telescope will be placed on the current 0.9-m site, which experiences the same excellent site seeing as the WIYN site. We will achieve significant cost savings by using the Sloan telescope mount design from L&F industries with minimum modification.

The Universities of Colorado and Minnesota will each provide 25% of both the $6M construction cost and the operations cost. KPNO offers $1M of skilled labor and cash and will provide 50% of the operating costs from its current budget by closing the 0.9-m. The HST Project has offered the polished HST spare mirror on long-term loan. NOAO will furnish the existing CCD Mosaic imager is developing a wide-field IR imager to cover a field of 24" square projected onto a 2048 square HgCdTe array. NOAO, which has experience in completing telescope projects on schedule and on budget, will provide the project management.

Our request is therefore for $2M from the NSF to provide NOAO users with the opportunity for imaging survey science with a half share of a unique Northern hemisphere telescope.
KITT PEAK 2.4-METER IMAGING TELESCOPE

We request support for 1/3 of the construction cost of a new 2.4-m imaging telescope on Kitt Peak. The telescope is designed to produce wide-field optical and near-IR imaging with consistently high image quality, to be remotely operable, and to have low operations costs. The telescope will support innovative instrumentation developed by faculty and students at the Universities of Minnesota and Colorado, who will be partners in the project. For the NOAO user community it will provide the opportunity to pursue qualitatively different science by enabling imaging surveys of limited portions of the sky to the limiting magnitudes observable spectroscopically with the new generation of large aperture telescopes, including Gemini; mapping of regions of interest in narrow bandpasses; or obtaining temporal coverage of variability. The resulting datasets will thus address problems very different from those being attacked through the Sloan Digital Sky Survey (SDSS) and the 2-Micron All-Sky Survey (2MASS).

This project will:

• **Leverage NSF resources through the formation of a strong scientific partnership.** The University of Colorado and the University of Minnesota will provide half of the $6M total construction costs and half of the operating expenses. These universities bring strong scientific and instrumental expertise to the project, and both plan to use the availability of this telescope to strengthen their programs of training instrumentalists. The NASA HST Project will make their polished 2.4-meter spare mirror available on long-term loan. NOAO will provide the final $1M through in-kind contributions of technical and engineering staff and through savings already identified in the operating budget. KPNO intends to operate the telescope within its current funding envelope.

• **Provide critical support required for the effective use of Gemini-class telescopes.** The new 2.4-m telescope for Kitt Peak offers a unique combination of image quality, field of view, permanently mounted wide-field optical and near-IR imagers, and open peer-reviewed access for community-based surveys necessary for the support of new, large-aperture facilities. That combination cannot be matched by other telescopes either at NOAO or at the independent observatories. Existing telescopes of less than 2 meters aperture cannot reach the limiting magnitudes accessible to the Gemini spectrographs, cannot support multiple instruments, and in most cases do not reliably achieve the image quality enabled by modern telescope technology. Both the WIYN and the Mayall telescopes are heavily subscribed, provide important access to spectroscopy, and would be difficult to reprogram for extensive imaging surveys. The KPNO/CTIO Users Committee has endorsed the replacement of the existing telescopes of 2.1-meters and smaller with full access to a 2.4-m imaging telescope in each hemisphere.

• **Use an innovative optical design that offers both versatility and high performance.** The telescope will have a Cassegrain and two Nasmyth foci fed by a tip/tilt tertiary. The optical wide field at the Cassegrain will be 1 degree square, with designed image quality of 0.34" FWHM for a 15-minute exposure in 10 m/s wind. A CCD Mosaic imager can be permanently mounted at this port. One Nasmyth port will be used for a dedicated wide field-of-view near-infrared imager, and the other for university-developed experimental and facility instrumentation. Development costs have been minimized by employing a near clone of the SDSS telescope mount from L&F Industries.

• **Serve as a platform for state-of-the-art imagers.** The CCD Mosaic imager, with 8192 x 8192 pixel format and science-grade blue-sensitive CCDs will be the first-light optical imager; this instrument is already in use at KPNO with engineering grade detectors. NOAO will also produce a wide field-of-view IR imager dedicated to the f/6 Nasmyth focus that will cover some 24 arcminutes on a side with a 2048 x 2048 HgCdTe array.
• **Take advantage of NOAO experience in building telescopes on time and on budget.** The WIYN Observatory was produced on schedule and within its originally estimated budget by NOAO-based management. That telescope delivers image quality near that of the site seeing on a consistent basis, and supports NOAO users and university partners with forefront capabilities. The SOAR and SOLIS projects are also currently being carried out under NOAO auspices. A process of external design reviews and consortium-based oversight will assure that project resources are managed effectively.

• **Enable additional partnership science.** At least five other university groups and two foreign countries have expressed interest in partnering with NOAO to produce 2.4-m telescopes. Success in this project will encourage further investment in observing facilities by these groups. NOAO’s own renewal plan, which has been endorsed by the Users’ Committee, calls for equal access in both hemispheres and therefore requires that a similar telescope be built in the southern hemisphere at CTIO. The university-NOAO consortium for the Kitt Peak telescope has been designed to include potential future partners in the planning stages, so that the basic design, consortium arrangements, and so forth will meet the needs of all interested parties.

**IMAGING SCIENCE**

KPNO plans to make a major portion of its share of time on the 2.4-m telescope available for community-based surveying. With the active support of the Users’ Committee, we are setting up an external panel to provide advice on how to handle the peer review of survey proposals and how to deal with questions of data rights and early community release. NOAO’s goal is to enable focused surveys of moderate scope, for which reduction, catalog production, archiving, and analysis can be carried out successfully within a resource envelope typical of pooled NSF individual grants or NOAO support of staff research. A specific example is already in progress. NOAO staff member Buell Jannuzi, Arjun Dey (Hubble Fellow), and collaborators are conducting the NOAO Deep Wide-Field Survey, which will cover 18 square degrees and provide a community-accessible deep optical/near-IR broad-band survey at high galactic latitude. The principal investigators plan to address issues of the evolution of galaxy spectral energy distributions and large-scale structure. Data reduction is being handled by three FTE’s. We also have a quote from STScI that would archive all CCD mosaic data produced annually by NOAO for a setup charge of $100,000 and an annual fee of $50,000.

Below we offer examples of surveys proposed by both the NOAO community and the university partners in this telescope project. The descriptions assume the availability of the NOAO CCD Mosaic imager and a wide-field near-IR imager, both with adequate sampling of the PSF (0.21” and 0.3” / pixel, respectively) to enable morphological discrimination of faint objects. In addition, the near IR imager is planned with a second camera (as in ONIS, the Ohio State-NOAO Imaging Spectrograph currently in service) to cover a wide field with coarser sampling of 0.7”/pixel.

**I. Narrow Band Surveys of the Local ISM and the Galactic Plane**

A full understanding of the formation and evolution of galaxies requires a characterization of the cycling of matter from stars to the various phases of the interstellar medium and back into stars. Emission lines produced by ions, atoms, molecules, and solid state features in the visual to near infrared portion of the spectrum trace the shocks produced by the outflows from pre-main sequence stars and the impact of radiation and mechanical energy released during the main sequence life of stars. They can be used to probe the rich physics and chemistry of the phases of the ISM. Furthermore, emission lines can be used as powerful probes of the death of high and low mass stars through which the ISM is chemically enriched.
by the products of stellar nucleosynthesis. Matter is recycled to the ISM where it mixes with unprocessed gas, and eventually is recondensed into star forming molecular clouds.

The advent of large mosaics of CCD detectors has for the first time provided both high sensitivity and a wide field-of-view (FOV) of order one degree for optical imaging. The combination of these two capabilities has opened opportunities for deep narrow-band imaging of entire star forming clouds (Fig. 1). The next generation IR imager will revolutionize spectral line imaging in the 1 to 2.5 μm spectral domain. Yu, Bally, & Devine (1997), working with only a 256x256 IR imager, have obtained a mosaic of 2.12 μm H₂ S(1) line images covering a 10x15 arcmin portion of OMC2/3 north of the Orion Nebula and have discovered over 80 molecular hydrogen shocks from more than 15 separate outflows. While these observations took three nights with current technology, the proposed 2.4-m telescope with a 2Kx2K HgCd imager will do this job in a single 15 to 30 minute observation.

Figure 1. Recent wide-field-of-view observations by Bally (University of Colorado) and co-workers show that many Herbig-Haro (HH) objects trace parsec-scale outflows from young stars. This composite Hα + [S II] image shows the 7 pc long outflow associated with the HH-111 jet. The upper (left) panel is a mosaic of two Curtis Schmidt CCD images showing the nearly 1° long Herbig-Haro flow. The middle frame (right) shows an HST image of the HH-111 jet. The lower-left (bottom-right) and lower-right (top-right) frames show CCD images of HH-113 and HH-311 at the far ends of the flow obtained with the ESO NTT. Superimposed vectors show the proper motions of the brightest knots. See Reipurth et al. (1997a, 1997b) for details.
Complete narrow-band surveys of molecular clouds and star forming regions in such lines as [OI], [OII], [OIII], Hα, [SII], 1.2 and 1.6 μm [FeII], 2.12 μm H₂, and Brackett γ will achieve the following science goals:

- Probe the physical conditions in shocks powered by outflows from young stars and in irradiated portions of molecular clouds. What is the nature of the interclump medium in molecular clouds? Is it ionized, atomic, or molecular? What are the densities and temperatures? What are the time scales on which gas is cycled from warm phases of the ISM, the interclump medium of molecular clouds, and dense cloud cores where stars form?

- Determine the origin of interstellar cloud turbulence and the impact of outflows on cloud structure. What are the area and volume filling factors of shocks that dissociate molecules and ionize atoms?

- Study the chemical rejuvenation of molecular clouds. What is the mean time between the passage of dissociative shocks in a variety of clouds?

- Investigate the nature and the physical structure of YSO outflows, jets, and Herbig-Haro objects. Proper motions, which can be obtained from images taken several years apart, can be combined with radial velocity measurements with other facilities to obtain the full 3D flow vector fields for comparison with 3D simulations. Such data will constrain the formation, evolution, and dissipation of star forming molecular clouds.

- Measure the fraction of stars that form in isolation. What fraction form in small or large groups? What fraction of stars survive in gravitationally bound clusters?

Specifically, Bally at Colorado and co-workers plan to spearhead a collaborative survey of clouds with low foreground extinction so that the red optical lines are visible. Included will be nearby regions such as Taurus, Orion, Perseus, and the Great Rift in the First Quadrant of the Milky Way, as well as more distant regions such as the Cepheus Flare and clouds in the Perseus Arm including W3, IC1396.

This survey will target relatively nearby star forming regions. A complementary survey of the inner Galactic plane can trace star formation and the ionized ISM in regions that are obscured at visual wavelengths. A survey of the mid-plane of the Milky Way defined by the molecular cloud distribution from Sagittarius to Cygnus in near-IR broad-band filters and selected narrow band emission lines could, with the telescope proposed here, easily reach at least five magnitudes deeper than the 2MASS survey with better angular resolution. Science goals of such a survey would be to:

- Identify hundreds of high mass star forming regions throughout the Galaxy. Characterize the IMF, luminosity function, IR excess emission, and distribution of stars in the Galactic disk.

- Obtain precision measurements of extinction toward many lines of sight in order to characterize grain properties and the range of variation in these properties.

- Measure the morphology and kinematics of the outflows from young stars, HII regions, supernova remnants, and planetary nebulae in distant visually obscured portions of the Galaxy.

- Probe the sizes, ages, and structures of hundreds of Galactic superbubbles and investigate the relationship between molecular clouds, HII regions, superbubbles, OB associations, and the cycling of matter between the various ISM phases. What are the length and time scales of gas cycling in the ISM? How do the various ISM phases interact? How do the hot and warm phases condense to form GMCs?
Imaging of nearby galaxies in the same atomic and molecular features is also feasible, and such studies can be used to probe the distribution, sizes, and morphologies of giant bubbles blown into the galactic ISM by the collective effects of OB associations and nuclear starbursts. The combination of Galactic and extragalactic observations will make it possible to investigate the ISM and star formation on a vast range of length scales from less than $10^3$ pc to over 1000 pc and to study the relationships between the various phases of the ISM and dependences on the physical environment and location within a galaxy.

Experience with existing NOAO instrumentation can be used to estimate the amount of observing time required to conduct the surveys of molecular clouds and the Galactic mid-plane. In the optical, each field will take about 1 hour to cover in each filter. This exposure time will yield a flux limit $\sim 10^{-19}$ erg s$^{-1}$ cm$^{-2}$ arcsec$^{-2}$. If 5 narrow band filters are used, it will take 5 hours per field to cover one pointing and the survey can progress at a rate of about 1/2 square degree per 10 hour night and 50 square degrees of sky can be covered in 100 nights. Each of the Orion molecular clouds subtends about 5 to 10 square degrees. Thus, such a survey can cover the most interesting star forming regions in dozens to hundreds of molecular clouds. The IR imager will have an FOV of 11' in its higher resolution mode (0.3''/pixel) and the IR survey of the nearby clouds and the Galactic plane will also require about 100 nights. The proposed 200 nights of observing will be spread over a period of about 4 to 6 years, requiring about 40 nights per year of dedicated time.

II. Studying the Near and the Far in the Near-IR: Examples of the Scientific Return from Wide-Field Near-IR Sky Surveys

The great scientific return from well executed surveys has provided the impetus for several new sky surveys from radio through X-ray wavelengths (e.g., radio: VLA FIRST and NVSS; Far-IR: WIRE and SIRTF; X-ray: ROSAT All-Sky Survey and AXAF deep pointings). The SDSS, an optical imaging and spectroscopic survey, will record CCD images of 10,000 square degrees of the sky in 5 pass-bands between 3540 and 9200 A and will reach 5$\sigma$ detection limits of between 21 and 23 AB magnitudes, depending on the band. This survey will detect $5 \times 10^7$ galaxies with a median $z \sim 0.5$ and a tail reaching in excess of $z \sim 1$. A subset of these galaxies will be observed spectroscopically ($10^6$ galaxies brighter than about 18th magnitude in r') and are expected to have a median $z \sim 0.1$ and a tail reaching to $z=0.25$. The 2MASS all sky survey will image the entire sky in the J, H, and K pass-bands, reaching 10$\sigma$ limits of 15.8, 15.1 and 14.3 respectively (AB=16.7, 16.5 and 16.1). This survey will find about 50 galaxies per square degree (as compared to 5000 per square degree for SDSS) with a very low median redshift and a tail reaching only $z \sim 0.1$.

While 2MASS provides an excellent census of nearby galaxies and Galactic stars, it is too shallow (by at least 4 magnitudes) to provide detection of sources at cosmologically interesting redshifts, to probe our own galaxy for a population of field brown dwarfs, or to provide a complete IR dataset for the sources detected in the radio, optical, and x-ray surveys listed above. These other topics can be addressed, however, by conducting deep wide-field near-IR imaging in the region covered by SDSS.

Specifically, the proposed 2.4-m telescope, equipped with the wide-field IR imager, will be capable of undertaking previously unimaginable surveys. NOAO will build a camera that will provide a 24'x24' field of view (FOV) with 0.7''/pixel. (The FOV and resulting pixel scale of 0.7''/pixel were chosen based on the results of simulations by Richard Elston that demonstrate that this choice is nearly optimal for near-IR surveys that are going to be dominated by galaxies at the detection limit of the survey.) Effective exposure times of $\sim 660$ seconds (combination of multiple shorter exposures) with this telescope and a HgCdTe array will reach depths in the J and K bands 35 times (3.8 magnitudes) greater than the 2MASS survey, which uses a 1.5-m telescope with a 1.2 second integration time. The 10$\sigma$ J and K band detection
limits would be respectively 20.5 and 18.5 (mag/sq. arcsec; \( \lambda(\text{AB})=21.4, \ K(\text{AB})=20.3 \)). At \( K=18.5 \) we would expect to find about 10,000 galaxies per square degree — comparable to the SDSS (e.g., Moustakas et al. 1997). To image in the K band the entire 10,000 square degree SDSS survey area would take over 1000 nights. Significant science can be certainly be done with smaller area surveys. Through archiving data obtained for such surveys, we can over time build up more complete coverage of the SDSS region.

Some results that can be obtained through a combination of such broad-band IR and optical imaging surveys are:

- **A Census of Brown Dwarfs in the Solar Neighborhood and The Low Mass Stellar Content of the Galaxy.** IR imaging surveys have the potential of improving our understanding of Galactic structure and the nature of baryonic dark matter by allowing a census of brown dwarfs and low mass stars in the disk and halo. The mean invisible mass in our local region of the galaxy is deduced to be 0.05-0.1 \( M/pc^3 \). If comprised of brown dwarfs, then there should be 4000 brown dwarfs within 10 pc (Burrows, 1995). The spectral energy distribution of cool brown dwarfs is relatively simple to differentiate from main sequence stars since brown dwarfs suffer strong intrinsic absorption in the K band (due to methane and other molecules in the brown dwarf atmosphere), and normal low mass stars do not. When combined with the SDSS database, any J and K band imaging survey with a limit of \( K=18.5 \) should provide a very strong limit on methane absorption for objects brighter than \( J=16.5 \) and be complete over the area surveyed to a depth of 10 pc. Over time, as data are archived from the 2.4-m telescope, IR surveys will yield a growing sample of brown dwarfs in the solar neighborhood. This same survey data would make it possible to study the lower main sequence in detail in both the disk and halo.

- **Galaxy Evolution at Redshift >0.7.** A survey with a detection limit in the K-band of 18.5 mag. will include normal \( L^* \) galaxies out to \( z \sim 1 \) and luminous galaxies like Brightest Cluster Galaxies to \( z \sim 2 \). Such a survey could provide a fundamental catalog of normal galaxies with \( z \leq 2 \), which will be key to the study of galaxy evolution. In the K band the light of galaxies is dominated by the light of near-solar mass stars whose lifetimes are similar to the age of a galaxy. The K corrections of all galaxy types are nearly identical in the near-IR, and near-IR selected galaxies will provide a uniform sample of galaxy types at all redshifts from 0 to nearly 2 (Poggianti et al. 1997). Near-IR evolutionary corrections are smaller and more easily modeled than corrections in the rest frame optical. Optically selected samples of galaxies tend to select galaxies based on their current star formation rates and are thus very skewed toward finding UV bright star-forming galaxies at higher redshifts (e.g., Graham & Dey 1996). A sample of galaxies selected from a K=18.5 survey should have a median galaxy redshift (determined at first from photometric redshifts using the IR and either the SDSS or additional optical data) of about 0.7 with a tail extending to a \( z \sim 2 \). Over this redshift range the J-K color of galaxies rises with redshift, so it can be used to select samples of galaxies in various redshift ranges for follow-up spectroscopy. The optical (rest frame UV) photometry from the SDSS would allow the determination of the star formation rates of the galaxies and constrain their evolutionary histories. From existing near-IR surveys it appears that normal galaxies undergo profound changes in their star formation histories between \( z=0.8 \) and 1.5. Unfortunately, current surveys are limited by their small sizes and may not provide fair samples of the Universe (i.e. their results vary significantly from field to field due to large scale structure). Only large area (10s to 100s of square degrees) deep near-IR surveys will allow the study of a fair sample of the Universe and provide a large enough sample of galaxies at each redshift to statistically constrain the evolution of galaxies out to redshifts of 2.

- **Tracing Large Scale Structure to Redshift 1.** A near-IR galaxy survey (J and K bands with a K-band detection limit of 18.5) would provide a catalog of clusters of galaxies complete out to a redshift
of 1. This would allow the study in significant detail of the evolution of large scale structure between
the current epoch and the CBR. Near-IR selection primarily chooses early type galaxies due to their
high surface brightnesses and higher luminosities \( L^* \) for early type galaxies is about 1.5 magnitudes
brighter than for late type galaxies in the \( K \) band). The well known density morphology relationship
tells us that early type galaxies are found preferentially in higher density environments and should
thus be excellent probes of large scale structure. This can be demonstrated in several ways. First,
near-IR samples of galaxies at \( K=18 \) are more strongly correlated than similar samples of galaxies at
\( B=24 \). Second we can compare the significance with which a cluster could be found at a redshift of 1
from an optically selected B band image to that achieved by selection in a K band image. At \( z=1 \), the
B-K color of a typical early type galaxy will be about 7.5. The equivalent depths necessary for the
detection of a \( z=1 \) early type galaxy in the K and B bands will be respectively 18.5 and 25.5 mag.
The signal of clustering must be detected against the noise of field galaxies. The slope of the field
galaxy counts flattens as one goes into the near-IR. The expected field galaxy background at \( K=18.5 \)
is about 10,000 per square degree while the \( B=25.5 \) background will be about 10 times higher (Cowie
et al. 1996), implying a 3 times lower detection significance for the cluster. Therefore, identification
of clusters in the K-band will be easier. In the 10,000 square degree area to be covered by the SDSS,
supplemental near-IR imaging should enable the identification of rich clusters similar to the Coma
cluster and very accurate photometrically determined redshifts (Connolly et al. 1995) out to a \( z \geq 1 \)
just from the multi-band imaging.

SURVEY SCIENCE IN SUPPORT OF GEMINI AND LARGE TELESCOPE USE

Surveys of the kind described above will be required to support effective use of the Gemini telescopes
and other 6.5- to 10-m telescopes now coming on line. This was one of the primary conclusions of a re-
cent science-based workshop sponsored by NOAO in order to begin to quantify these supporting require-
ments. Forty-six participants, including astronomers from universities both with and without their own
facilities, were divided into eight subject-matter panels and were challenged to devise major scientific
programs aimed at addressing important astronomical problems. They were then asked to estimate the
requirements for telescopes, instruments, surveys, software, and operations modes needed to complete
the entire program.

All the panels identified large-scale surveys as essential in order to undertake observing programs that
would take full advantage of the new capabilities offered by very large telescopes. No existing or
planned all-sky surveys reach the deep limiting magnitudes that can be reached spectroscopically by
Gemini and other telescopes of similar aperture. The surveys proposed by the workshop are shown in
Table 1 (below), where the specific observations proposed in the workshop have all been critically exam-
ined and matched to realistic sizes of detectors. (Some of the proposed deep galaxy searches could not
be performed by any present or planned telescope; the full report of the workshop is available through the
NOAO website at http://www.noao.edu.) Different in detail but similar in their overall requirements,
these surveys are required for sample selection or refinement, identification of reference stars in certain
fields, and offloading the observations of the brighter objects onto smaller telescopes. They generally
require imaging over several tens of square degrees in multiple bands to fairly deep limits with good
precision. Estimates of the number of nights to undertake the surveys typically range from 10 to 100.
These estimates were made for both “average” performance telescopes (1" image quality and 10% emis-
sivity) and for “high” performance telescopes (0.5" image quality and 3% emissivity). A high perform-
ance 2.4-m compares well to the Mayall 4-m in these estimates; the emissivity of an optical wide-field
telescope will not be quite that favorable. This workshop made no effort to identify all possible such
surveys but rather was simply an attempt to quantify the requirements for one major program in each of eight different areas of active research.

The 2.4-m telescope proposed here would support the science driven by large telescopes in three ways. First, it would be possible to obtain astrometric or photometric frames on short notice in order to provide information on program objects or reference stars. Second, astronomers would undertake surveys of small regions in order to provide samples that they would then study with large telescopes. Third, groups would be able to undertake larger surveys as described above. The amount of NOAO time allocated to surveys will depend on the quality of the proposals, but it is likely to be well over half the nights available to NOAO. The surveys will be selected on the basis of peer review, and the entire community will have the opportunity to propose. The data taken for such surveys would be made available in a timely way to the entire community and would provide the basis for many observational programs to be undertaken subsequently with Gemini and other telescopes.
RESEARCH, TRAINING AND EDUCATIONAL GOALS

Kitt Peak National Observatory supports US astronomers by providing telescope and instrument combinations that are competitive at an international level through peer-reviewed proposal access. The community actively utilizes the existing near-IR and wide-field optical imaging capabilities on the moderate aperture Kitt Peak telescopes (≤ 2.1-m). Over the last two six-month semesters, an average of 128 astronomers from 43 institutions in 19 states had their names on proposals granted observing time on the smaller KPNO telescopes. Seventeen graduate students were involved in these proposals, of whom 9 were pursuing thesis research. The intense competition for observing time and the rigorous peer review of the observing proposals have resulted in scientific output that is consistently of high quality and high impact (e.g. Trimble 1995). The key advantages to the NOAO community of this proposal are that: (1) it will replace the aging 0.9-m telescope, which will be closed, with a modern facility that is powerful enough to support observations with Gemini-class telescopes; and (2) it will enable qualitatively new types of scientific programs by providing a capability for focused, moderate-size surveys.

The University of Colorado considers membership in a 2.4-m telescope consortium to be the highest priority for its research and educational goals in astronomy and planetary science. The Astrophysical and Planetary Sciences department has the largest group of researchers at a nationally ranked university with a top-rated program that does not have its own groundbased research observatory. The department, along with affiliated research centers (Laboratory for Atmospheric and Space Physics, the Center for Astrophysics and Space Astronomy, and JILA) has approximately 14 senior scientists, 9 research associates and 15-20 Ph.D. graduate students who would be expected to use this facility regularly for their research. Scientific programs include observations of galaxies, galaxy clusters and large-scale structure, quasar absorption lines, the interstellar medium, stellar atmospheres, and planetary atmospheres/ magnetospheres. Some of these programs are currently being carried out at NOAO facilities and as collaborative programs at private facilities, and are funded by NASA or NSF under various programs. A university facility will greatly enhance the feasibility of supporting observations for spacecraft, including a major need for groundbased observations in support of Colorado's role in The Far-Ultraviolet Spectroscopic Explorer (FUSE) and the Cosmic Origins Spectrograph (COS) for the Hubble Space Telescope. The aperture and wide-field capability of the telescope is also well-suited for long-term survey work, which is of particular interest to Colorado astronomers.

The proposed observatory will be used for research and instrumentation development involving senior faculty through undergraduates. It will play a particularly important role in Ph.D. graduate training, as students would be encouraged to carry out longer-term or riskier observational projects than are currently practical using national facilities. The observatory will also play a key role in the development of an optical and infrared instrumentation program, in complement to the established space instrumentation (e.g. FUSE, COS) programs at Colorado. This new program is considered a vital expansion of research goals and graduate education in the department. The department is also planning a new undergraduate major, and it is expected that 5-10 undergraduates per year would use the facility as part of their senior practicum. There is also the possibility of using live internet links to bring some of the observing experience to larger introductory classes for non-science majors (as many as 1000 students per semester).

The Astronomy Department of the University of Minnesota includes seven faculty observers, typically about three post docs in observational astronomy, and approximately eighteen graduate students. Minnesota also has six to ten astrophysics undergraduates each year.

The new telescope would represent: (1) the possibility of longer term projects, especially by graduate students for their theses; (2) a training facility for graduate students; (3) a testbench for new instrumenta-
tion; (4) an opportunity to undertake risky projects for which success is not guaranteed; (5) the possibility of conducting surveys and long term monitoring programs; (6) the ability to respond to transient events like novae or comets; and (7) the opportunity for thesis research by senior undergraduates.

Equally important, Minnesota sees the telescope as an opportunity to increase its access to national facilities. Observing programs on the largest ground-based telescopes such as Keck and Gemini, space-based platforms such as the Hubble Space Telescope, and even radio interferometers usually require a considerable effort in preparatory work with smaller telescopes. The wide-field imaging capability of the planned telescope fits this need very well, but spectroscopic capabilities, which will be provided at the "university" Nasmyth focus, will also be important and frequently used.

Minnesota has an active infrared instrumentation development group. The new telescope will considerably strengthen this program by offering the opportunity to instrument a modern, powerful telescope. The partnership with NOAO will also strengthen the training of graduate students in instrumentation development. Obviously, the facilities available at the national observatories will exceed those available locally, and access to those facilities and the expertise of the staff of the NOAO represents a tremendous opportunity for Minnesota's graduate students. Given the uncertainty of academic employment in astrophysics, graduate students are searching for more "hands-on" experiences in order to increase their skills. Just the act of observing at a major facility is an empowering experience, but involvement with the planning, designing, and building of instrumentation is perhaps one of the most beneficial experiences that can be offered to students.

Having guaranteed access to a major research facility is one of the main criteria that potential graduate students use in choosing a department. Minnesota expects that the planned telescope will significantly improve recruiting efforts. Since their graduate students already have a strong representation from underrepresented groups and women (39%), they expect this trend to continue.

PROJECT AND MANAGEMENT PLANS

Scientific Performance Requirements

The scientific programs discussed above call for the capability of imaging in the optical and near-infrared over significant areas of sky to faint flux limits. A new telescope should also provide a convenient platform for experimental instrumentation developed at partner universities as a strong component of student training. The telescope must deliver good image quality for depth of detection and accurate astrometry for large-aperture follow-up. A critical aspect of achieving high scientific throughput is minimizing downtime. A requirement for infrequent changing of the major imaging instruments helps realize that goal, while enabling more reliable synoptic observations. The observatory should also be capable of remote operation for enhancement of educational opportunities and for economy of staffing. The aperture size is set by a combination of practicality and the need to undertake substantial broad-band surveys for spectroscopic targets on large-aperture telescopes. As an illustration, for a background-limited point-source spectrum at spectral resolution of 1000 taken in median seeing on Gemini North in two hours, that source can be imaged with comparable S/N through a broad-band filter on Kitt Peak in median seeing in 18 minutes on a telescope of 2.4-m aperture. An aperture of 2.4 meters represents a cost-effective option, because there are existing altitude-azimuth telescope mount designs that can be directly employed, saving engineering design costs. An optical configuration with wide-field corrected Cassegrain and addressable Nasmyth foci meets the needs for versatility and minimal instrument changes.
The image quality goal is set for the optical wide field at Cassegrain by the criterion of not degrading the median visible seeing of 0.7" FWHM by more than 10%. The goal for the moderate field Nasmyth is not to degrade the median K-band seeing of 0.5" FWHM by more than 10%. The optical wide-field specification is therefore a diameter of 0.80" for 80% encircled energy (EE) at zenith at 5500 Å in a 15-minute exposure. That value corresponds to a Full Width Half-Maximum (FWHM) of 0.34". For mirror smoothness, the goal is 95% EE within a diameter of 1.40". The UV performance goal is 80% EE at 3500 Å within a diameter of 1.05". The moderate-field values are 72% of these numbers. The scaling with zenith distance goes as \((\sec z)^{0.6}\). Image quality specifications will be met for closed loop tracking in winds of up to 10 m/s (as measured at the secondary).

The final focal ratio of the corrected wide field will be set by the pixel sampling scale of the detector, along with practical design considerations such as limiting distortion at the edges of the field. The goal is to sample adequately the best quartile seeing, leading to a scale of 0.21" per 15 micron CCD pixel. The Cassegrain focal ratio includes power introduced by the corrector. The resulting 3-mirror Nasmyth focal ratio is ~f/6.26. The reimaging optics of the two cameras within the near-infrared imager will set the sampling scales there. The configuration is for a single secondary and tip/tilt tertiary. The corrected wide-field will have a field of view of at least 1 degree diameter with a goal of 1 square degree accessible. The Nasmyth foci will have a field of view of at least 11' diameter, with a strongly desired goal of 34' diameter. Field curvature will require correction to utilize the entire field of view.

The plan is for NOAO to provide two instruments for first light: the CCD Mosaic imager and a near-IR imager. The CCD Mosaic will have 8 scientific-grade STe devices of 2048x4096 format, 15 μ pixels. Although the camera does not fully exploit the accessible field of view initially, the growth of digital detector format and supporting computer capability makes a goal of a 4 times larger CCD camera early in the lifetime of the facility entirely plausible. Compatibility with a future Southern Hemisphere telescope is also a goal; when that facility is realized, Chris Stubbs’ MACHO group intends to provide a camera with 22 CCDs that more fully exploits the field.

The Near-Infrared Imager will be designed and constructed by NOAO to be dedicated to this telescope. The design is baselined for the ultimate installation of a 2048x2048 HgCdTe detector with 18 micron pixels. This wide-field imaging telescope will not be IR optimized except for the coating on the tertiary, so a reimaged pupil will be masked to control background. The moderate field camera will project an 11’ square FOV with 0.3”/pixel sampling. This mode will be used for narrow-band imaging and stellar photometry in crowded fields. The wide field camera will produce a 24’ square FOV with 0.7”/pixel sampling for faint extragalactic work. The imager will be provided as close to the beginning of science operations as possible.

Technical Description

The 2.4-m telescope is designed to take advantage of the lessons learned from the current generation of telescope development, e.g. ARC, WIYN, Sloan, Gemini. No new technology development or advances in the state of the art are required to meet the telescope performance specifications.

Telescope Site

The telescope will be sited at the location of the Kitt Peak .9-m telescope. The current .9-m telescope will be removed at the beginning of the second year of the 2.4-m project. The superb quality of this
south ridge site has already been demonstrated by the simultaneous site testing at both ends of the ridge, correlated with WIYN imaging data.

**Telescope Building**

A new pier and structure will be erected to accommodate the 2.4-m telescope. A new Observa-Dome will be installed and vented using the vents from the existing 0.9-m dome. The control and support facilities will be minimized and designed to easily migrate to a remote controlled facility. The baseline plan for mountain-based observing is to house the control room in the Administration building, thus minimizing local heat sources. A minimal control room will be co-located with the computers in the dome for commissioning and maintenance.

**Telescope Mount**

The telescope design is a 2.4-m Cassegrain based on the Sloan Telescope designed and built by L&F Industries (Figure 2 below). The Sloan design will be modified to accommodate both a Cassegrain and two Nasmyth foci. L&F Industries have reviewed the feasibility and cost of adding two WIYN style Nasmyth ports and rotators to the mount. No difficulties are expected. One Nasmyth port will feed an f/6.2 beam to a dedicated 2048 x 2048 pixel IR imager. The second Nasmyth port will be reserved for university instrumentation development. The Cassegrain port is designed with a field corrector and rotator to feed an f/6.0 beam to the KPNO CCD Mosaic. To accommodate both foci with a single secondary, the secondary mirror will be designed to move 65 mm along the z axis. A tertiary mirror will swing into the beam to feed the Nasmyth ports. The design of the tertiary mirror cell is based on the WIYN tertiary cell that also feeds two Nasmyth ports and a (reimaged) Cassegrain. The field size at Nasmyth has a conservative diameter requirement because of the altitude bearing size in the current Sloan telescope design. Every effort will be made to meet the goal of a larger field.

![Figure 2](image.png)

To promote good seeing and to minimize thermal distortions it is essential that the telescope mount follow the ambient temperature as closely as possible. The mount proposed by L&F Industries incorporates the lessons learned at ARC, WIYN, and Sloan. The relatively light weight and rigid mount enhances performance in several ways. High structural frequencies allow high bandwidth servo drives, and stiff structures are less affected by external disturbances, such as wind.
Primary Mirror
The primary mirror planned for this telescope is the spare HST mirror. The mirror is a lightweight ULE blank with a plano-concave structure. The low expansion glass will minimize the thermal distortions of the mirror. An active support system is planned for the mirror with a limited number of actuators designed to allow active collimation, some correction of spherical aberration, and compensation for the zero-g design. Periodic alignment and focus adjustments will be accomplished using a wave front analysis system similar to that used at the WIYN telescope. Forced air cooling in the plenum behind the primary mirror will condition the mirror to achieve a set point for primary mirror front surface temperature. The temperature set point will be based on the prior nights starting temperature.

Secondary Mirror
The secondary mirror will be lightweight low expansion material. Actuators and encoders will allow the secondary to be moved 65 mm to feed both Nasmyth and Cassegrain ports. Focus adjustments will be made at the beginning of the night based on analysis software and images produced by scientific instruments. A tip/tilt mode for the secondary will be investigated during the design. The large Cassegrain field and weight of the secondary may make the implementation of tip/tilt at the secondary impractical.

Tertiary Mirror
The tertiary mirror rotator will be modeled after similar components on the WIYN telescope. The mirror will be a flat of low expansion material. The rotator will move the mirror between Nasmyth ports and flip the mirror out of the beam to feed the Cassegrain port. Tip/tilt at the tertiary mirror will be implemented if secondary tip/tilt is not practical. Tip/tilt displacement limits in the focal planes will be of order an arcsecond, for image motion compensation. Chopping of many arcseconds is not a feature.

Wide Field Corrector
A three-element wide field corrector with atmospheric dispersion correction prisms has been designed for the Cassegrain port. The corrector will remain in place during Nasmyth operation allowing a quick change from IR to optical instruments.

Acquisition and Guiding
The instruments will provide the capability for digitized CCD frames to be transferred to the control system computer. The control system will provide an image display so that the telescope operator can identify a guide star, which will then be used to generate an error signal for the drive electronics.

Control System
The servo drive controls for the telescope will be part of the product delivered by L&F Industries. The upper level software will be a combination of purchased software and Graphical User Interfaces written especially for this telescope. Maximum use of existing software is anticipated, based on Kitt Peak heritage.

Project Organization and Management
The University – NOAO Consortium has teamed with L&F Industries to produce a state of the art 2.4-m telescope. NOAO will provide the management and system engineering for the project. L&F Industries will produce the telescope mount and drives. NOAO will provide the systems integration and engineer-
ing startup manpower for the project. The polishing of the secondary mirror, tertiary, and corrector optics will be reviewed for a make/buy decision. The Project Manager and Project Scientist will report to a 2.4-m Consortium Board. The WIYN Board model has a scientist and administrator with fiscal authority from each partner institution, driving strong accountability for both fiscal and technical project management. A Project Organization Chart follows.

**2.4-M Project Organization Chart**

```
2.4-M Board
   ` Project Scientist
     ` Ronald Probst
     ` Project Manager
     ` Larry Daggert
     ` Optical Engineer
     ` Charles Harmer
     ` Mechanical Engineer
     ` Larry Goble
     ` Electrical Engineer
     ` Scott Bulau
     ` Software Engineer
     ` Richard Wolff
```

Full-time project supported staffing will be limited to a project manager, mechanical engineer, electronic engineer, and software engineer. The need for an optical designer will decrease to part-time after the first six months of the project. Additional resources will be added to the staff on a temporary basis as required.

The Project Scientist is responsible for the overall scientific quality and meeting the performance goals of the project. Ron Probst has significant experience as Kitt Peak 2.1-m Telescope Scientist and Instrument Scientist for the Cryogenic Optical Bench, along with his active role in the development of near-IR instrumentation with the NOAO instrument projects group. The Project Manager is responsible for defining and implementing a program plan, establishing a budget and cost management process. Larry Daggert has managed the NOAO Engineering and Technical Services for eleven years and prepared the technical and management plan for the US Gemini proposal. Both the Project Manager and Project Scientist report to the Project Board. All of the key personnel have previous experience in building telescopes (e.g., WIYN) and in maintaining and upgrading existing telescopes on Kitt Peak.

Contracts will be placed through the normal NOAO procurement process. All contracts are expected to be fixed price. No development effort is budgeted in the project. No instrument budget is included in the project. Wherever possible, existing equipment designs will be copied to reduce designs costs. The first instrument planned for the telescope is already in operation at Kitt Peak. University instruments designed for the operation at the University port must meet the interface requirements and will be the responsibility of the building University.

**Project Timeline**

An aggressive three year timeline from placing the telescope mount contract to first light is planned. Since the primary mirror already exists and has an excellent figure, the project critical path is mount fabrication and site construction. Minimizing new design effort will be required to meet the first light
schedule. Based on our experience in building WIYN, as well as our involvement in developing the management plans for Gemini and SOAR, we are confident of our ability to meet this ambitious schedule.

The project timeline is shown below. The first six months of the project will be focused on preparing the system error budget and its distribution to subsystem performance, specified through system interface requirements documents. A complete Work Breakdown Structure will also be prepared and submitted to the Project Board during the first six months of the project. A major system external design review will be held at the completion of the initial design effort. With the review and acceptance of the design and plan, the telescope mount contract can be released. Design reviews will also be held for the control system and the facility. Subsystem tests will be conducted at vendor facilities prior to shipment.

**TIMELINE – Kitt Peak 2.4-M Telescope**

<table>
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<tr>
<th>WBS ELEMENTS</th>
<th>YEAR ONE</th>
<th>YEAR TWO</th>
<th>YEAR THREE</th>
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<td>2. Facility</td>
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<td>5. Primary Mirror</td>
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<td>17. Engineering Startup</td>
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REFERENCES CITED


RICHARD F. GREEN
Principal Investigator

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P.O. Box 26732
Tucson, AZ 85726-6732

Telephone: (520) 318-8299
(520) 318-8170 (Facsimile)

Birthdate: February 13, 1949, Omaha, Nebraska

Ph.D., Astronomy, California Institute of Technology, 1977

Appointments: 1997 - Director, Kitt Peak National Observatory (KPNO)
1993 - Deputy Director, Natl Optical Astronomy Observatories (NOAO)
1992 - 1993 Acting Director, NOAO
1990 - Astronomer, NOAO
1986 - 1990 Associate Astronomer - NCAO
1983 - 1985 Assistant Astronomer - KPNO
1979 - 1983 Assistant Astronomer - Steward Observatory
1977 - 1979 Research Fellow in Astronomy - Calif. Institute of Technology

Professional Associations and Committees
Member: American Astronomical Society; Astronomical Society of the Pacific; International Astronomical Union; American Association for the Advancement of Science
AAAS: Council Delegate; Committee on Council Affairs, President Elect – Astronomy
NASA: Instrument Definition Team – Space Telescope Imaging Spectrograph;

Graduate Students and Postdoctoral Scholars:
Graduate Theses Supervised as Adjunct Professor of Astronomy, University of Arizona: Jill Bechtold, Buell Jannuzi, Erica Ellingson, James Lowenthal, Charles Liu, Vicki Sarajedini, Patrick Hall. Postdocs: Gary Bower

Publications Most Closely Related to Proposed Project:


Other Significant Publications:


Collaborators Not Listed in Publications:
Telescope Collaboration: Astronomy staff members at Kitt Peak National Observatory (KPNO), University of Colorado, University of Minnesota.

Graduate Advisor: Maarten Schmidt, Calif. Institute of Technology
LARRY G. DAGGERT
Project Manager

Address: National Optical Astronomy Observatories (NOAO)
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Telephone: (520) 318-8361
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Degrees: B.S., Electrical & Electronic Engineering, cum laude, Michigan State University, 1972
MBA, University of Washington, 1978

Experience:

1987 – Manager, Engineering & Technical Services, National Optical Astronomy Observatories (NOAO)

1990 – Safety Officer, NOAO


1977 – 1981 Manager, Instrumentation & Control Engineering, Hanford Engineering Development Laboratory

1974 – 1977 Electronic Engineer, Hanford Engineering Development Laboratory


Professional Associations
Member: Institute of Electrical and Electronic Engineers
RONALD G. PROBST
Project Scientist

Address: National Optical Astronomy Observatories (NOAO)
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Tucson, Arizona 85726-6732

Telephone: 011-56-51-205206
011-56-51-205212 (Facsimile)

Birthdate: November 23, 1948, Crawfordsville, Indiana

Degrees:
B. S., Astrophysics, Indiana University, 1971
M. A., Astronomy, University of Virginia, 1976
Ph.D., Astronomy, University of Virginia, 1981

Appointments:
1995 - Infrared Support Scientist, Cerro Tololo Inter-American Observatory
1983 - 1995 Infrared Support Scientist, Kitt Peak National Observatory
1989 - 1993 Telescope Scientist for 2.1-m telescope refurbishment
1981 - 1983 NASA-NRC Postdoctoral Associate, NASA/Ames Research Center

Professional Associations and Committees
Member: American Astronomical Society

Graduate Students and Associated Postdoctoral Scholars: None

Publications Most Closely Related to Proposed Project:


**Other Significant Publications:**


**Collaborators Not Listed in Publications:**

Mónica Rubio, Dept. Astronomia, Universidad de Chile
Darren DePoy, Astronomy Dept., Ohio State University
Robert Blum, CTIO.
### AURA/National Optical Astronomy Observatories

**PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR**

**Richard F Green**

#### A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates

<table>
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#### B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)

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**TOTAL SALARIES AND WAGES (A + B)**


#### C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)

**TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)**


#### D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)

- **Purchase of Telescope Mount from L&F Industries**
  - $2,000,000

**TOTAL EQUIPMENT**


#### E. TRAVEL

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<td>3. SUBSISTENCE</td>
<td>0.00</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4. OTHER</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TOTAL PARTICIPANT COSTS**


#### G. OTHER DIRECT COSTS

<table>
<thead>
<tr>
<th>Category</th>
<th>Person-mos.</th>
<th>Funds Requested by proposer</th>
<th>Funds granted by NSF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. MATERIALS AND SUPPLIES</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>3. CONSULTANT SERVICES</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>4. COMPUTER SERVICES</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. SUBAWARDS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. OTHER</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TOTAL OTHER DIRECT COSTS**


#### H. TOTAL DIRECT COSTS (A THROUGH G)

**TOTAL DIRECT COSTS**


#### I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)

**General & Administrative % of MTDC (Rate: 0.00, Base: 0)**

**TOTAL INDIRECT COSTS (F&A)**


#### J. TOTAL DIRECT AND INDIRECT COSTS (H + I)

**TOTAL DIRECT AND INDIRECT COSTS**


#### K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.J.)

**RESIDUAL FUNDS**


#### L. AMOUNT OF THIS REQUEST (J OR (J MINUS K)

- **J** | $2,000,000
- **(J - K)** | $2,000,000

**TOTAL COSTS**


**M. COST SHARING PROPOSED LEVEL**

**ORG. REP. TYPED NAME & SIGNATURE**

**DATE**

**FOR NSF USE ONLY**

**INDIRECT COST RATE VERIFICATION**

**ORG. REP. TYPED NAME & SIGNATURE**

**DATE**

**SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.B)**
** D- Equipment
Purchase of Telescope Mount from L&F Industries  (Amount: $ 2000000)
See Budget Justification

** I- Indirect Costs
As per Cooperative Agreement AST-9613615, NOAO is required to waive indirect costs for awards granted by NSF.
### SUMMARY PROPOSAL BUDGET

<table>
<thead>
<tr>
<th>Organization</th>
<th>AURA/National Optical Astronomy Observatories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Principal Investigator / Project Director</td>
<td>Richard F Green</td>
</tr>
</tbody>
</table>

#### A. Senior Personnel: PI/PD, Co-PI's, Faculty and Other Senior Associates
(List each separately with title, A.7. show number in brackets)

<table>
<thead>
<tr>
<th>Name</th>
<th>NSF Funded Personnel</th>
<th>Funds Requested By Proposer</th>
<th>Funds Granted by NSF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Richard F Green - none</td>
<td>0.00</td>
<td>0.00</td>
<td>0 $</td>
</tr>
</tbody>
</table>

#### B. Other Personnel (Show numbers in brackets)

<table>
<thead>
<tr>
<th>Number (0) Post Doctoral Associates</th>
<th>0.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>(0) Undergraduate Students</td>
<td>0.00</td>
</tr>
<tr>
<td>(0) Graduate Students</td>
<td>0.00</td>
</tr>
<tr>
<td>(0) Secretarial - Clerical (If charged directly)</td>
<td>0.00</td>
</tr>
<tr>
<td>(0) Other Other</td>
<td>0.00</td>
</tr>
</tbody>
</table>

#### C. Total Salaries and Wages (A + B)

| Total Salaries and Wages | 0.00 |

#### D. Equipment (List item and dollar amount for each item exceeding $5,000.)

| Equipment | $2,000,000 |

#### E. Travel

<table>
<thead>
<tr>
<th>Travel 1. Domestic (Incl. Canada and U.S. Possessions)</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Foreign</td>
<td>0</td>
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</tbody>
</table>

#### F. Participant Support Costs

<table>
<thead>
<tr>
<th>Stipends</th>
<th>$0</th>
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<tr>
<td>Travel</td>
<td>$0</td>
</tr>
<tr>
<td>Subsistence</td>
<td>$0</td>
</tr>
<tr>
<td>Other</td>
<td>$0</td>
</tr>
</tbody>
</table>

| Total Participant Costs | $0 |

#### G. Other Direct Costs

<table>
<thead>
<tr>
<th>Materials and Supplies</th>
<th>$0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Publication Costs/Documentation/Dissemination</td>
<td>$0</td>
</tr>
<tr>
<td>Consultant Services</td>
<td>$0</td>
</tr>
<tr>
<td>Computer Services</td>
<td>$0</td>
</tr>
<tr>
<td>Subawards</td>
<td>$0</td>
</tr>
<tr>
<td>Other</td>
<td>$0</td>
</tr>
</tbody>
</table>

| Total Other Direct Costs | $0 |

#### H. Total Direct Costs (A Through G)

| Total Direct Costs | $2,000,000 |

#### I. Indirect Costs (F&A)

<table>
<thead>
<tr>
<th>Total Indirect Costs (F&amp;A)</th>
<th>$0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Direct and Indirect Costs (H + I)</td>
<td>$2,000,000</td>
</tr>
<tr>
<td>Residual Funds (If for Further Support of Current Projects See GPG II.D.7j)</td>
<td>$0</td>
</tr>
</tbody>
</table>

| Amount of This Request (J) or (J minus K) | $2,000,000 |

#### M. Cost Sharing Proposed Level

<table>
<thead>
<tr>
<th>Cost Sharing Proposed Level</th>
<th>$0</th>
</tr>
</thead>
</table>

| Agreed Level If Different | $2,000,000 |

**For NSF Use Only**

**Indirect Cost Rate Verification**

**Org. Rep. Typed Name & Signature**

**Proposed**

**Duration (months)**

**Award No.**

**For NSF Use Only**

**Indirect Cost Rate Verification**

**Date**

**Date of Rate Sheet**

**Initials - ORG**

---

NSF Form 1030 (10/97) Supersedes all previous editions

*Signatures required only for revised budget (GPG III.B)*
This proposal asks NSF for a 1/3 share of the $6.0 million construction cost for a 2.4-meter telescope. That total cost includes the design, fabrication, and assembly on-site of the facility building and pier, telescope mount, telescope optics, cells, rotators, and control system. It also includes removal of the existing 0.9-m telescope and associated equipment, and demolition of the building. It does not include facility instrumentation, commissioning or operations manpower, but the consortium has identified the means to provide all three.

The costs were determined in a bottom-up fashion on a subsystem basis. Construction, site preparation, and building infrastructure estimates were based on informal contractor bids. The costs for telescope structure, rotators, and low-level servo controls come from L&F Industries, based on the assumption of minor modifications to the existing Sloan telescope design. Mirror and corrector blank costs come from vendor quotes. Polishing costs, cell design and construction, and integration are baselined to be in-house efforts, with the level of effort determination based on years of experience with optics for WIYN and the NOAO 4-meter telescopes. The master control system is based on the heritage of control systems at Kitt Peak.

The specific proposal is for the purchase of (most of) the L&F effort to produce the telescope mount, rotators, and controls (Items 4.1-4.5 on the Work Breakdown Structure below). (The baseline telescope comes with a Cassegrain rotator, so Item 4.3 calls out the Nasmyth rotators as a specific extra.) The total cost from L&F is $2.21M, or $2.06M exclusive of installation. This proposed request is for $2.0M, the limit of the MRI program. According to the terms of the Cooperative Agreement between AURA and the NSF to operate NOAO, we do not charge overhead on either labor or purchased goods and services in proposals to other NSF programs. The terms also demand that the entire sum be available in order to enter into any contractual agreement with a vendor. The proposal period is therefore for the first year only of the three-year project, since the contract to L&F must be let after six months to assure the aggressive three-year schedule.

Non-federal cost sharing of $3.0M is provided by the University of Minnesota and the University of Colorado, which have committed $1.5M each according to the attached letters of commitment and intent. KPNO will contribute $1M in kind and in cash from savings in its operations budget. The NASA Hubble Space Telescope Project has agreed to make the polished HST spare primary mirror available on long-term loan to NOAO.

We are confident that the vigorous fundraising efforts in progress at Colorado and Minnesota will easily generate the full $3.0M on the timescale of review and funding of this proposal. Several other US universities, such as Rutgers and the University of Virginia, have also expressed active interest in being part of the consortium to produce 2.4-m telescopes, and would be asked to contribute in the case of a shortfall. If there is official concern about the $900K remaining in Colorado’s fundraising plan, KPNO guarantees that the project will go forward on schedule by making up a shortfall through reprogramming of its operating budget. The cost to the community in near-term scientific productivity would be substantial, however, because we would need to close the 2.1-m telescope during the 3-year development period of the 2.4-meter plus its commissioning. KPNO would not make such a pledge if we were not strongly confident that our university partners are committed to this project and will meet their promised goals.

The following two pages categorize the cost components according to the Project Work Breakdown Structure.
BUDGET JUSTIFICATION

PROJECT BUDGET – 2.4 METER TELESCOPE FOR KITT PEAK

<table>
<thead>
<tr>
<th>WBS ELEMENT</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>TOTAL Source of Quote</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1.0 Interface Documents</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1 Conceptual Design</td>
<td>$28,000</td>
<td>$28,000</td>
<td>mpe</td>
<td></td>
</tr>
<tr>
<td>1.2 Optical Design</td>
<td>$26,000</td>
<td>$26,000</td>
<td>mpe</td>
<td></td>
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<tr>
<td>1.3 Error Budget &amp; Tolerance</td>
<td>$8,000</td>
<td>$8,000</td>
<td>mpe</td>
<td></td>
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<tr>
<td>1.4 Mechanical Design</td>
<td>$90,000</td>
<td>$90,000</td>
<td>mpe</td>
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</tr>
<tr>
<td>1.5 Architecture &amp; Engineering</td>
<td>$100,000</td>
<td>$100,000</td>
<td>M3</td>
<td></td>
</tr>
<tr>
<td>1.6 System Modeling</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>2.0 Facility</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1 Design Engineering</td>
<td>$26,000</td>
<td>$26,000</td>
<td>mpe</td>
<td></td>
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<tr>
<td>2.2 9m removal</td>
<td>$146,000</td>
<td>$146,000</td>
<td>Barnett &amp; Shore</td>
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<tr>
<td>2.3 Pier &amp; Foundations</td>
<td>$46,000</td>
<td>$46,000</td>
<td>TA **</td>
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<tr>
<td>2.4 Control and Service Building</td>
<td>$125,000</td>
<td>$200,000</td>
<td>$325,000</td>
<td>TA **</td>
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<tr>
<td>2.5 Equipment</td>
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<td>$32,000</td>
<td>TA **</td>
<td></td>
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<tr>
<td>2.6 Utilities &amp; Services</td>
<td>$30,000</td>
<td>$30,000</td>
<td>TA **</td>
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</tr>
<tr>
<td>2.7 Environmental Controls</td>
<td>$50,000</td>
<td>$50,000</td>
<td>Honeywell</td>
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<tr>
<td><strong>3.0 Enclosure</strong></td>
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<tr>
<td>3.1 Dome System</td>
<td>$275,000</td>
<td>$275,000</td>
<td>Observa-Dome</td>
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<tr>
<td>3.2 Shutter System</td>
<td>$75,000</td>
<td>$75,000</td>
<td>slip rings</td>
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<td>3.3 Azimuth Rotation</td>
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<td>$8,000</td>
<td>TA **</td>
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<tr>
<td>3.4 Utilities &amp; Equipment</td>
<td>$20,000</td>
<td>$40,000</td>
<td>$60,000</td>
<td>KP Est</td>
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<tr>
<td>3.5 Shipping &amp; Installation</td>
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<td></td>
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<tr>
<td><strong>4.0 Telescope Mount</strong></td>
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<td></td>
<td></td>
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<tr>
<td>4.1 Design</td>
<td>$200,000</td>
<td>$200,000</td>
<td>L&amp;F Industries</td>
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<tr>
<td>4.2 Mount</td>
<td>$1,250,000</td>
<td>$1,250,000</td>
<td>L&amp;F Industries</td>
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<td>4.3 Nasmyth Rotator(2)</td>
<td>$50,000</td>
<td>$100,000</td>
<td>$25,000</td>
<td>$175,000</td>
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<tr>
<td>4.4 Tertiary Table</td>
<td>$40,000</td>
<td>$100,000</td>
<td>$20,000</td>
<td>$160,000</td>
</tr>
<tr>
<td>4.5 Controls</td>
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<td>$200,000</td>
<td>$25,000</td>
<td>$275,000</td>
</tr>
<tr>
<td>4.6 Installation</td>
<td>$150,000</td>
<td>$150,000</td>
<td>L&amp;F Industries</td>
<td></td>
</tr>
<tr>
<td><strong>5.0 Primary Mirror</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.1 Model Test Data</td>
<td>$2,000</td>
<td>$2,000</td>
<td>mpe</td>
<td></td>
</tr>
<tr>
<td>5.3 Mirror</td>
<td>$8,000</td>
<td>$8,000</td>
<td>Enterline quote</td>
<td></td>
</tr>
<tr>
<td>5.2 Ship to NOAO</td>
<td>$8,000</td>
<td>$8,000</td>
<td>Enterline quote</td>
<td></td>
</tr>
<tr>
<td><strong>6.0 Primary Cell &amp; Supports</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.1 Design</td>
<td>$50,000</td>
<td>$50,000</td>
<td>Parts + Labor</td>
<td></td>
</tr>
<tr>
<td>6.2 Fab</td>
<td>$175,000</td>
<td>$175,000</td>
<td>Parts and labor</td>
<td></td>
</tr>
<tr>
<td>6.3 Test Installation With Mirror</td>
<td>$14,000</td>
<td>$14,000</td>
<td>mpe **</td>
<td></td>
</tr>
<tr>
<td>6.4 Install In Telescope</td>
<td>$7,000</td>
<td>$7,000</td>
<td>mpe **</td>
<td></td>
</tr>
<tr>
<td><strong>7.0 Secondary Mirror</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.1 Design &amp; Contract</td>
<td>$7,000</td>
<td>$7,000</td>
<td>mpe **</td>
<td></td>
</tr>
<tr>
<td>7.2 Blank</td>
<td>$120,000</td>
<td>$120,000</td>
<td>ULE</td>
<td></td>
</tr>
<tr>
<td>7.4 Polish</td>
<td>$125,000</td>
<td>$100,000</td>
<td>$225,000</td>
<td>NOAO</td>
</tr>
<tr>
<td>7.3 Ship to NOAO</td>
<td>$5,000</td>
<td>$5,000</td>
<td>Enterline quote</td>
<td></td>
</tr>
</tbody>
</table>

Budget Justification 3
Kitt Peak 2.4-m Telescope
### BUDGET JUSTIFICATION

**PROJECT BUDGET – 2.4 METER TELESCOPE FOR KITT PEAK (continued)**

#### 8.0 Tertiary Mirror

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost 1</th>
<th>Cost 2</th>
<th>Cost 3</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1 Design &amp; Contract</td>
<td>$3,000</td>
<td>$3,000</td>
<td>mpe **</td>
<td>** Key to Project Budget:</td>
</tr>
<tr>
<td>8.2 Blank</td>
<td>$80,000</td>
<td>$80,000</td>
<td>ULE</td>
<td>mpe = manpower estimate for components dominated by labor cost</td>
</tr>
<tr>
<td>8.3 Polish</td>
<td>$60,000</td>
<td>$60,000</td>
<td>NOAO</td>
<td>TA = Tony Abraham, Engineering lead for Kitt Peak, providing vendor estimates</td>
</tr>
<tr>
<td>8.4 Ship to NOAO</td>
<td>$3,000</td>
<td>$3,000</td>
<td>Enterline Quote</td>
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</tr>
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</table>

#### 9.0 Tertiary Cell & Flip Mechanism

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost 1</th>
<th>Cost 2</th>
<th>Cost 3</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.1 Design</td>
<td>$10,000</td>
<td>$10,000</td>
<td>WIYN clone</td>
<td></td>
</tr>
<tr>
<td>9.2 Fab</td>
<td>$24,000</td>
<td>$24,000</td>
<td>parts &amp; labor</td>
<td></td>
</tr>
<tr>
<td>9.3 Assemble and Test</td>
<td>$10,000</td>
<td>$10,000</td>
<td>mpe **</td>
<td></td>
</tr>
</tbody>
</table>

#### 10.0 Cassegrain Corrector

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost 1</th>
<th>Cost 2</th>
<th>Cost 3</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.1 Design &amp; Contract</td>
<td>$10,000</td>
<td>$3,000</td>
<td>$13,000</td>
<td>mpe **</td>
</tr>
<tr>
<td>10.2 Glass</td>
<td>$104,000</td>
<td>$104,000</td>
<td>Schott</td>
<td></td>
</tr>
<tr>
<td>10.3 Polish</td>
<td>$75,000</td>
<td>$75,000</td>
<td>NOAO</td>
<td></td>
</tr>
<tr>
<td>10.4 Coatings</td>
<td>$11,000</td>
<td>$11,000</td>
<td>Continental</td>
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</tbody>
</table>

#### 11.0 Corrector Cell

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost 1</th>
<th>Cost 2</th>
<th>Cost 3</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.1 Corrector Cell Design</td>
<td>$10,000</td>
<td>$10,000</td>
<td>CTIO clone</td>
<td></td>
</tr>
<tr>
<td>11.2 Cell Fab</td>
<td>$22,000</td>
<td>$22,000</td>
<td>parts &amp; labor</td>
<td></td>
</tr>
<tr>
<td>11.3 Assembly &amp; Test</td>
<td>$18,000</td>
<td>$18,000</td>
<td>mpe **</td>
<td></td>
</tr>
</tbody>
</table>

#### 12.0 Secondary Cell & Tip/Tilt

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost 1</th>
<th>Cost 2</th>
<th>Cost 3</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.1 Design</td>
<td>$16,000</td>
<td>$16,000</td>
<td>$32,000</td>
<td>mpe **</td>
</tr>
<tr>
<td>12.2 Fab</td>
<td>$100,000</td>
<td>$100,000</td>
<td>$200,000</td>
<td>CTIO clone</td>
</tr>
<tr>
<td>12.3 Controls &amp; Sensors</td>
<td>$50,000</td>
<td>$35,000</td>
<td>$85,000</td>
<td>WIYN clone</td>
</tr>
<tr>
<td>12.4 Assembly &amp; Test</td>
<td>$10,000</td>
<td>$15,000</td>
<td>$25,000</td>
<td>mpe **</td>
</tr>
</tbody>
</table>

#### 13.0 Electronics & Controls

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost 1</th>
<th>Cost 2</th>
<th>Cost 3</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.0 UPS System</td>
<td>$18,000</td>
<td>$2,000</td>
<td>$20,000</td>
<td>18KVA</td>
</tr>
<tr>
<td>13.2 Sensors</td>
<td>$35,000</td>
<td>$40,000</td>
<td>$75,000</td>
<td>Est</td>
</tr>
<tr>
<td>13.3 Electronics &amp; Cabling</td>
<td>$20,000</td>
<td>$80,000</td>
<td>$100,000</td>
<td>Est</td>
</tr>
<tr>
<td>13.4 Safety &amp; Interlocks</td>
<td>$20,000</td>
<td>$80,000</td>
<td>$100,000</td>
<td>Est</td>
</tr>
</tbody>
</table>

#### 14.0 Computers & Programming

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost 1</th>
<th>Cost 2</th>
<th>Cost 3</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.1 Master Control</td>
<td>$60,000</td>
<td>$65,000</td>
<td>$65,000</td>
<td>$190,000</td>
</tr>
<tr>
<td>14.2 Secondary Focus System</td>
<td>$16,000</td>
<td>$16,000</td>
<td>$32,000</td>
<td>mpe **</td>
</tr>
<tr>
<td>14.3 Pointing &amp; Tracking</td>
<td>$25,000</td>
<td>$25,000</td>
<td>$50,000</td>
<td>mpe **</td>
</tr>
</tbody>
</table>

#### 15.0 System Integration

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost 1</th>
<th>Cost 2</th>
<th>Cost 3</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.0 System Integration</td>
<td>$250,000</td>
<td>$250,000</td>
<td>mpe **</td>
<td></td>
</tr>
</tbody>
</table>

#### 16.0 Engineering Startup

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost 1</th>
<th>Cost 2</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.0 Engineering Startup</td>
<td>$-</td>
<td>Ops Budget</td>
<td></td>
</tr>
</tbody>
</table>

#### 17.0 Project Management

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost 1</th>
<th>Cost 2</th>
<th>Cost 3</th>
<th>Cost 4</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>17.0 Project Management</td>
<td>$90,000</td>
<td>$80,000</td>
<td>$80,000</td>
<td>$250,000</td>
<td>Capital &amp; Labor</td>
</tr>
</tbody>
</table>

**TOTAL**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost 1</th>
<th>Cost 2</th>
<th>Cost 3</th>
<th>Cost 4</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL</td>
<td>$1,188,000</td>
<td>$3,361,000</td>
<td>$1,451,000</td>
<td>$6,000,000</td>
<td>Capital &amp; Labor</td>
</tr>
</tbody>
</table>

**Key to Project Budget:**

- mpe = manpower estimate for components dominated by labor cost
- TA = Tony Abraham, Engineering lead for Kitt Peak, providing vendor estimates
FACILITIES, EQUIPMENT & OTHER RESOURCES

FACILITIES: Identify the facilities to be used at each performance site listed and, as appropriate, indicate their capacities, pertinent capabilities, relative proximity, and extent of availability to the project. Use "Other" to describe the facilities at any other performance sites listed and at sites for field studies. USE additional pages as necessary.

Laboratory:

Clinical:

Animal:

Computer:

Office:

Other:

MAJOR EQUIPMENT: List the most important items available for the project and, as appropriate, identifying the location and pertinent capabilities of each.

The proposed 2.4-m telescope will be built primarily through outside contracts. The Consortium will be responsible for commissioning. Kitt Peak is a fully developed site with equipment for measuring wavefronts to test optical alignment and performance; optical coating chambers; electronic test equipment; and equipment for moving large telescope components.

OTHER RESOURCES: Provide any information describing the other resources available for the project. Identify support services such as consultant, secretarial, machine shop, and electronics shop, and the extent to which they will be available for the project. Include an explanation of any consortium/contractual arrangements with other organizations.

The 2.4-m project team will be based at the Tucson headquarters of the National Optical Astronomy Observatories. NOAO, which is funded by the NSF, is one of the world’s leading astronomical observatories with fully equipped electronics and machine shops, as well as an optics laboratory capable of testing all the optical components for this project. Experienced staff will oversee construction of the site. Tucson-based staff engaged in other telescope projects (e.g., Gemini, SOAR, SOLIS) will be available to consult and to participate in design reviews.
A community workshop was held in Tucson on September 26-28, 1997 to identify and quantify required supporting capabilities for 6.5-10 meter telescopes. The motivation for this workshop was the realization that the new generation of very large telescopes would have a) the ability to study in detail objects fainter than the limiting magnitudes of most existing wide-area surveys and b) the requirement to come to the telescope with accurate astrometry and photometry for both unknowns and reference stars. The goal of the workshop was to formulate and develop science-based arguments that would identify capabilities that are not currently available and suggest priorities or possible approaches to acquiring these capabilities.

A total of 46 astronomers representing 26 different institutions took part in the workshop. Eight discipline-based panels were created (Solar System Studies, Extrasolar planets/Low Luminosity Stars, High Resolution Studies of Stars, Star Formation/ISM, Activity in Nearby Galaxies, Stellar Populations, Galaxy Formation and Evolution, and Large Scale Structure), each with two co-chairs to lead the panel discussions. The entire group heard presentations on the capabilities and observing constraints of a number of large telescopes (Keck, Hobby-Eberly Telescope, MMT, Magellan, LBT, and Gemini). The charge to the panels was to:

1. Develop one or more large, representative observational programs for 6.5-10 meter telescopes.

2. Analyze the support requirements for these programs including telescopes, instruments, surveys, software, and operations modes needed for sample selection, calibration, complementary or preparatory observations.

The panel co-chairs and the workshop organizers met the final day to merge the panel results, attempt to quantify the common needs, and identify capabilities to which general access does not exist.

Table 1 gives for each program a summary of the observations on the large (6.5-10 meter) telescope, including the type of instrument needed and the estimated number of nights.

All of the panels identified large-scale surveys as essential in order to undertake the observing programs on very large telescopes. These surveys, different in detail but similar in overall...
requirements, are needed for sample selection or refinement, identification of reference stars in certain fields, and offloading the observations of the brighter objects onto smaller telescopes. Both imaging and multi-object spectroscopy were called for, over fields of view that range from 10-20 arcminutes in the IR to one degree in the optical. The survey parameters are given in Table 2, including the area to be surveyed, the filter bands (or spectral resolution) required, and the limiting magnitude for each filter.

In order to understand the practicality of undertaking these surveys using various existing or planned facilities, the number of nights to carry out each survey has been estimated for a uniform set of assumptions. Four cases were considered: a "new" 2.5 meter telescope that produces 0.5 arcsecond FWHM images and has 3% emissivity in the thermal IR, an "old" 2.5 meter telescope that produces 1.0 arcsecond FWHM images and has 10% emissivity in the thermal IR, and two telescopes of 4 meter aperture with the same sets of imaging/emissivity performance. In all cases an 8K X 8K optical imager and a 1K X 1K IR imager were assumed. Table 3 shows the predicted number of nights to carry out the imaging surveys under these conditions. It can be seen that:

- Most of the surveys could be completed in a few tens of nights with a modern 2.5 meter telescope
- The gain due to the better image quality (0.5 arcsecond images vs. 1.0 arcsecond images for an older telescope) is substantial in a number of optical surveys.
- There are few, if any, cases in which a 4 meter aperture is required except for the surveys that require an unreasonably large number of nights even for a 4 meter telescope to complete.

The facilities and infrastructure that were identified as prerequisites to carry out these surveys include:

**Detectors** – Optical arrays are just approaching sizes to make optimal use of existing telescope focal planes. Obviously, development of IR arrays leading to larger formats and buttable physical packages would increase efficiency for survey use.

**Software/protocols/pipelines** – Standardized, well-tested software will allow rapid and consistent reduction of data obtained for surveys. Construction of catalogs with accurate measurement of fluxes and positions will make the use of these data more efficient. Uniform procedures for ingesting data into (and delivering data out of) archives will permit the entire community to make better use of this information.

**Community sociology** – The workshop participants recognized that conflicting pressures exist in trying to enable a survey. Community support requires substantial community input and ready access to the output. However, there must be a scientific return for an individual or team to put in the very large effort that is required to carry the survey out. Any plan to carry out one of these surveys must find an acceptable balance to these two forces. Various telescope resources were discussed as potential tools to carry out these surveys.

**Other desired capabilities** – Although lower in priority than the survey requirements, several additional capabilities were identified as desirable. There was some interest in image quality improvement via tip-tilt correction or low-order adaptive optics. The emphasis was clearly on correction over a substantial field of view and so might be considered as correction for wind-shake.
tracking errors and dome and mirror seeing. Also, non-traditional operations modes were noted as important, particularly those that would support target-of-opportunity observations.

Three general aspects of the results are worth noting. First, arguments for specific supporting capabilities have always been anecdotal. We know that the Palomar Schmidt sky survey, undertaken in the 1950s, provided an extremely important database for the next 30 years of observations on 4 and 5 meter telescopes. By analogy we expect that similar but deeper surveys (such as SDSS) will be necessary to effectively use 6.5-10 meter telescopes. Now, for the first time, we have made that argument in a scientific context and in a more quantitative way. Second, we must acknowledge the limitations of the process of the workshop. Many disciplines, wavelength ranges, and types of observation were not well represented. We did not do a good job of including radio and x-ray observatories and the connection to ongoing or planned space observatories is not as strong as it could be. Third, we did succeed in identifying some specific areas that will require development and significant effort for the effective community use of very large telescopes. It is necessary to begin immediately the job of planning and carrying out these surveys. Over the long term the results of this workshop and of future workshops should provide input for national public and private policy and funding decisions. Over the short term we must engage the community in starting now to assemble the tools and the infrastructure to carry them out.

The scientific programs proposed by the panels are appended to this summary.
# Table 1

## Large Telescope Requirements

<table>
<thead>
<tr>
<th>Program</th>
<th>Title</th>
<th>Instrument</th>
<th>No. of nights</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/a</td>
<td>Physical &amp; Population Studies of KBOs</td>
<td>Wide Field Opt. Imager</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>2/a</td>
<td>Three Ages of the Mass-Lum. Relation</td>
<td>Near-IR Imager</td>
<td>200</td>
<td>10 yr program</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R=5000 Opt. Spect.</td>
<td>100</td>
<td>10 yr program</td>
</tr>
<tr>
<td>2/b</td>
<td>Age of the Galactic Disk</td>
<td>R=1000 Opt. Spect.</td>
<td>30</td>
<td>Wide-Field Multi-Object</td>
</tr>
<tr>
<td>2/c</td>
<td>Variations in the sub-stellar mass fn.</td>
<td>R=5000 Opt. Spect.</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R=30,000 Opt. Spect.</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Near-IR Spect.</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>3/b</td>
<td>Gravitational Microlensing</td>
<td>R=30,000 Opt. Spect.</td>
<td>*</td>
<td>TOO/3 hrs per event</td>
</tr>
<tr>
<td>3/c</td>
<td>Planets and the Pleiades</td>
<td>R=100,000 Opt. Spect.</td>
<td>75</td>
<td>6 yr program</td>
</tr>
<tr>
<td>4/a</td>
<td>Nature of Protostars</td>
<td>R=50,000 NIR Spect.</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R=100,000 Mid-IR Spect.</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>4/b</td>
<td>IMF in Nearby Star Forming Regions</td>
<td>R=5000 Near-IR Spect.</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>5/a</td>
<td>Cosmological Evolution of Starburst Galaxies</td>
<td>R=1000 Opt. Spect.</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R=2500 Opt. Spect.</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>NIR AO Imager</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

| 6/a | Halo Populations in the Local Group | R=1000 Opt. Spect. | 50 | Multi-slit |
| 6/b | Galaxy Formation and Evolution: Dwarf Sph. | R=10,000 Opt. Spect | 100 | Multi-slit |
| 6/c | Galactic Disks 10 Gyrs ago | R=30,000 Opt. Spect | 30 | |
| 7/a | Formation and Growth of Galaxies | NIR Imager | 50 | |
|  | | R=5000 Opt/NIR Spect | 150 | |
|  | | R=10,000 Int. Field Spect. | 30 | |
|  | | R=500,000 Opt. Spect. | 5 | |
|  | | R=20,000 Opt. Spect. | 10 | |
| 8/a | Large-Scale Structure at High Redshifts | R=5000 NIR Spect. | 130 | |

Posted: 1/29/98
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## Parameters for Supporting Surveys

### Table 2

Parameters for Supporting Surveys

<table>
<thead>
<tr>
<th>Program</th>
<th>Program title</th>
<th>Survey title</th>
<th>Survey location</th>
<th>Sq. Deg</th>
<th>filters</th>
<th>limits</th>
<th>additional requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/a</td>
<td>Physical &amp; Population Studies of Kuiper Belt Objects</td>
<td>1000 KBOs</td>
<td>ecliptic</td>
<td>1500</td>
<td>R</td>
<td>R=24</td>
<td>observe discovered objects twice/year for 5 years</td>
</tr>
<tr>
<td>1/a</td>
<td>Physical &amp; Population Studies of Kuiper Belt Objects</td>
<td>largest KBOs</td>
<td>ecliptic</td>
<td>#</td>
<td>R</td>
<td>R=21</td>
<td>must observe twice; standards of various types</td>
</tr>
<tr>
<td>2/a</td>
<td>Three Ages of the Mass-Luminosity Relation</td>
<td>Pleiades</td>
<td>Pleiades</td>
<td>10</td>
<td>JK</td>
<td>K=15.5, J=16.5</td>
<td>calibration binaries?, radial velocity programs</td>
</tr>
<tr>
<td>2/b</td>
<td>The Age of the Galactic Disk</td>
<td>Cool WDs</td>
<td>t&gt;20 fields</td>
<td>20</td>
<td>B,V,I,MgH, CaH</td>
<td>V=24</td>
<td>limits B=25, I=23; MgH=5150/250, CaH=6830/250; alternative 300 sq deg to V=22</td>
</tr>
<tr>
<td>2/c</td>
<td>Variations in the sub-stellar mass function</td>
<td>open clusters (Hyades)</td>
<td>Hyades</td>
<td>50</td>
<td>R,I,z,H(short), H(long)</td>
<td>R=23, I=21, z=20, H=19</td>
<td>H:20% photometry; low-res spect, astrom to confirm membership</td>
</tr>
<tr>
<td>2/c</td>
<td>Variations in the sub-stellar mass function</td>
<td>open clusters (young)</td>
<td>5 young clusters</td>
<td>5 X 10</td>
<td>R,I,Z</td>
<td>R=24, I=22, z=21</td>
<td>5% photometry</td>
</tr>
<tr>
<td>3/a</td>
<td>Physical Params of Luminous Stars in Extragal. Env.</td>
<td>local group galaxies</td>
<td>fields in 6 local group galaxies</td>
<td>10</td>
<td>BVRI</td>
<td>V=23</td>
<td>need 10 epochs to find Cepheids; need featureless standards, radial vel. stds.</td>
</tr>
<tr>
<td>3/b</td>
<td>Gravitational Microlensing</td>
<td>NONE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/c</td>
<td>Planets and the Pleiades</td>
<td>spect monitoring</td>
<td>100 stars in Pleiades</td>
<td>NA</td>
<td>R=20,000</td>
<td>V=10-14</td>
<td>100 m/s accuracy; 10 observations/target over 2 years</td>
</tr>
<tr>
<td>4/a</td>
<td>The Nature of Protostars</td>
<td>protostar candidates</td>
<td>Star forming regions &lt;1 kpc</td>
<td>120</td>
<td>JHKL</td>
<td></td>
<td>10% photometry</td>
</tr>
<tr>
<td>4/b</td>
<td>IMF in Nearby Star-forming Regions</td>
<td>PMS objects</td>
<td>10 mol. clds</td>
<td>120</td>
<td>RIJHKL</td>
<td></td>
<td>10% photometry; FOV large enough to tie in with Hipparcos; variability survey to I=20; spectroscopic standard grid</td>
</tr>
<tr>
<td>Parameters for Supporting Surveys</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>5/a</strong></td>
<td>Cosmological Evolution of Starburst Galaxies</td>
<td>WIRE src redshifts</td>
<td>WIRE deep survey fields (10,000 sources)</td>
<td>8</td>
<td>Redshift survey (R=1000)</td>
<td>Guess of 4-hour exposures</td>
<td></td>
</tr>
<tr>
<td><strong>5/a</strong></td>
<td>Cosmological Evolution of Starburst Galaxies</td>
<td>WIRE src spectrophotom.</td>
<td>WIRE deep survey fields (400 sources)</td>
<td>8</td>
<td>R=2000, S/N &gt;20</td>
<td>Guess of 1-hour exposures</td>
<td></td>
</tr>
<tr>
<td><strong>6/a</strong></td>
<td>Halo Populations in the Local Group</td>
<td>halo star IDs</td>
<td>M31, M33, N185, N205</td>
<td>9</td>
<td>I, M,T1,51</td>
<td>V=25</td>
<td>1% photometry; spect. calib. grid of 200 stars at R=10,000</td>
</tr>
<tr>
<td><strong>6/b</strong></td>
<td>Galaxy formation and evolution from Dwarf Spheroidals</td>
<td>turnoff star IDs</td>
<td>10 MW dwarf spheroidals</td>
<td>90</td>
<td>BVRI</td>
<td>V=24.5</td>
<td>0.5% photometry</td>
</tr>
<tr>
<td><strong>6/c</strong></td>
<td>Galactic disks 10 Gyrs ago</td>
<td>old disk stars</td>
<td>disk fields in MW, M31, M33</td>
<td>22</td>
<td>Stromgren (b,y,c1)</td>
<td>V=19</td>
<td>0.5% photometry</td>
</tr>
<tr>
<td><strong>6/c</strong></td>
<td>Galactic disks 10 Gyrs ago</td>
<td>RVs of MW disk stars</td>
<td>disk fields in MW</td>
<td>R=3.000</td>
<td></td>
<td></td>
<td>Guess of 2 nights/field</td>
</tr>
<tr>
<td><strong>7/a</strong></td>
<td>Formation and Growth of Galaxies</td>
<td>1st tier; largest scale</td>
<td>5 fields across sky</td>
<td>125</td>
<td>I</td>
<td>I=25</td>
<td></td>
</tr>
<tr>
<td><strong>7/a</strong></td>
<td>Formation and Growth of Galaxies</td>
<td>2nd tier; deep galaxy search</td>
<td>5 fields across sky</td>
<td>5</td>
<td>UBVRIJK</td>
<td>UBVRI=27, AB, J=26, H=24, K=23</td>
<td>20% photometry, do spect of brighter srcs with 4m telescope</td>
</tr>
<tr>
<td><strong>8/a</strong></td>
<td>Large-scale structure at High Redshifts</td>
<td>wide field</td>
<td>4 fields across sky</td>
<td>10</td>
<td>UBVRIJK</td>
<td>K=21.5</td>
<td>5% photometry</td>
</tr>
<tr>
<td><strong>8/a</strong></td>
<td>Large-scale structure at High Redshifts</td>
<td>deep</td>
<td></td>
<td>0.5</td>
<td>UBVRIJK</td>
<td>K=23</td>
<td>5% photometry</td>
</tr>
</tbody>
</table>

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### Table 3

**Required Capabilities for Imaging Surveys on 2.5-4 Meter Telescopes**

<table>
<thead>
<tr>
<th>Survey</th>
<th>Survey Title</th>
<th>Area</th>
<th>bands</th>
<th>Comments</th>
<th>Nights – Tel #1 [2.5m diam/ 0.5 arcsec FWHM/ 3% emissivity]</th>
<th>Nights – Tel #2 [2.5m diam/ 1.0 arcsec FWHM/ 10% emissivity]</th>
<th>Nights – Tel #3 [4.0m diam/ 0.5 arcsec FWHM/ 3% emissivity]</th>
<th>Nights – Tel #4 [4.0m diam/ 1.0 arcsec FWHM/ 10% emissivity]</th>
<th>other</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/a</td>
<td>1000 KBOs</td>
<td>1500</td>
<td>R</td>
<td>plus 20 nights/yr to not lose</td>
<td>110</td>
<td>248</td>
<td>77</td>
<td>131</td>
<td></td>
</tr>
<tr>
<td>1/a</td>
<td>largest KBOs</td>
<td>#</td>
<td>R</td>
<td>do twice to discover</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2/a</td>
<td>M/L in Pleiades</td>
<td>10</td>
<td>JK</td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2/b</td>
<td>Cool WDs in disk</td>
<td>20</td>
<td>BVIMgHcHaH</td>
<td></td>
<td>4.7</td>
<td>11.1</td>
<td>3</td>
<td>5.4</td>
<td></td>
</tr>
<tr>
<td>2/c</td>
<td>open clusters (Hyades)</td>
<td>50</td>
<td>RIZ</td>
<td></td>
<td>3.1</td>
<td>3.6</td>
<td>3</td>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td>2/c</td>
<td>open clusters (Hyades)</td>
<td>50</td>
<td>RIZ</td>
<td></td>
<td>21.2</td>
<td>21.2</td>
<td>12.6</td>
<td>12.6</td>
<td></td>
</tr>
<tr>
<td>2/c</td>
<td>open clusters (young)</td>
<td>50</td>
<td>RIZ</td>
<td></td>
<td>7.5</td>
<td>19.8</td>
<td>4.7</td>
<td>9.5</td>
<td></td>
</tr>
<tr>
<td>3/a</td>
<td>Luminous extragalactic stars</td>
<td>10</td>
<td>BVRI</td>
<td>do 10 times for var's</td>
<td>9.6</td>
<td>13.2</td>
<td>8.3</td>
<td>9.7</td>
<td></td>
</tr>
<tr>
<td>4/a</td>
<td>protostar candidates</td>
<td>120</td>
<td>JHKL</td>
<td>L not included</td>
<td>28.2</td>
<td>30.1</td>
<td>23.2</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>4/b</td>
<td>PMS objects</td>
<td>120</td>
<td>RI</td>
<td>L not included</td>
<td>4.7</td>
<td>5</td>
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Posted: 1/29/98
Email: webmaster@noao.edu
# APPENDIX E

## Table E-1

### NATIONAL OPTICAL ASTRONOMY OBSERVATORIES

**FY 1999 - 2003 Long Range Plan**

**Base Budget Summary**

*(Amounts in $1,000)*

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(a) FY 1998 Program Plan Revision I (preliminary) excluding carryover of $3,784M.
(b) Plus $0.15M from Division of Atmospheric Sciences.
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**APPENDIX E**

**Table E-3**

**NATIONAL OPTICAL ASTRONOMY OBSERVATORIES**

**FY 1999 - 2003 Long Range Plan**

**Initiatives**

(Amounts in $1,000)

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(a) Remaining $1.85M NOAO contribution will be paid from FY 1997 carryover funds.
### APPENDIX E

Table E-4

NATIONAL OPTICAL ASTRONOMY OBSERVATORIES
FY 1999 - 2003 Long Range Plan
Total Base Budget, Increments to Operating Budget,
and Proposed Initiatives
(Amounts in $1,000)

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