

**REPORT
OF THE
PORTFOLIO ALLOCATION REVIEW
OF THE
NSF DIVISION OF ASTRONOMICAL SCIENCES**

I. INTRODUCTION

A. The State of Astronomy in the United States

We are entering a golden age in the history of astronomy, and the prospects of more advanced facilities and supporting infrastructure (*e.g.*, internet, computing, new technologies) promise to stimulate exceptionally vigorous growth of the field. In the past decade, there has been a profound change in structure for the tools of astronomy and their sponsorship. The construction of NASA's Great Observatories and the tremendous capital outlay for the large telescopes of the private observatories and Gemini has resulted in dramatic new observational capabilities. There has also been a convergence of, *e.g.*, high-energy (particle) physics and astrophysics in particle-astrophysics. The situation is now at a point where NSF's Division of Astronomical Sciences (NSF/AST), with a relatively modest budget, must assume a new role in the larger picture. However, both expert and lay observers are increasingly voicing the concern that the NSF portfolio has not responded in structure or size to this new era. This is not to minimize the stunning array of astronomical discoveries that have been made by NSF sponsored scientists, but there is a concern that NSF, which should have the most visionary, high-risk/high-reward portfolio, is instead in danger of playing a secondary role in the coming decades. A key to exploiting this golden age of astronomy to its fullest extent is the fostering of a new and vital generation of astronomers with the facilities of the world at their disposal, and a vision of astronomy in the broadest sense to drive them. The underlying principle of the NSF to entertain the broadest possible intellectual portfolio is fundamentally correct. Nonetheless, for a variety of reasons, the numbers of grants have not kept pace with the opportunities nor do NSF-sponsored scientists have adequate access to the best facilities supported by the best NSF-sponsored instruments. There need to be increases in research grants support and a concerted effort to leverage world-wide investments in frontier facilities built and operated in whole or in part with NSF resources.

B. Background of the Portfolio Allocation Review (PAR) Committee Activity

In view of the concerns described above, the Division of Astronomical Sciences (AST) of the National Science Foundation (NSF) Committee of Visitors (COV) met in March, 1999, to consider, among other matters, the internal allocation of funds for the AST Grants Program (GP). Their charge was to evaluate the review process used to distribute the funds and to consider the level of GP funding within the greater context of the AST budget. After examining more than 300 proposal jackets, selected at random, they reached several important conclusions, among which were:

1. The GP funding level was exceedingly low, and although the science that was funded was of the highest rank, many first-rate proposals failed to receive funding because of the lack of resources.

2. The relative ratios of the funding levels between the GP subdisciplines and between the Grant, Instrumentation, and Facilities Programs has remained approximately constant for many years with no clear rationale as to why that balance had been maintained.

3. Based upon findings (1) and (2), the Mathematical and Physical Sciences (MPS) Directorate should convene a panel to review the allocation of resources within AST, to develop recommendations concerning whether AST funds are currently optimally allocated, and to outline procedures for adjusting the balance in a timely fashion in the future.

In response to these recommendations, MPS and AST convened a committee to carry out a Portfolio Allocation Review (PAR) for the National Science Foundation's Division of Astronomical Sciences (NSF/AST). A list of the committee members is attached (Appendix A). The PAR Committee is a subcommittee of the Advisory Committee for the Mathematical and Physical Sciences (MPS/AC), and the report of the PAR Committee will be addressed to the MPS/AC. The PAR was conducted in well-attended, open sessions in room 375 at the NSF Building in Alexandria, VA, beginning on the evening of November 29. The meeting ran the full days of November 30 and December 1, and ended at noon on December 2, 1999. A number of supporting documents were distributed to the PAR Committee by NSF/AST prior to their arrival at NSF, and the first two days of the meeting were largely devoted to fact-finding through AST presentations and question/answer sessions. The agenda is attached (Appendix B).

C. The Charge to the PAR Committee

The charge to the PAR Committee was based upon the observation that fiscal support through AST for the conduct of astronomical research has not kept pace with the growth of the field. In consequence of this concern and the COV findings, MPS and AST asked the PAR Committee to examine whether the current allocation of Divisional resources among the several components of AST's portfolio is still appropriate or whether there are alternatives that would better serve the U.S. astronomical community. The Committee was instructed to assume a budget projection for AST that would support only a constant level of effort.

The stated purpose of the PAR was to assist AST and NSF in evaluating the current distribution of support by conducting a review with the following scope and charge (as cited in the document empanelling the PAR Committee):

- *Scope:*

In order that AST's investments be maximally effective and beneficial to the U.S. astronomical community (and, therefore, to the U.S. taxpayer), the committee is directed to adopt an international perspective as well as one that embraces all of U.S. astronomy. For example, in making recommendations pertaining to AST support of research in a particular subfield of astronomy, the review committee is asked to consider whether the U.S. is currently, or should be, among the world leaders in that subfield. In addition, the committee is asked to consider not only

NSF support for such research, but support by NASA or other funding sources as well. The purpose of the review is to advise AST as to better ways of making the difficult decisions we must make.

- *Charge:*

Given the science opportunities available to the U.S. astronomical community, the committee is asked to provide guidance as to the most effective way to utilize available NSF resources to ensure a world-leading program of research and education in astronomy and astrophysics.

This evaluation is requested within the context of:

1. The overall portfolio of resources available in the federal government and the private sector for astronomy.
2. Activities going on in the rest of the world.
3. The special responsibility that NSF has in relation to U.S. universities, to more general education, and to diversity issues.

D. Underlying Principles Adopted by the PAR Committee

To guide and motivate the discussion in this report, we have identified a set of principles that we believe will facilitate the analysis of the content of the portfolio of the Division of Astronomical Sciences.

1. The Division's portfolio must emphasize forefront science that addresses critical questions, supports the development of innovative technology, and emphasizes the unique strengths of the entire U.S. astronomical community.
2. Since resources are limited, all aspects of the Division's program (grants, facility operations, telescopes and instrument development) must be carried out in the most efficient and cost effective manner, but without sacrificing the quality of the scientific program.
3. The Division must maintain a dynamic program that is motivated by its strategic plan, but is responsive to changing conditions, new technologies, and the dynamics of the U.S. and international astronomical communities. Timely advice from the community is critical to maintaining a dynamic program

We wish to emphasize the importance of concentrating the Division's resources in areas that utilize unique strengths of the U.S. astronomical community. Some examples of areas in which U.S. astronomers have established and maintained world leadership include:

1. Millimeter and microwave interferometry

2. The application of adaptive optics to solar imaging
3. The use of high-speed computing to model astronomical phenomena
4. The development of fast, large-aperture optical systems for deep surveys
5. The development of large-format imaging arrays for both optical and infrared (O/IR) imaging.

II. NSF SHARE OF U. S. FEDERAL AND PRIVATE FUNDING FOR ASTRONOMY

A. NSF Support in the Context of U.S. Astronomy

Astronomy research is supported by NASA and NSF grants and facilities. Space-based astronomical observatories are the responsibility of NASA, with some involvement from private industry. NASA research support is “mission-oriented:” much of it is tied to specific space missions and therefore both specialized and volatile. NASA does also support theoretical and cross-mission research through, in particular, astronomical data analysis and astrophysical theory programs. Altogether, NASA grants to individual investigators support astronomical research with a total of about \$90M/year. NSF's support for astronomy through the AST Division amounts to \$120M/year, of which grants to individual investigators, including instrumentation development and educational grants account for a little over \$30M/year (independent of facilities, old and new, and major instrumentation). NASA provides a modest amount of support for a few ground-based optical/IR projects, again primarily tied to specific present or planned space missions (*e.g.*, interferometry development) or projects particularly close to NASA's scientific goals (*e.g.*, Keck Observatory time paid for by NASA and made available to the community specifically for planet searches). (Data presented in this paragraph are abstracted from material presented at the PAR Committee sessions; a more detailed report is under preparation by the Committee on Astronomy and Astrophysics of the National Academy of Sciences [NAS].)

For night-time astronomy, ground-based optical-IR facilities have been built with state and private funds (*e.g.*, Keck Foundation) and with NSF support (*e.g.*, the U.S. half of the International Gemini project), with the balance shifting in recent years towards dominance by the “independent” observatories which do not have an obligation to provide open, competitive access to the community. The national observatories employ a small fraction of the U.S. research astronomers; most of this community is located at universities. Ground-based radio facilities, in contrast, are predominantly supported by NSF, whether national in character (National Radio Astronomy Observatory, NRAO) or operated by individual universities.

In solar physics, university-based research tends to be related to space projects and/or theory, and a substantial fraction of the ground-based observers are located at the National Solar Observatory (NSO), funded mainly by NSF and the Air Force. The U.S. solar physics community is relatively small and none of the major national facilities is newer than 25 years old. Recent big projects supported by NSF include the Global Oscillation Network Group (GONG) project (small observing stations around the world) and Synoptic Optical Long-Term Investigations of the Sun (SOLIS, updated solar activity monitoring).

B. U. S. Astronomy in the International Context

With the development of several very-large-aperture telescopes, The U.S. astronomical research emphasis has shifted towards extragalactic astronomy and cosmology – particularly at the most competitive research universities with privileged access to “big glass.” Solar astronomy has not developed as rapidly in recent years in the U.S. as it has abroad, and the same is true of stellar astronomy, particularly with international and European space missions providing a strong impetus for some stellar specialties.

Worldwide, technological advances have led to an explosion of available telescopes with apertures 4m or greater. Only in the U.S., however, are most of these new telescopes “private.” The international Gemini project will allow all U.S. astronomers to access competitive facilities, but there are concerns about whether all or only some of the community will have access to the smaller survey and follow-up telescopes that are needed to compete successfully for time and make proper use of the data obtained on these 8m telescopes. Therefore, the issue of providing for new national survey telescopes and a “virtual observatory” of accessible archived data are central to the issues considered by the PAR Committee .

III. FACILITIES AVAILABLE TO U. S. ASTRONOMERS

A. Radio

The NSF supports two national radio observatories. The Arecibo telescope of the National Astronomy and Ionosphere Center (NAIC), managed by Cornell University, is the world's largest centimeter wave antenna. The NRAO operates several telescopes. The Green Bank Telescope (GBT), a 100m reflector for centimeter wavelengths, is going into operation in Green Bank, West Virginia. The Very Large Array (VLA), near Socorro, NM, operating in several bands from 1 meter to 0.7 cm with baselines up to 35 km, is the world's most powerful centimeter wave radio telescope. The Very Long Baseline Array (VLBA), with ten antennas distributed from Hawaii to the Virgin Islands, produces the highest-angular-resolution images in radio astronomy.

At millimeter and submillimeter wavelengths, the NSF supports several telescopes. The 12m reflector of the NRAO at Kitt Peak operates over the 1 to 3 millimeter wavelength range. In addition, there are four university millimeter/submillimeter telescopes in the University Radio Observatory (URO) program. The Five College Radio Astronomy Observatory (FCRAO) in Amherst, MA, has a 14m antenna with a large focal-plane array operating at 3 mm. There are two arrays in California. The Owens Valley Radio Observatory (OVRO) consists of six 10m antennas, and the Berkeley-Illinois-Maryland Association (BIMA) array is comprised of ten 6m dishes; both operate at 1 to 3 mm. These two facilities are in the process of merging at a higher altitude site and will be known as the California Array for Research in Millimeter Astronomy (CARMA). For the submillimeter region, there is the Caltech Submillimeter Observatory (CSO), operated by Caltech in Hawaii. Finally, the Coordinated Millimeter VLBI Array (CMVA), operated by the Haystack Observatory coordinates *ad hoc* very long baseline interferometry (VLBI) at both 1 and 3 mm. Some public access by the astronomical community is guaranteed at all these university radio facilities.

In the radio spectrum there are also foreign facilities available to U.S. astronomers. At centimeter wavelengths there are the Westerbork Synthesis Radio Telescope (WSRT) in the Netherlands, the Merlin array in Britain, the 100m at Bonn, the Nançay telescope in France, the Giant Meter-Wave Radio Telescope (GMRT) in India and the Parks telescope and the Australian Telescope Centimeter Array (ATCA) in Australia. At millimeter wavelengths, the Institut Radio Astronomie Millimetrique (IRAM) operates two systems, a 30m reflector and an array of five 15m antennas. Also there is the Swedish European Southern Telescope (SEST) 15m antenna in Chile, the James Clerk Maxwell Telescope (JCMT) in Hawaii, and the array of ten 6m antennas in Nobeyama, Japan. With few exceptions, and by contrast with general practice at U.S. facilities, use of these instruments requires collaboration with astronomers at these facilities.

B. Optical/IR Ground-based and Space-based

NSF supports the National Optical Astronomy Observatories (NOAO) which are responsible for O/IR telescopes at NOAO's Kitt Peak National Observatory (KPNO) and Cerro Tololo Interamerican Observatory (CTIO), as well as solar telescopes at Kitt Peak and at Sacramento Peak. The Kitt Peak facilities consist of the 4m Mayall and the 3.5m Wisconsin-Indiana-Yale-NOAO (WIYN) telescopes, along with a 2.1m telescope. The last Kitt Peak 0.9m telescope and the Coude feed will be phased out in 2000. The Mayall telescope is equipped with several spectrographs for the optical and 0.9-5.5 micron regions and several cameras, most notably an 8K x 8K CCD (charge-coupled device) mosaic array with a 35 arcminute field. The WIYN telescope (in which NOAO has a 40 percent observational stake in return for operations support) has a CCD camera giving a field of about 6 arcminutes and the HYDRA 100 fiber positioner and bench spectrograph. The 2.1m is equipped with several optical and infrared (IR) spectrographs and imaging devices.

At CTIO the major telescopes are the Blanco 4m and the 1.5m, both of which are instrumented with a large suite of spectrographs and imagers for both the optical and infrared. Under construction is the Southern Observatory for Astronomical Research (SOAR), a thin-mirror 4m telescope which should produce high-resolution images. NOAO will allocate 30 percent of its observing time in return for providing some capital contributions and full operating costs. (After SOAR becomes operational, NOAO support for the Schmidt, 1.5m and 0.9m telescopes at CTIO will be transferred to SOAR.) NOAO will also allocate the U.S. share of observing time on the 8m Gemini North telescope, beginning in 2000. Also starting next year, NOAO will award 27 nights per year on the Hobby-Eberly Telescope (HET) and 27 on the Multi-Mirror Telescope (MMT), for a 6-year period.

The McMath-Pierce solar telescope, located on Kitt Peak, is the only large solar telescope in the world with no entrance window, thus giving it access to the IR beyond 2.5 microns. As a consequence, much of the imaging and spectrographic work with this telescope is done in the IR, though instruments sensitive to the optical region are also available. A new large-format IR array (1k x 1K replacing the 256 x 256 camera) is under development. On Sacramento Peak are more recently constructed solar facilities including the Dunn Solar Telescope and the Evans Solar Facility. These are equipped with spectrographs and imagers that operate in the 1-5 micron region.

GONG is a six station network for helioseismology. With its worldwide sites, it provides nearly continuous observations of the 5-minute solar oscillation. The next upgrade of these instruments would be the replacement of their 256 x 256 arrays by 1024 x 1024 detectors.

Under construction is SOLIS (Synoptic Optical Long-term Investigations of the Sun), which, as its name implies, is designed to make various optical measurements of the sun over long time periods. It is expected to become operational in 2001 on Kitt Peak, until a better site is found.

All of the solar facilities will be operated by an autonomous NSO, perhaps by 2002. While the small number of solar facilities outside of NSO play unique roles in solar research, the large aperture NSO telescopes, and SOLIS and GONG are world-class instruments that are critical to the U.S. solar program.

We note the priorities recommended by the recent Parker Committee report to (i) complete and operate SOLIS with adequate funding for data analysis by the U.S. solar community, (ii) upgrade GONG, (iii) develop a 3m-to-4m Advanced Solar Telescope (AST), and (iv) begin an exploratory program for a frequency-agile solar radio telescope, using existing radio observatories. The adaptive optics program, which is essential to the AST development, has achieved impressive results, but support for this critical program should be increased. We recommend that the major NSO facilities, SOLIS, GONG, and the Vacuum Tower Telescope, which is essential to the adaptive optics program, should receive the highest priority.

Many first-rate foreign ground-based and space-based observatory facilities are accessible to U.S. astronomers under the right conditions. Ground-based O/IR facilities include the telescopes on La Silla, Chile; the Very Large Telescope (VLT) at Cerro Paranal, Chile; the Japanese National Large Telescope (JNLT, "Subaru") at Mauna Kea, HI; the UK's William Herschel Telescope on Tenerife; telescopes in Spain; and the telescopes at Mt. Stromlo-Siding Spring in Australia. Among the advanced space facilities recently or currently in use abroad are ASCA, ROSAT, ISO, Beppo-SAX, and soon XMM. While time is available for many of these space missions through open competitions run by NASA, time allocations on the ground-based telescopes must usually be tied to a foreign collaboration. In either case, funding for travel and data analysis must come from U.S. grant programs.

IV. THE NSF/AST STRATEGIC PLAN

A. The Existing Plan

We applaud the AST Division for taking steps to formulate a strategic plan. The current plan, as released in September, 1999, describes a clear and coherent scientific vision for astronomical research in the U.S. The plan concentrates on the major thematic areas that motivate this research in the next decade. These responsibilities include providing or identifying resources to capitalize on major new opportunities, education and outreach efforts to increase the public awareness of science (and of the NSF accomplishments in particular), and to facilitate management of the electromagnetic spectrum. The AST strategic plan must of course be reconciled with the results of the decadal survey when the latter is released. The plan must then be augmented by a clear vision of how funding within the NSF (for AST as well as for other astronomy-related divisions) will

enable the science goals to be achieved. In particular, mechanisms should be developed by which several questions can be addressed, for example: What is the relative importance of the various components of the program (grants, facilities, development for future telescopes and instruments) and how will these components be structured, and dynamically adjusted, to the overall U.S. and global astronomical environment? What are the top priorities of the NSF in terms of its existing portfolio and in terms of its new initiatives, and how will these priorities be addressed? Are there tough decisions that we need to make to ensure a stronger program in the future? If so, what are these decisions and how will they be made? These are some of the key questions which the AST Division must address in planning for the future.

B. Prioritization of Future Projects

The AST Strategic Plan for the next 4 years contains about 14 items (see Appendix C). We believe that 6 of these are of the highest priority:

- Initiation of a program of grants for research using new facilities (*e.g.*, Gemini, GBT, Arecibo).
- Establish or provide for the “National Virtual Observatory,” a system of accessible data archives.
- Ensure that the grant success rate is high enough to allow all the high priority projects to proceed with adequate funding. Combined with the first point above, the annual total in new individual grant dollars should be increased by a substantial amount. A minimum annual increase to the program of at least \$5 M would appear to be a desirable goal.
- Develop education initiatives and increase the visibility of NSF astronomy.
- Provide for instrumentation, particularly facility instrumentation and several large survey telescopes that will serve as the “eyes” for the large aperture telescopes.
- Provide the funds to allow for investment in areas where there are particularly rapid developments in technology and new opportunities – as, for example, at the current time is true for high energy and particle astrophysics.

The other suggested augmentations to the AST budget, though worthwhile, are of lower priority.

V. COMMITTEE OVERVIEW OF THE CURRENT NSF/AST PORTFOLIO ALLOCATION

The recent report of the COV stressed the quality and innovative nature of the grants portfolio of research, and the effective use of new technologies that have helped to create a “Golden Age” of discovery and increased understanding of astronomical phenomena.

The scientific grants program is now allocated by a process that explicitly responds to “proposal pressure” in that all subdisciplines are deemed equally vital and that a roughly uniform success rate across program subdisciplines is sought as an outcome. The process classifies proposals according to scientific content into Extragalactic and Cosmology, Stellar Astronomy and Astrophysics, Galactic Astronomy, and Planetary Astronomy, categories that have not been changed for many years. The COV expressed some concern about the lack of apparent mechanisms for redistributing effort as the field changes. The committee learned, however, that the content of the programs has been more fluid than the fixed titles imply, with some topics assigned now to one, now to another program to keep the administrative loads more evenly distributed. More importantly, we note that the grants program has evolved significantly in terms of both scientific content and the techniques used. However, the continued use of traditional categories by which the grants program is organized has masked the response of the program to the dynamic nature of astronomy. We recommend that the Division consider a new set of research categories that stresses the goals of the division as outlined in its strategic plan.

The program managers use an *ad hoc* process to communicate with other funding organizations (NASA, private observatories, *etc.*) to gauge the uniqueness and relevance of proposals. In addition, AST recently introduced a discretionary fund that is used to fund a fraction of those projects that the individual programs have not been able to fund, selected by scientific merit without consideration to the program of origin. Experience with these discretionary awards suggests that the grants programs are reaching cutoff at similar quality levels. This mechanism appears to be allowing for gradual reapportionment of resources among the grants program, and seems to have enough flexibility to deal with broad changes of emphasis in astronomy as well as interesting and innovative proposals. The discretionary fund was ~\$800k in FY1999, and is projected to be ~\$1M for FY2000. While this is a move in the right direction, it seems appropriate to increase such cross-disciplinary competition. It would be good if a means could be found to bring in elements of the facilities budgets as well, bearing in mind that the effects of uncertainty in facilities budgets can be detrimental unless handled with care.

We believe that the process of an initial allocation of resources according to proposal pressure, combined with a discretionary fund that can enhance the support available to areas with an abundance of high-quality proposals not fundable under the initial allocation, is an effective apportionment mechanism. However, we recommend that the discretionary fund level should be increased to about 10% of the grants program budget.

Though the present metric used for determining the scientific balance within the grants program is reasonable, other metrics may be of interest, particularly in post-analysis of proposal distributions: for example, scores from committee deliberations, publication rates, *etc.* Also, continued and even increased coordination with other agencies to ensure balanced federal investment is important. Both flexibility and vigilance are needed to ensure the optimum balance in the face of tight funding constraints.

There was considerable discussion of the advisability of AST adopting a strategy of focusing on particular areas of astronomy in light of large investments by NASA and private institutions. After considering the benefits of having a more focused program, the committee concluded that limiting

the scope of the program would not likely benefit astronomy, and that the breadth and openness of the NSF portfolio is one of its great unique strengths.

VI. PAR COMMITTEE RECOMMENDATIONS

This is not a rank-ordered list; the committee feels that all are important. They are arranged by topic and somewhat by immediacy of implementation.

- **Need for an AST Advisory Committee:** We strongly believe that the ongoing review and oversight that is necessary to adjust AST funding allocations and programmatic priorities requires an Advisory Committee for Astronomical Sciences (ACAST) that meets a few times a year on a regular basis. Recognizing that there is a Presidential mandate to limit the number of such committees agency wide, we would argue nonetheless that AST be considered for such a committee within the agency cap limit. The wide range and unusual complexity of the AST programs as exemplified by the recommendations in this report demands this ongoing oversight at least for the next few years.
- **Augmentation of the AST grants program:** It is clear that the recent evolution of ground-based astronomical science has left the AST GP woefully underfunded. Creative ways must be sought to increase the level of support coming to NSF, MPS, and AST for support of the GP. The total grants budget (including the amount associated with new facilities, see below) should increase by at least \$5m.
- **Funding for major projects should include monies for doing science:** Support for new telescopes by the NSF should include provision for operation of the telescope, once it is complete, for the cost of making observations with the telescope, including data analysis and publications costs and for instrumental developments both for this telescope and for future instruments.
- **Need for improved, proactive public relations from AST:** The American public is largely unaware of the fundamental importance of the NSF in supporting research that is at the forefront of science. Likewise, the U.S. astronomical community is less aware than it should be of the key role of the NSF in providing broad, non-restrictive access to facilities in support of all astronomical research. We note also that the wide public interest in astronomy provides a natural avenue to widen public understanding of and enthusiasm for all the physical sciences and even some of the biological disciplines. AST needs to develop a proactive program to highlight important new AST-funded scientific results, in a manner that makes NSF's role clear. We recommend additional investments of time, money and effort on the part of AST and MPS to highlight the research achievements of Principal Investigators (PIs) supported by NSF/AST. Responsibility also rests with the astronomical community. News releases by NSF-supported investigators do not always attribute credit to NSF as the funding source. Web sites describing investigator research should properly acknowledge NSF support and provide links to NSF funded instrument sites. We urge individual investigators to contact their program officers

at NSF before issuing press releases, and in general to ensure that NSF gets proper credit for the support of their research. Additional avenues for improvement might include increased use of the capabilities of the Press Office of the AAS and a more activist role by the NSF Press Office, *e.g.*, in reminding all investigators of their responsibility to acknowledge the sources of their support.

- Facilities instrumentation: As have previous committees, this committee also recognizes the U.S. community's need to properly instrument our new suite of 8m class telescopes if we are to remain competitive in the international arena. The NAS in its O/IR Panel Report (McCray *et al.* 1995) recommended the creation of a facilities instrumentation program specifically to provide such funds while simultaneously encouraging access to the community at large. The program was started with existing and new funding, but has since ceased. The urgent need, however, remains. The committee recommends that this special program be reinitiated, ramping up to the level recommended in the O/IR Report as funding becomes available. The committee recommends that this program be in addition to AST's existing Advanced Technologies and Instrumentation (ATI) program, and that it involve reasonable and substantial return to the community, much as the community realizes the benefits of the NSF University Radio Observatories program through openly available telescope time.
- University Radio Observatories (UROs): It is now timely to convene a committee, like the Taylor Committee, to evaluate the programs of the UROs. This committee should rank the UROs and make recommendations for phasing out or expanding any of the observatories.
- AST should examine new technologies, means of communication, and the feasibility of combining certain operations at O/IR facilities and determine if economies are possible, as well as enabling more effective use of astronomical data to be made. It is not clear that the current relationships among the national radio/optical/IR observatories have been optimized in terms of either facility management or communications between the scientific staffs. An advisory process should be established to determine whether there are improvements that would save costs and improve the support to scientific users. Efficient archiving of data taken at NSF-supported facilities could greatly expand their usefulness. Given the disparity among various databases this is a challenging task, but the rewards could be large. NSF should establish such a program perhaps as part of the new Information Technology Initiative.
- Public access to private observatories: AST should investigate the initiation of programs that would allow the general community of astronomers to gain access to observing time at the private observatories, both domestic and foreign, especially in the O/IR. In addition to travel and publication support for visiting investigators, this might involve funding for advanced instrumentation (see below), or even limited support for operations in exchange for community access.

- Fellowships and scholarships: There is a need for a program similar to NASA's Hubble Fellowship program for the larger community of young astronomers, including, especially, radio astronomers. There is also a need for an expanded program of NSF graduate assistantships. We applaud the AST division's plans to support the training of a new generation of instrumentalists.
- NSF/AST should take a pro-active leadership role in ground-based astronomy: The instrumental and technological capabilities of NOAO with respect to the rest of the national and international O/IR community have changed dramatically over the last decade. Facilities at KPNO and CTIO, though still tremendously useful and productive, are dwarfed by a dozen large new telescopes currently or soon to be operational. Nor does NOAO have the leadership role it once held in some aspects of astronomical technology. At the same time, it is crucial that there exists a strong voice speaking for U.S. astronomy as a whole, both because, increasingly, large facilities are internationalized, and also to prevent a development of "haves" and "have-nots" within the US community. After all, it was such a dichotomy that, over 4 decades ago, led to the establishment of NOAO in the first place.

NSF, as the supporter of much of U.S. O/IR astronomy in general and NOAO in particular, has the responsibility to see that a strong, effective national presence be maintained. The committee believes that the NOAO of ten years from now should look quite different from the NOAO of today. The part to be played by NOAO in the emerging national and international arena must be looked at from the broadest possible perspectives. The goals should be to maximize the scientific effectiveness of all available astronomical facilities, both federally and non-federally funded, and to establish NOAO as the focus of national activities.

The committee believes that it is essential to develop a degree of flexibility in the funding for astronomy in general, and night-time O/IR astronomy in particular, to make it possible for NOAO, the independent observatories, and the community to work together to achieve their common goals. As first steps to achieving a new vision of NOAO, the committee recommends a three-step process. First, the NOAO budget should be restructured to separate the solar from the night-time functions, preparatory to the establishment of an independent NSO at a new site. Second, the night-time budget should be structured so as to permit NOAO to effectively operate the U.S. gateway to the Gemini telescopes and support U.S. participation in instrumentation development for Gemini, as well as operating and supporting instrumentation development for CTIO and KPNO. Any instrumentation program should be done with community and student involvement as the training of the next generation of instrumentalists is of very high priority for astronomy as a field. While the exact numbers cannot be specified at this time, a very rough estimate for the budget required to carry out this portion of the program is that the NSO portion will be in the range of \$8M - \$10M/year and the night-time observatories will require about \$15M to \$20M/year. Assumptions going into this estimate include that the McMath solar telescope will be closed to liberate funds for the development of the Advanced Solar Telescope, and that the night-time programs will have substantially

less direct investment in in-house instrumentation capability than it has had. Third, funds released through restructuring NOAO – and also from similar restructuring applied to other NSF programs within the AST Division – should be used to maintain flexibility for funding new initiatives. In particular, such funds should permit NOAO to seek additional funding to develop essential new functions. Two possible initiatives specifically noted in the Future Directions report are:

1. NOAO should provide unique surveys and work to provide unique survey capabilities, such as very large (*e.g.*, 6.5m) wide-field telescopes and accessible pipelines and archives of survey data, to the community.
2. NSF, presumably through NOAO, should become the point organization for the community planning and development activities necessary to develop a proposal for the next large ground-based O/IR facility.

The committee cannot too strongly emphasize its finding that the competitive future of night-time O/IR astronomy in the U.S. in the face of large investments elsewhere in the world will require continuing leadership from a strong national observatory. This is also important for fully exploiting heavy private investments in the U.S. To further strengthen NOAO's leadership position, the committee encourages NSF and NOAO to look for ways to enhance the coupling between the international Gemini project and NOAO. NOAO manages the U.S. community's access to Gemini, and this should be evident to its users.

The next major night-time telescope initiative, currently referred to as "MAXAT" (Maximum-Aperture Telescope) or "NBT" (Next Big Telescope), is likely to require planning over at least the next decade, and must be a project with community-wide access and support. Having major facilities built privately with insufficient funds for full operations and instrumentation, but with limited access, will not maximize the U.S. scientific return. NSF/NOAO must be at the table in the planning for the NBT, independent of the sources of the capital. Finally, the structure of NOAO and the need for the current sites eventually must be reexamined in the context of the development of the NBT.

- Instrumentation development: NSF should encourage more effective collaborations between private, state, and national facilities with respect to instrumentation development. There should be increased participation of industry in instrumentation development.
- Travel and data reduction costs: National facilities should provide travel and data reduction costs for time-winning observers who are not funded by other grant support from which they can finance these costs. This would eliminate the double jeopardy for successful telescope time applicants and would be extremely cost effective.

- Multi-disciplinary activities should be actively encouraged: Astronomical research is becoming increasingly interdisciplinary, involving a number of divisions within the MPS Directorate, including AST and the Division of Physics (PHY), as well as NSF's Office of Polar Programs (OPP), and possibly in the future, Computer Science, as well as the Department of Energy (DOE) and NASA. The NSF has achieved significant success in the funding of interdisciplinary astronomical and astrophysical research. For example, the Center for Particle Astrophysics (CfPA) was funded through AST, but the future projects emerging from the center have obtained support from various other sources: the Cold Dark Matter Search (CDMS-II) experiment will be funded in large part by DOE and NSF/PHY. Particle and gravitational-wave astrophysics are exciting and developing areas of research. Additional funding for these areas within AST would leverage investments made beyond the AST domain, and would help to enable the construction and operation of several new important initiatives. This action would allow the NSF to continue to play the leadership role in these areas in the U.S. in addition, perhaps education should be considered a multi-disciplinary activity and collaborations established with the NSF Education Directorate.
- Funding for large telescope instrumentation development at the national facilities: The first priority in instrumentation for large aperture O/IR telescopes should be to maintain the capabilities of our national large telescopes (Gemini North and South) at the very forefront of astronomy.

In making these recommendations the committee recognizes that we are asking much of both the AST division and the MPS directorate. We are fully confident that they will implement these recommendations in ways and over time periods that maximize their effectiveness while minimizing disruptions.

Respectfully submitted,

Robert D. Gehrz, Chair
For the Portfolio Allocation Review Committee

Appendix A: Portfolio Allocation Review (PAR) Committee Membership

Appendix B: PAR Agenda

Appendix C: Augmentation Needed for Full Implementation of AST Strategic Plan