REPORT of the COMMITTEE OF VISITORS
Division of Astronomical Sciences
National Science Foundation
February 6-8, 2008

COMMITTEE

Dr. Charles Bailyn, Yale University
Dr. Robin Canup, Southwest Research Inst.
Dr. John Carlstrom, (CoChair), University of Chicago
Dr. Darren Depoy, Ohio State University
Dr. Rose Finn, Siena College
Dr. Erick Guerra, Rowan University
Dr. George Helou, California Institute of Technology
Dr. James Klimchuk, Goddard Space Flight Center
Dr. Bruce Margon (CoChair), University of California Santa Cruz
Dr. Alice Monet, U.S. Naval Observatory
Dr. Norman Murray, University of Toronto
Dr. Antonella Nota, Space Telescope Science Institute
Dr. John Salzer, Indiana University
Dr. Joel Tohline, Louisiana State University

I. Executive summary

The 2008 AST Committee of Visitors (COV) was enormously impressed with the management of the AST Division, its accomplishments over the past three years, and its goals and strategic planning for the future. Despite formidable resource obstacles and the inexorably growing complexity of many of the community's highest priority projects, AST continues to aggressively implement the community's goals while coping with the sometimes disappointing fiscal realities of the federal science budget.

The COV review resulted in no suggestions for fundamental changes in direction of procedures or planning. Rather, a variety of areas were identified where the Committee felt that modest changes might optimize the use of existing constrained resources; or other areas (inevitably already recognized by the AST leadership) where it felt that particular vigilance will be needed to ensure success. The committee's recommendations are enumerated by the order they appear in the report. The numbering is for convenience only and does not refer to a priority ranking of the recommendations.

AST oversees an extraordinarily complex operation with an exceedingly thin staff and resource level, and the COV is convinced that the AST Division simply cannot be asked to do more and more without additional resources. Further, some AST projects are now of such large scope and international visibility that their success is a matter of crucial concern not just to the Division, but to the entire Foundation. AST staffing and resources need to reflect this pragmatic reality.

Recommendation #1: NSF should thoroughly review the staffing requirements of AST to determine the level required for AST to adequately support its base program while playing

a leadership role in the complex, international development of the next generation of world-class observatories.

Recommendation #2: Double AST's travel budget to ensure adequate support for the Division's global oversight and management responsibilities.

AST recently convened a high level community peer review of existing commitment and future priorities, and the resulting report, "From the Ground Up: Balancing the NSF Astronomy Program" – hereafter referred to as the *Senior Review* – provides a comprehensive look at the challenges and budget realties that the overall program will face over the next several years, together with realistic options to attempt to align community expectations and needs with available resources. Developments since the *Senior Review* continue to illustrate the necessity of aggressive planning, and innovative management where possible, to meet a seemingly unending set of challenges.

Recommendation #3: NSF (and the astronomy community) should treat the *Senior Review* report as a baseline which, when combined with the next NRC Decadal Survey, constitutes a disciplined and thoughtful path for the future of AST activities. When appropriate, NSF should use the *Senior Review* recommendations as a community-derived tool to resist non-competitive earmarking of the federal budget.

Recommendation #4: AST should consider conducting subsequent *Senior Reviews* on a pro-active, regular basis rather than simply as a response to moments of crisis. Given their scope and comprehensive nature, it may be impractical to conduct such reviews at a 5-year interval; perhaps future *Senior Reviews* should be activated at 10-year intervals and timed to fall midway between NRC Decadal Surveys.

Recommendation #5: As plans are being developed for the upcoming NRC Decadal Survey, AST should encourage the Survey committee to reexamine the priority of previously recommended projects that have undergone substantial cost growth.

Recommendation #6: NSF should build sufficient flexibility into MREFC processes and practices to optimize the Foundation's ability to partner with private or public entities in the funding of the design, construction, operation and/or maintenance of large facilities.

The AST grants programs, whether for individual investigators or larger collaboration-driven projects, remain at the core of the Division's successes over the decades, and also serve as primary connections between the stakeholders and the Foundation. AST's stewardship of these programs remains exemplary, particularly as it faces the stresses of ever-increasing community aspirations.

Recommendation #7: AST should continue its efforts to ensure that the composition of review panels is as diverse as possible, including members with high levels of research activity.

Recommendation #8: To further improve the efficiency and effectiveness of grant proposal processing, AST Program Officers should consider (a) including comments extracted from generally insightful PO summary analyses in the written responses sent to PIs; (b) providing information to PIs regarding the general ranking (e.g., quartile ranking) of their proposal; and (c) becoming less tolerant of non-compliant proposals.

Recommendation #9: AST should work in concert with its community of researchers to assess how best to take advantage of the NSF's new, substantial Cyber-Infrastructure investments.

Recommendation #10: AST should explore ways to optimize its approach to supporting astronomical instrumentation development, perhaps by restructuring its current set of instrumentation related programs.

Recommendation #11: AST should inform the astronomy community of NSF's general goals and expectations for mid-size projects and should notify the community that unsolicited proposals for mid-size projects may be submitted. However, the COV does not recommend that a formal "mid-size projects" program with pre-allocated funds be initiated at this time.

Recommendation #12: Utilizing funds from an enhanced travel budget, AST should strengthen its oversight support of University Radio Observatories (URO) projects and their associated instrumentation development programs. As many new UROs are being planned, the COV recommends that NSF strive to maintain the proper balance of radio observatories —the radio system— while keeping in mind the need to develop new techniques and to train the next generation of radio instrumentalists.

Large national facilities, while absolutely crucial to the success of our field, place a special oversight burden on AST.

Recommendation #13: The COV strongly cautions NSF against instituting a routine, five-year re-competition of the management of large AST facilities as this would create an overwhelming burden of work for the Foundation and the astronomy community, and would likely result in a net decline in the scientific output of these facilities.

Recommendation #14: AST should complete the full course of action proposed by the *Senior Review* for the NOAO program.

Solar astronomy in this nation has seen no new major ground-based facility for decades, but such a project is now within reach.

Recommendation #15: AST should make every effort to bring the ATST project into its construction phase as soon as possible.

Effective management of the electromagnetic spectrum is critically important for astronomical research worldwide, but it has become increasingly difficult to manage as electromagnetic bandwidth has become such a precious commodity. The COV applauds the Division's efforts in Electromagnetic Spectrum Management (ESM).

Recommendation #16: NSF should consider moving responsibility for Electromagnetic Spectrum Management (ESM) to the MPS Directorate office, if not to the NSF Director's office, to increase the visibility of ESM within the Foundation and also to stress the Foundation's commitment to spectrum management to the global community.

II. Schedule and process

The Committee of Visitors (COV) to the Division of Astronomical Sciences (AST) met at NSF on 6-8 February 2008. The written charge to the COV had been given by Dr. Tony Chan, Assistant Director for Mathematical and Physical Sciences (MPS), and included the following topics to be addressed:

- The integrity and efficacy of processes used to solicit, review, recommend, and document proposal actions;
- The quality and significance of the results of the Division's programmatic investments;
- The relationship between award decisions, program goals, and Foundation-wide programs and strategic goals;
- The Division's balance, priorities, and future directions;
- The Division's response to the prior COV report of 2005;
- Any other issues that the COV feels are relevant to the review.

Dr. Chan welcomed the COV members to NSF and reviewed the charge to the COV. Dr. Morris Aizenman (Senior Science Associate, MPS) briefed the COV on conflicts of interest and confidentiality, and introduced the COV reporting requirements. Dr. Wayne Van Citters, Division Director, followed this by an overview of the AST Division programs, their context within NSF and the community, and the Divisional organization.

Dr. Nigel Sharp, team leader for the individual investigator programs, provided an introduction to the various grants programs supported within the Division, and described in particular the approach taken in the management of the Astronomy and Astrophysics Research grants. Dr. Eileen Friel, Executive Officer, AST, outlined the activities of the following three days and introduced the COV to the use of the electronic jacket for the review of proposal actions.

The COV then moved to a series of parallel breakout sessions to review individual grants programs. The first session covered the four scientific themes of the Astronomy and Astrophysics Research Grants – Extragalactic Astronomy and Astrophysics, Galactic Astronomy, Stellar Astronomy, and Planetary Astronomy. The second session reviewed the variety of AST-specific and NSF- or MPS-wide special programs. Each session started with a brief introduction by the cognizant Program Officer, followed by the examination of proposal and award records in that program. The grant programs reviewed were:

Session I:

- Extragalactic Astronomy and Cosmology – Dr. Nigel Sharp
- Stellar Astronomy and Astrophysics – Dr. Michael Briley
- Galactic Astronomy – Dr. Brian Patten
- Planetary Astronomy – Dr. Vernon Pankonin

Session II:

- Education and Special Programs – Dr. Brian Patten
- Astronomy and Astrophysics Postdoctoral Fellowship Program - Dr. Dana Lehr
- Foundation-wide programs – Dr. Nigel Sharp

- Instrumentation Programs (Advanced Technologies & Instrumentation/ Major Research Instrumentation/ Program for Research and Education with Small Telescopes) – Dr. Julian Christou and Dr. Andrew Clegg.

The review covered all proposal and award actions made during FY2005, 2006, and 2007. Sample, representative proposal "jackets" for each of the AST program elements were examined in these sessions by means of the electronic jacket system. Conflicts of interest for all COV members had been entered into the electronic jacket system by the Division Executive Officer. A total of 467 jackets were made available for review, representing 18% of the proposal and award actions during the period under review. The COV reviewed 73% of these or 13% of all actions during the period under review.

During a working lunch on the first day, Dr. Van Citters presented the strategic planning underway in the Division. He reviewed the motivation for, the process of, and the recommendations made by the *Senior Review* that AST had carried out during the COV period. He discussed the progress the Division had made and the challenges it faced in implementing the recommendations of the review.

The second day was devoted to review of the observatory facilities and large projects in the AST portfolio. Dr. Van Citters opened the day with an orientation to the role of the managing organization and the NSF program officer in the oversight and management of NSF-funded facilities. An overview of each facility was presented by its Program Manager, and discussion with the COV followed each presentation. The facilities and programs presented were:

- National Optical Astronomy Observatory (NOAO) and National Solar Observatory (NSO) – Dr. Thomas Barnes
- Gemini Observatory – Dr. Craig Foltz
- University Radio Observatories – Dr. Richard Barvainis
- National Astronomy and Ionosphere Center (NAIC) – Dr. Richard Barvainis
- National Radio Astronomy Observatory (NRAO) – Dr. Vernon Pankonin
- Atacama Large Millimeter Array (ALMA) – Dr. Philip Puxley
- Electromagnetic Spectrum Management – Dr. Tomas Gergely
- Mid-scale and technology development projects – Dr. Vernon Pankonin

The third day was spent in committee discussion and preparation of a draft of this report. The COV met with members of the Office of the Assistant Director (Dr. Tony Chan, Dr. Jack Lightbody) in the afternoon of the third day for a discussion of the Committee's primary conclusions and recommendations.

III. Science Highlights

AST sponsored projects have fundamentally advanced astronomy in literally every area of the discipline. It is impossible to do justice to the breadth of these discoveries here; instead we provide a small sample of some of this exciting work since the last COV report. Given the impressive quantity, quality and breadth of science supported, and the resulting breakthroughs, **there is little doubt that the Division is investing wisely, engaging and partnering successfully with the research community.**

Cosmology: The discovery of acoustic oscillations – sound waves – in the early universe through measurements of anisotropy in the cosmic microwave background (CMB) radiation has

far advanced our knowledge of the evolution of the universe. The CMB is not the sole information on the very early universe that can still be probed today. The fine details of the distribution of galaxies on the sky today still carry the imprint of the physical conditions shortly after the Big Bang. However, these subtle data are obtainable only via extremely large, homogeneous surveys of galaxy redshifts. The NSF support of analysis of the Sloan Digital Sky Survey (SDSS) through individual investigator grants has provided spectacular detections of these earliest acoustic oscillations imprinted in the distribution of galaxies today, thereby providing a fundamental cosmological measuring tool that complements CMB data, as well as other cosmological observations. The results provide confirmation that the expansion of the universe is accelerating as well as accurate, quantitative constraints.

Galaxy Formation: Laser guide star adaptive optics, as applied to new generations of imaging and spectroscopic instruments supported by NSF, have opened entirely new capabilities for quantitative probes of the morphology, chemistry, and stellar dynamics of extremely distant galaxies. This information, until recently available in detail only for nearby galaxies, may now be observed for light emitted from objects when the universe was less than half its current age, and galaxies and clusters of galaxies were still evolving towards their present state. As a result, quantitative information on star formation rates, tidal interactions, and collision frequencies at redshifts $z > 1$ are now becoming common (and well constrained) input data for models of galaxy evolution, rather than speculative parameters.

Probes of Dark Matter: Large, systematic surveys of the distribution of galaxies in the relatively nearby universe have begun to yield highly detailed constraints on dark matter, the mysterious source of gravitation that overwhelms by nearly an order of magnitude the gravitational attraction of all the familiar light-emitting constituents of the Universe, namely galaxies of stars. Although the dark matter cannot be probed directly, the mere fact that it apparently does dominate the gravitational budget of all sections of the universe means that the three-dimensional sky distribution of luminous galaxies is carrying quantitative data on the dominant gravitational component. Again, however, this information is subtle and requires very large, homogeneous surveys for extraction. Such a project, using the 2MASS imaging survey plus large scale spectroscopic programs to extract distance, is now yielding fundamental results.

Massive Black Holes: Massive black holes, equivalent to between millions and hundreds of millions of times the mass or our sun, are now known to be common, and perhaps ubiquitous, in the nuclei of otherwise normal galaxies. Aside from the fascinating general relativistic physics of the objects themselves, black holes also play important roles in the evolution of galaxies over cosmic time. Yet even the most fundamental issues concerning this exotic but oddly common phenomenon are still obscure, e.g., at what stage in galaxy evolution do these black holes appear? It is a frustrating irony that by far the nearest example of the phenomenon of a massive black hole in a galactic nucleus, namely that at the center of our own Milky Way galaxy, is also one of the most difficult to observe, due to obscuration of thick clouds of cosmic interstellar dust along the line of sight from our Solar System to our Galactic Center. Further, atmospheric distortion of images of this structure muddy what would otherwise be a relatively straightforward measurement of the motion of nearby stars, which could then be used to precisely characterize the black hole which controls their orbits. However, recent NSF-supported technical advances in laser guide stars in the near infrared have now permitted routine correction of atmospheric-induced distortions in the imaging of these stars, and thus direct detections and characterization of their motions, permitting us to constrain this closest supermassive black hole with exquisite precision.

Sound Waves Rock a Star to Death: A long standing theoretical problem in astronomy has been "how do massive stars explode at the ends of their lives?" These events, called supernovae, occur only among the most massive stars (10-25 times the mass of our Sun). While it is understood that a tremendous amount of energy is released at the moment of death, it has not been clear how the energy gets out. Previous simulations suggested the layers of gas surrounding the core were just too dense for the energy to escape. The simulated blast wave would stall and die before it reached the star's surface, and observers on the outside would see nothing at all. Through NSF-funded research, new numerical techniques have been developed that allow a more natural modeling of the flow of this material and radiation, especially in the central regions of the star. These new simulations show that the initial energy release at the core excites oscillations in the surrounding layers of gas (an acoustic wave). Within a fraction of a second these waves grow so violent they tear the star apart, blowing its outer layers into space.

Chemical Evolution of the Galaxy: Since the universe began with only hydrogen, helium, and lithium synthesized in the first few minutes after the Big Bang, all of the other familiar chemical elements in the periodic table, including all of those most familiar to us in our everyday lives, must have been synthesized later in the interiors of stars. This conclusion, now almost a century old, immediately leads to the conclusion that for those stars where this nucleosynthesis has for various reasons proceeded very slowly or not at all, we should today see at least a few examples of stars that remain with this virtually primordial chemical composition. These “ice cores from the beginning” would be fundamental signposts in tracing how our Galaxy has gradually changed its chemistry, and in the process created atoms which have permitted the evolution of life. The discovery of these so-called “Population III” stars has been a holy grail of observational stellar astronomy for generations of astronomers. In the past few years, thanks mainly to the spectroscopy of very faint stars enabled by the new generation of 8-10m class telescopes, plus the results of painstaking surveys that search for clues to these earliest stars, these elusive Population III stars have begun to emerge. Like many phenomena in astronomy, the discovery has not been as clear cut as once (perhaps naively) hoped, and has raised as many new questions as it has answered. These newly identified most ancient stars, although hugely deficient in the more complex nuclei that appear in later stellar generations such as our own Sun, are not quite completely devoid of every atom more complex than lithium; and those few more complex nuclei whose signatures do appear, do so in a confusing and not yet understood pattern. Yet we can say that in just a few years, we have progressed from literally just a handful of “candidate” Population III stars, to a sample of dozens of objects that contain the clues we need to make great progress in understanding the chemical history of the Milky Way. Multiple NSF-sponsored investigators are now using the newest generation of large telescopes to convert this field from one of speculation to one of quantitative properties.

Extrasolar Planets: The maturation of the field of discovery of planets around nearby stars continues at an amazing pace. There are now hundreds of such planets known, with a wide range of masses and orbital properties, and also a range of properties of the host stars. However, for both astronomers and the public, a distinctly important goal is clearly the discovery and characterization of Earth-like planets, rather than the Jovian gas giants that have dominated this field for its first decade. Under NSF support, a planet of only 7.5 Earth masses has now been found orbiting Gliese 876, an unremarkable star only 15 light years away. Although this particular planet is probably too close to its host star to be habitable in the sense we commonly define it, perhaps more important is the improvement in observational technique which permitted its discovery. Astronomers have pushed measurement techniques to the point where motions induced in the host star by the unseen planet at the level of 1 meter per second – human walking speed – are now detectable. Combined with upcoming surveys designed to systematically uncover particularly promising host star candidates, it is finally appearing reasonable to expect

that we will soon be cataloging significant lists of nearby Earth-like planets, a prospect that was completely inconceivable only 20 years ago.

Active Evolution of Icy Solar System Objects: For literally centuries we have assumed that outer solar system objects are in evolutionary stasis, literally frozen in time due to their low observed surface temperatures. A variety of NSF-supported investigations, both observational and theoretical, have now shown how remarkably incorrect this very basic assumption has been. For example, the copious quantities of methane in Saturn's giant moon Titan should have vanished long ago, due to interaction with ultraviolet radiation from the Sun. Building on prior suggestions, recent observations have yielded a surprisingly simple yet still amazing clue – transient structures observed on Titan strongly indicate that methane is continuously produced and injected into the atmosphere, perhaps upwelling through surface cracks, or even injected explosively by exotic volcanic-like activity. NSF-supported laboratory studies have now provided proposed mechanisms for volcanic-like activity on Enceladus, another Saturnian moon with an apparently evolving surface structure.

Active Solar Magnetism: In this centennial year of the discovery of magnetic fields on the Sun, much remains to be learned about them. Recent observations using instruments on the ground and in space have revealed surprising features of solar magnetism. For half a century there were hints that changing magnetic fields were deeply involved in solar flares, the largest explosions in the solar system. Until recently, the observations were confusing and contradictory. High cadence and good magnetic sensitivity afforded by NSO's Global Oscillation Network Group (GONG) instruments have unequivocally shown ubiquitous, permanent field changes with large solar flares. Although these changes do not appear to be the trigger or power source of flares, their existence has led to an entirely new model of solar flares. In a second recent ground-based discovery, the so-called quiet solar photosphere was found to be filled with a large amount of transient, horizontal magnetic flux. These fields may help solve a solar "dark matter" puzzle in which various indirect observations previously indicated that there must be a large amount of unseen, small-scale magnetic flux on the Sun. Observations indicate that there is several times more horizontal than vertical magnetic flux in the photosphere. Unseen for a century, this horizontal component of solar magnetism poses several questions and is now under close scrutiny by observers and modelers.

IV. AST Division Management

A. General comments.

The extent and complexity of the challenges the AST Division management faces can be overwhelming. They are engaged in the management of individual investigator grants, national facilities, intra-agency programs, and international projects with lifetime costs well beyond a billion dollars. Unique within NSF, a substantial fraction of the AST Division's base funding (currently 55%) is used to support several large community facilities. The extensive international activities under AST oversight add yet another level of management and financial complexity.

There is enormous and scientifically well-justified pressure from the community for considerable growth of the Division's overall program. In opposition to pressure for new facilities, the Division is also responsible for stewardship of a base program of astronomical capabilities, and for maintaining a flexible and responsive, merit-based reviewed, grants program.

The Division understands the need for strategic planning using realistic growth expectations. Community input has been sought out and brought into all stages of the planning. Equally important, the Division communicates its findings to the community. AST has made it clear that, taken at face value, all of the community's desires simply cannot be met in the desired timescale. The Division's largest challenge is therefore to sustain a balanced program that best meets the goals of the community and enables the best science results.

B. Staffing:

The COV was enormously impressed with the outstanding job that the AST Division is doing in managing this increasingly complex enterprise. Under the leadership of the Division Director and Executive Officer, the staff conducts its business with great enthusiasm, energy and with the highest integrity. The flexibility of the staff allows them to support each other as (is often) needed.

It was clear to this COV – as well as to the last three COVs – that the program officers are overworked and that additional staffing is required.

Over the 2005 – 2007 period reviewed by the COV, the number of proposals submitted to the grants program has increased by 23% (28% in the AAG program) to an average of 140 proposals per program officer. The number of mid-scale projects, each of which requires extensive oversight, has increased by 50%. The COV notes that a simple formula for the required staffing based on the case load per program officer will come up short for the AST Division due to the substantial effort required to provide oversight to the many facilities located throughout the world. In many ways AST is leading NSF in managing large and international projects, such as ALMA and Gemini. As NSF's Facilities and Projects Office becomes more involved in establishing NSF's practices in large projects, requiring more oversight and reporting, the workload on AST program officers has steadily increased.

The staffing shortfall indicated by the 2005 COV was partially addressed by the net addition of three FTEs – 1 or the grants program, 1.5 for facilities, and 0.5 for electromagnetic spectrum management. However, additional staffing is still required to 1) meet the increased proposal pressure while maintaining the integrity and responsiveness of the programs; 2) provide adequate review and oversight of the new mid-scale programs, many of which are interagency programs; and 3) provide sufficient leadership and oversight of the considerable efforts for new large scale projects. Regarding this third point, we note that ALMA is at a critical construction phase; a new line has been created in the MREFC account to support the late stage design and development of ATST; a proposal for LSST is pending; two competing, complex partnerships are developing plans for the GSMT; and international efforts to develop the SKA have accelerated.

Recommendation #1: NSF should thoroughly review the staffing requirements of AST to determine the level required for AST to adequately support its base program while playing a leadership role in the complex, international development of the next generation of world-class observatories.

C. Division Travel Requirements:

A problem that surfaced frequently throughout the three day COV meeting was the need for additional travel funds to support the oversight and management activities of AST and its Program Officers. This need is acute, and has been mentioned in previous COV reports with only

modest effect. We would like to comment here on the particular features of Astronomy as a discipline, and of the AST Division's activities, that make this need so acute.

Astronomical research is by its nature geographically dispersed. The need for appropriate atmospheric conditions for observing leads to intense activity in extraordinarily remote locations. For example, the Atacama desert in Chile hosts ALMA, one of the largest activities in the Foundation as a whole, and mid-sized (~ 10M$) projects are underway in the Atacama and in the deserts of Western Australia. Site visits by Program Officers are critical – the workforce and activities in these areas present management challenges that are critical to the success of these high-profile projects.

Astronomical research is also rapidly becoming internationalized, and many expensive and important AST Division activities are being undertaken as part of international collaborations. ALMA is one example, and Gemini is another. Management of the electromagnetic spectrum on behalf of the Foundation also falls (appropriately) to AST. All of these crucial activities require frequent Board meetings and other management activities, many of which necessarily occur outside the United States.

The AST Division is also more dominated by large facilities than are other Divisions within MPS or within the Foundation. This is also a necessary consequence of the way astronomical research is conducted in the 21st century. The management demands of these facilities are more extensive than those of relatively small (< 1M$) PI projects, and the consequences of mismanagement are potentially devastating to large parts of the Division's portfolio, and to the astronomical community as a whole. To skimp on the necessary travel funds for crucial oversight and management is a false economy, and one that may someday have very negative consequences.

Recommendation #2: Double AST's travel budget to ensure adequate support for the Division's global oversight and management responsibilities.

V. Strategic planning and implementation

AST and the astronomical community in general have been engaged in a series of strategic planning efforts, which have continued through the current review period. We commend the continuing efforts of AST to foster strategic planning in the astronomical community and to implement the results. The fundamental current blueprint was established by the National Research Council (NRC) *Decadal Survey* entitled, "Astronomy and Astrophysics in the New Millennium" that was completed in 2001. The AST Division works closely with the National Academy of Sciences (NAS) Committee on Astronomy and Astrophysics (CAA) and, particularly for interagency initiatives, the Astronomy and Astrophysics Advisory Committee (AAAC). They are also guided by the NRC report "Connecting Quarks with the Cosmos" and the Office of Science and Technology Policy (OSTP) report "Physics of the Universe."

The 2001 *Decadal Survey* and its predecessors have shaped the current NOAO, NSO, NRAO, ALMA and Gemini projects in fundamental ways. Many aspects of the 2001 report, however, were overtaken by events, as the funding profile for most of the relevant agencies could not keep up with the community's aspirations. As a result, most of the large-scale recommended projects have not yet been completed. The AST Division, along with other agencies, is now providing input to the NRC as it plans the next *Decadal Survey*. **We strongly support the Division's involvement in this planning process.**

Plans for the next *Decadal Survey* are not yet fully developed, but we strongly support one likely break from tradition, namely the reconsideration, and if necessary reprioritization, of previously recommended projects that have not yet been undertaken.

Since 2001, a series of community-based task forces has provided guidance to NSF and other agencies on various aspects of astrophysics. In 2006, two interagency task forces submitted their reports, the "Task Force for Cosmic Microwave Background Research" and the "Report of the Dark Energy Task Force," providing reviews of critical research areas that had advanced substantially since the 2001 *Decadal Survey*. Most of the "mid-sized" projects described below are responsive to these and other previous community reports.

A. The *Senior Review*

The appearance in October 2006 of the document "From the Ground Up: Balancing the NSF Astronomy Program," hereafter referred to as the *Senior Review* or SR, is a watershed even in the long and distinguished history of AST. The Division has always sought community input on not just individual proposals or groups of proposals, but also on longer term policy. However the *Senior Review* represents an extraordinarily comprehensive and thoughtful analysis of the state of astronomy today, and how the Foundation can optimally move it forward in the face of sharply constrained resources, complex international collaborations, and very high community expectations.

The community authors of the SR obviously deserve a huge amount of credit for this tremendous effort, which spanned an entire year. But the 2008 COV wishes to also strongly commend the AST Division for its support of the SR in multiple ways, not just for coordinating logistics and information gathering, but (far more importantly) for diligently alerting the community, canvassing opinion, and widely disseminating the results, potential consequences, and planned Foundation response. The result of this close collaboration between the SR community authors and AST is a document which we believe will have impact in US astronomy fully as important as the NRC Decadal Surveys, assuming that the community and the Foundation can rise to the challenge of exhibiting sufficient discipline to heed the SR conclusions.

The chief conclusion of the SR is so important that it bears quotation over and over:

"Proper maintenance of current facilities while simultaneously developing and beginning operation of the proposed new facilities is infeasible under any reasonable expectations for federal budget support based on past funding levels. The cuts that are recommended here are as deep as they can be without causing irreparable damage and will only allow a start to be made on the new initiatives."

The COV suspects, and initial collegial reactions confirm, that the SR recommendations for several of the well-established large national AST-supported facilities may be especially controversial within our community. Therefore **the COV wishes to explicitly affirm its support of the *Senior Review* recommendations**. Although the specific details of how these major, scientifically revered facilities make the transitions recommended in the SR should surely be constantly evaluated, the need for these (and other) transitions is a matter of simple arithmetic only given any reasonable budget projections for the Division. As the SR represents scientific peer review in its finest incarnation, we urge the Foundation to resist to the best extent possible attempts to subvert the conclusions via direct contact with legislators, and in these circumstances to cite the SR as the reasoned conclusions of the community.

We do not expect the SR to constitute a perfect, verbatim management roadmap for a lengthy interval into the future. Indeed, a first major surprise and perturbation since its publication, namely the announced intention of the UK to reduce its share of the Gemini partnership, is presumably just one of many surprises, managerial, technical, and scientific, that will occur and require evaluation of how the SR may or may not then pertain. However, we strongly urge the Foundation and our community to treat this document as a baseline, which when combined with the next NRC *Decadal Survey* should constitute a disciplined and thoughtful path for the future of AST activities.

The COV heard during AST presentations that the Foundation strongly supports the SR process and its recommendations, and that the Division has indeed begun their implementation via a variety of actions. We commend this rapid response, and also note the special effort that AST has made to keep the community well informed and involved during implementation of the changes. Other sections of this report will highlight and discuss specific SR-related actions.

Recommendation #3: NSF (and the astronomy community) should treat the *Senior Review* report as a baseline which, when combined with the next NRC Decadal Survey, constitutes a disciplined and thoughtful path for the future of AST activities. When appropriate, NSF should use the *Senior Review* recommendations as a community-derived tool to resist non-competitive earmarking of the federal budget.

Recommendation #4: AST should consider conducting subsequent *Senior Reviews* on a pro-active, regular basis rather than simply as a response to moments of crisis. Given their scope and comprehensive nature, it may be impractical to conduct such reviews at a 5-year interval; perhaps future *Senior Reviews* should be activated at 10-year intervals and timed to fall midway between NRC *Decadal Surveys*.

As noted above, community aspirations do not always match fiscal reality, and the Division convened the *Senior Review* in large part to help reconcile this for NSF. This effort was unusually effective in carefully gathering community input, and in recommending realistic priorities. However, it is clear that, while the *Senior Review* provided vital short-term guidance, the long-term mismatch between aspirations and resources has not been resolved.

Recommendation #5: As plans are being developed for the upcoming NRC Decadal Survey, AST should encourage the Survey committee to reexamine the priority of previously recommended projects that have undergone substantial cost growth.

B. Maximizing Scientific Exploitation of Major Facilities

The AST Division remains a pathfinder within NSF in its relatively large investment in major facilities, and is therefore in a unique position to foster synergies between those and individual grants. Some of that arises naturally when researchers apply for grants to analyze data obtained at national observatories, or propose technology efforts relevant to providing new instruments for the facilities. However, AST should consider looking ahead to major facilities still in development and assess whether there is a need to target specific areas of investigation to enhance and accelerate the scientific returns from the major facilities.

C. Major Research Equipment and Facilities Construction (MREFC) Appropriations

With Major Research Equipment and Facilities Construction (MREFC) funding, the AST Division has created world-class facilities that have led to transformational science.

The COV notes, however, that current processes and practices concerning the Foundation's Major Research Equipment and Facilities Construction (MREFC) account seem to be a significant impediment to timely and cost-effective completion of certain high priority AST programs. Consider the Giant Segmented Mirror Telescope (GSMT), the highest future priority for a significant fraction of the stakeholders in the astronomy community. This major project almost surely will be too expensive for any one stakeholder, be it the Foundation or any community entity, to finance when both capital and operating costs are included. It would be disappointing if the only barrier to successfully financing the total costs of this type of major project via a joint agreement amongst multiple stakeholders were the apparent restrictions placed on the Foundation by the MREFC and federal budget processes. For example, it might prove beneficial for NSF funds to be provided as contributions to facility operations costs in an effort to match private philanthropy or institutional investments that are targeted at capital construction costs. Clearly for this to work would require that an advanced commitment of the operations funds be made. Although such a procedural change is undoubtedly not lightly made, it could prove crucial to the success of the largest, highest priority AST programs.

Recommendation #6: NSF should build sufficient flexibility into MREFC processes and practices to optimize the Foundation's ability to partner with private or public entities in the funding of the design, construction, operation and/or maintenance of large facilities.

D. Interagency Collaboration

Finally, the COV notes with pleasure the very significant progress made by NSF and its sister federal agencies that support astronomy in the area of interagency collaboration. In much less than a decade, this area has gone from virtually zero, to today's thriving and successful level of collaboration between NSF, NASA, and DOE. Given the growing confluence of physics and astronomy, the increasing number of techniques applicable only from space, and the considerable cost of certain high priority projects, these interagency collaborations are absolutely fundamental to achieving community goals. **The COV commends AST for its role in both initiating and nurturing interagency collaborations**. There seems little doubt that the desirability and indeed requirement for interagency collaborations will be a feature of astronomical research for the indefinite future.

VI. Programs

A. Individual Investigator Programs

A.1. General Remarks

The COV spent considerable time during the first day examining the jackets of grant proposals covering a broad variety of topics, with the goal to assess whether there were any notable concerns regarding the integrity and fairness of the award process. We note that the web-based jacket-review infrastructure (eJacket) functions well, although improvements could be considered to the speed and ease of access to the system.

All members of the COV agreed that, overall, **AST's proposal-evaluation process has been handled by the Program Officers (POs) thoroughly, carefully and professionally, with remarkably good scientific judgment across the board**. Their enthusiastic support of the science is highly commended. Especially noted, and commended by the COV, is the detailed set of reports and records justifying every decision taken. The PO summary analyses were found particularly comprehensive and useful. The COV found very good alignment between the various panel recommendations and the final award decisions.

In examining panel composition, the COV found that the panels generally were composed of experts in the field. The effort invested in assembling diverse and inclusive panels also was noted and commended. The low number of women found in particular panels – such as those focused on instrumentation – unfortunately most likely reflects the availability in the recruiting pool. The COV recommends that continued attention be dedicated to the issue of assembling diverse panels. It was noted that in some cases, e.g., some SAA panels, a relatively small fraction of review panel members were from institutions with large astronomy graduate programs. While the COV supports a diverse base of participants, at the same time care should be taken to ensure that the research activity of panelists is high. Given that such potential reviewers have crowded calendars, the COV suggests that an effort be made to recruit panelists as early as possible – even prior to the deadline for receipt of proposals – to facilitate the construction of panels with the most balanced distribution of research experience. To ensure the presence of necessary expertise, it may also at times be necessary to increase the size of a panel and/or obtain additional external reviews.

Recommendation #7: AST should continue its efforts to ensure that the composition of review panels is as diverse as possible, including members with high levels of research activity.

The COV supports the current balance of the Division's portfolio of funded projects. We note, however, that many meritorious proposals remain unfunded. The COV is therefore confident that the investment of additional resources in AST Division programs would result in the generation of additional high-quality science. It is evident in the PO summaries that careful attention is paid to analyzing the details of proposed budgets, as well as ensuring that there is no overlap of funding or effort with other programs. **The COV commends the Division's general policy of striving to fully fund the most meritorious proposals.** Budget reductions that did occur in funded projects appeared well considered and justified.

The COV notes that improvements could be made to the way in which PIs receive feedback after their proposals have been reviewed. It is laudable that the POs make a concerted effort to personally call every PI to verbally summarize the outcome of each review. However, the written information that is sent to each PI (panel summaries as well as panelist and *ad hoc* reviews that are written prior to the meeting) is uneven and potentially confusing. Suggestions were made to standardize the feedback, possibly by initially using email to provide in writing key elements of the PO's final analysis review, then providing the PI an opportunity to follow up with verbal communication. The PIs also generally would be interested to know the broad relative ranking of their proposals. The COV realizes that improving the written feedback to the PIs will increase the workload of the already overcommitted POs.

It has been noted that a nontrivial fraction of AAG proposals are not fully compliant with NSF proposal guidelines when they arrive via Fastlane: most often, investigator biosketches contain incomplete conflict-of-interest lists and the body of proposals have insufficient reporting of

results from prior funding. AST program officers have been generous in their efforts to solicit supplemental information from individual proposers to correct such issues of noncompliance, but the time spent by POs addressing these issues takes away from time that would be better utilized evaluating compliant proposals. We recommend that the AST be less generous in its handling of noncompliance issues at the time of AAG proposal submission, phasing in procedures that enforce stricter compliance over a period of a few years. We note that similar efforts made by the Division to ensure all proposals are compliant with meeting the Broader Impacts criteria have been successful.

Recommendation #8: To further improve the efficiency and effectiveness of grant proposal processing, AST Program Officers should consider (a) including comments extracted from generally insightful PO summary analyses in the written responses sent to PIs; (b) providing information to PIs regarding the general ranking (e.g., quartile ranking) of their proposal; and (c) becoming less tolerant of non-compliant proposals.

A.2 Astronomy and Astrophysics Grants (AAG) program

Scientific categories covered by the Astronomy and Astrophysics Grants (AAG) program solicitation were planetary (PLA), stellar (SAA), galactic (GAL) & extragalactic (EXC) astronomy. We note that all AAG proposals have a common deadline. The Division then sorts the proposals into categories depending on what was actually proposed, and sets up review panels accordingly. New panels are established, as needed; for example, a new panel on extrasolar planets was recently created. By adopting this approach, the organization and management does not artificially constrain the scope of the proposals being submitted. The COV applauds this procedure as it builds flexibility into the AST program and, in particular, allows the program to respond quickly to the voice of the research community. **It is a credit to the Program Officers (POs) that the AAG program has continued to maintain a well-balanced portfolio of high-quality science projects over the past three years.**

The COV encourages the Division to work in concert with its community of researchers to assess how best to take advantage of the NSF's new, substantial Cyber-Infrastructure investments. In particular, new petascale computing platforms that will become operational at NSF supercomputing centers over the next couple of years will provide the capability for theorists to simulate a variety of complex astrophysical phenomena for the first time with a significant degree of physical realism. Generally speaking, present simulation tools will not be able to scale up to run efficiently on petascale computers without significant additional development by interdisciplinary teams of researchers. Many new discoveries will likely be forthcoming following a strategic investment of AST funds into key numerical simulation projects.

Recommendation #9: AST should work in concert with its community of researchers to assess how best to take advantage of the NSF's new, substantial Cyber-Infrastructure investments.

A.3 Instrumentation programs

The instrumentation proposals received and reviewed by the various astronomical instrumentation programs (ATI, MRI, AODP, etc.) have extensive range and scope. In particular, the proposals cover diverse methods and technologies and often propose novel, new ideas. The feasibility and risk associated with these ideas are not always well understood. The program officers clearly

work hard to ensure reviewers are included that can evaluate directly each proposal received. Furthermore, the panels have occasionally instructed the PO to obtain more information from additional outside experts before a proposal is ranked. The POs themselves are to be commended for their efforts to understand these complex and technically innovative proposals in detail. This effort is critical to a fair review process, and requires significant extra effort on the part of the POs for instrumentation projects in particular.

As noted above, one weakness of the oversight process is that the current travel budget is apparently too limited to allow an adequate number of site visits. While an inadequate travel budget affects the entire AST Division, the problem is especially acute in the ATI, MRI, TSIP, and other instrumentation programs. The awards in these programs are typically large and aimed at producing instruments and facilities. Visits by the pertinent NSF personnel should be an important component of the oversight and management of these grants. A particular feature that impacts astronomy more than other disciplines is that the program activities often occur at remote sites - but that makes it even more important for program officers to exercise appropriate oversight on these programs. Site visits could also be coupled to a set of design and progress reviews (the details of which could vary with award size and scope), which would help to keep projects on schedule and help the projects identify problems early. In principle, the NSF could also facilitate communication between groups, helping to distribute solutions to common problems.

The PREST program was paused last year as the results of the *Senior Review* were considered. AST plans to use the recently released ReSTAR report to reconcile the intent and approach of this program, when it is restarted. The COV approves of this decision and encourages the Division to continue to develop programs to fund small and medium size facilities.

We note that many programs across AST fund astronomical instrumentation. These include the PREST, TSIP, ATI, MRI, URO, and mid-scale programs. We encourage AST to explore ways to optimize its approach to funding instrumentation, perhaps by merging some of these programs to better meet the needs of the community.

Recommendation #10: AST should explore ways to optimize its approach to supporting astronomical instrumentation development, perhaps by restructuring its current set of instrumentation related programs.

A.4 Educational and Special Programs (ESP)

There are a number of programs that fall under the umbrella of the ESP program that are very important to the astronomy community. The key elements include the Faculty Early Career Development Program (CAREER), the Research Experiences for Undergraduates (REU) sites, REU Supplements to regular (AAG) awards, and unsolicited education-related grants that do not fall under one of the other programs. In general, these programs are highly regarded within the community, and the COV supports continuing the Division's focus in these areas. We mention a few issues below as suggestions for improving on an already excellent suite of opportunities.

CAREER awards are widely recognized as one of the highest – perhaps *the* highest – recognitions of excellence that a junior faculty member can receive in our field. These awards are highly sought after and prized. Yet the current success rate for applicants to the CAREER program is only 10%. This struck us as being rather low. While there is an argument to be made that these are prestigious awards, and hence should be more competitive than the general AAG program,

10% may be too low. We note that the number of applicants has risen steadily in recent years, while the budget for CAREER awards has remained flat (actually falling slightly).

The COV strongly supports the REU program and having organized REU sites. The COV felt that the REU sites needed and deserved more oversight from the AST Division. We understand that there have been site visits, and that additional ones were initiated this past summer. Without site visits it is not possible to verify the educational experiences of the students, which may become rather uneven. **The COV recommends increased oversight of the major REU programs, perhaps at the level of a site visit every other year for the major sites.** We are aware that this will require additional travel funds and an additional workload for the POs. The COV also suggests that, in addition to awarding REU supplements to individuals with existing NSF grants, AST consider broadening the reach of this program by allowing investigators whose research is not presently supported by NSF to apply for REU funds.

A.5 Astronomy and Astrophysics Postdoctoral Fellowships program (AAPF)

The Astronomy and Astrophysics Postdoctoral Fellowships (AAPF) program has been very successful in developing both the research and educational skills in its awardees, and past awardees have achieved a broad range of permanent positions. The COV noted that this program is unique among prize post-doctoral programs in that it places significant emphasis on an E/PO component. The AST Division, the applicants, and the review panels all take this E/PO component seriously. The COV supports this emphasis, which provides useful experience for the fellows, and nudges the community as a whole in a useful direction. As far as can be determined, the E/PO activities of the Fellows do not negatively impact their career paths – in fact, most Fellows move directly into faculty positions, rather than holding another post-doc or temporary position. The AAPF program has seen more than a 50% increase in the number of applicants in the 2004 to 2007 time frame, although this has not been accompanied by a commensurate increase in funding, leading to a relatively low success rate for this program.

Two management problems were noted in the AAPF, both of which apparently also apply to other post-doctoral programs across the Foundation. First, direct funding of individuals sometimes leads to difficulties in dealing with benefits, particularly medical benefits. Recent changes in the structure of the non-salary part of the award should help, but this issue should be closely monitored to make sure that potential Fellows – especially those who are supporting families – are not deterred from accepting these positions. Also, the AAPF program is not integrated in the NSF's electronic eJacket system, creating significant extra workload for the program officer. We recommend that the eJacket system be extended to incorporate the AAPF program as quickly as possible.

B. Special Programs:

This category comprises proposals for research or development of analysis tools which serve a wide range of scientific disciplines, or creation of resources of value to a large portion of astronomical community. These include Information Technology Research for National Priorities (ITR), Special Projects (AST), and Mathematical Sciences Priority Area (MSPA). Awards granted in these categories span a very wide range, from a little more than $100K to $10M.

The proposal receiving the largest award was the National Virtual Observatory (NVO), which was proposed under the ITR competition. This is a major, interagency, multi-year program to

develop and operate what is essentially a national, or even global, astronomical facility. Subjected to both *ad hoc* and panel reviews, it was very highly rated and was awarded funding for the requested 5 year performance period. It was extended in FY2006 and FY2007 while the Division worked on related joint activity with NASA.

Under the Special Projects category, only one of the proposals sampled by the COV was a true research project: the extension of the Sloan Digital Sky Survey. Other proposals were for support of the NAS Committee on Astronomy and Astrophysics (CAA), travel support for participants in the IAU General Assembly, and partial support for IRTF observers. The Review Analysis for the CAA proposal demonstrates the ways in which AST management uses their leverage as a funding agency to evaluate the performance of groups receiving ongoing funding, and to press for improvements in the CAA's internal practices.

The category of proposals that seemed to pose some challenges to the merit review process was the MSPA group. These proposals are cross-disciplinary, requiring reviewers who are themselves experts in multiple disciplines or more than one panel, each evaluating different aspects of the proposals. Members of the COV noted that the resulting reviews seemed less consistent than those for single-discipline proposals. The COV noted, that individuals asked to review one-of-a-kind projects did not really know against what they should be compared; the dispersion of proposal rankings (E, VG, G, F) among the separate reviewers was larger than normal. This may be an unavoidable consequence of accepting cross-disciplinary proposals.

C. Mid-size programs

The Mid-Scale Projects program is actually a "pilot" activity introduced in response to a long standing problem of how to best accommodate proposals that exceed the scope of the individual investigator grants programs – such as the Advanced Technologies and Instrumentation (ATI) program or the Major Research Instrumentation (MRI) program – yet fall short of the scale of the Major Research Equipment and Facilities Construction (MREFC) program. Mid-Scale projects run in the $10 million range. They are considerably more complex and larger than a typical AAG proposal, but significantly smaller than a multi-user observatory or facility proposal. They usually involve a collaboration of several institutions as well as other federal agencies. As a result, the proposals require more attention for scientific and management review and if awarded required continued project oversight. Currently, PIs do not apply directly to a mid-size program. Rather, proposals are submitted directly to the AST Division, or they may have been originally aimed at another area and were redirected to the Mid-size program activity at the discretion of a Program Officer.

Mid-size projects are needed to address of variety of community recognized needs, such as specific astronomical measurements recommended in task force reports. The recent task force reports, "Task Force for Cosmic Microwave Background Research" and the "Report of the Dark Energy Task Force," have recommended projects of this scale, and we expect the upcoming report of the Exoplanet task force will also. Typically the science justification for these projects is extremely exciting and the awarded proposals are excellent.

In contrast with the typical MREFC funded project and in line with the task force recommendations, the Mid-Scale projects are not facilities (such as observatories or similar installations) with indefinite lifetimes; the projects have a particular goal; when that goal is achieved, the project is over.

NSF has been receiving and supporting projects on this scale for a decade, and has been handling them on a case by case manner, *i.e.*, without a formal funding program. However, the rate of proposals has accelerated significantly in recent years. Projects currently supported by the Mid-Scale program include contributions to Veritas (Very Energetic Radiation Imaging Telescope Array System), the Atacama Cosmology Telescope, SDSS-II, the Murchison Widefield Array (searching for 21cm emission at high redshift, a signature of reionization), QUIET and POLARBear (pathfinding experiments to measure the polarization of the CMB) and the Dark Energy Survey. All of these projects are directed at exciting and specific science goals.

Also at the Mid-size scale are the Division's strategic Technology Development activities. In support of *Decadal Survey* recommendations, AST is funding critical R&D activities in support of future major facilities, including GSMT, LST, and the SKA. The COV is in full support of these strategic investments.

The COV was impressed with the quality of the programs supported in this mid-size category; the successful proposals received exceptionally high rankings, as might be expected given the community support in defining the science and scope of the project goals. As the number of proposals of this sort has increased dramatically since the last COV review, and it seems that it will continue to increase, the COV recommends that AST inform the community that such proposals may be submitted. Furthermore, we recommend that AST advise the community regarding NSF's general goals for funding Mid-size projects as well as the requirements for a successful proposal, such as the inclusion of a detailed management plan. Considering the financial constraints faced by the Division, the COV does not recommend that a formal program with pre-allocated funds for Mid-sized projects be established at this time.

Recommendation #11: AST should inform the astronomy community of the NSF's general goals and expectations for mid-size projects and should notify the community that unsolicited proposals for mid-size projects may be submitted. However, the COV does not recommend that a formal "mid-size projects" program with pre-allocated funds be initiated at this time.

D. University Radio Observatories (URO)

The URO program promotes innovative research and development of radio astronomical instrumentation and techniques (covering wavelengths spanning the submillimeter to meters), and the availability of unique observing capabilities to the community (30% – 50% access to the community). A key feature of the URO program is the training of the next generation of radio instrumentalists. For example, the UROs have developed, and continue to develop, the millimeter and submillimeter technology and science that is crucial for the success of ALMA. Funded URO proposals are for projects that are considerably larger than a standard individual investigator award. These projects have larger risks that are mitigated by the benefits of technology development and education.

The existence of a separate URO program is largely historical, and we note that the Division funds university based optical/infrared observatories and instrumentation at similar levels, although through a variety of other programs as discussed above. In contrast to the considerable private funding associated with U.S. optical observatories, the majority of radio facilities available to U.S. astronomers have been reliant on NSF funds. NSF therefore plays a much larger and absolutely critical role in the stewardship of the availability and health of the U.S. radio astronomical instruments.

The four URO projects currently funded are: Combined Array for Research in Millimeter Astronomy (CARMA), Caltech Submillimeter Observatory (CSO), Five College Radio Astronomy Observatory (FCRAO), and Allen Telescope Array (ATA). These projects have roughly 250 users per year including approximately 60 students and postdocs per year, and produce of order 150 publications per year. URO have trained over 70 PhD students over the past decade. The AST's investments in the URO program have clearly earned a high return.

The URO are funded in response to proposals solicited and reviewed on three-year centers; all UROs compete every three years. URO's have been closed, merged, and new ones have been started. The cognizant Program Officer monitors awards via teleconferences with PIs, site visits, and annual reports. NSF has a cooperative agreement with one facility for additional oversight; the remaining awards are grants.

NSF oversight of the URO program used to include periodic site visits of the major URO installations, including participation by peer reviewers, but this level of oversight has been curtailed by AST because of insufficient travel funds. To ensure adequate review and oversight of the URO projects, the COV recommends reinstating the site visits, at least to the larger projects if not all. Reverse site-visits by a handful of researchers, are a poor substitute for inspecting these multimillion dollar class observatories.

Recommendation #12a: Utilizing funds from an enhanced travel budget, AST should strengthen its oversight support of University Radio Observatories (URO) projects and their associated instrumentation development programs.

The COV commends AST for balancing the benefits and risks in URO projects. The partial and conditional funding of FCRAO and ATA are examples of this balance. Partial funding of ATA (12% of request) was made partially contingent on outside fund raising and progress on array construction. This award decision is consistent with the management plan of providing seed funding to develop new UROs. The ATA is also an example of a private/public partnership that should be encouraged. We note also that the four participating universities provided two thirds of the funds required to merge the OVRO and BIMA observatories at a new site to form CARMA. The FCRAO represents a continuing investment by NSF and partial funding (17% of request) was awarded on the condition that progress is being made on the LMT.

The COV heard that many new, powerful, and costly URO projects are being planned, while existing projects are proposing exciting new developments. The COV recommends that NSF strive to maintain the proper balance of radio facilities, including national, university and private observatories—the radio system— while keeping in mind the need to develop new techniques and to train the next generation of instrumentalists. A review conducted with participation of a broad range of observational and theoretical astronomers would be particularly valuable.

Recommendation #12b: As many new UROs are being planned, the COV recommends that NSF strive to maintain the proper balance of radio observatories —the radio system— while keeping in mind the need to develop new techniques and to train the next generation of instrumentalists.

E. National Observatories and Large Facilities:

E.1 General Comments

The AST Division is steward to an impressive suite of powerful astronomical observatories and facilities that form the base of the astronomical program. These include the national observatories as well as international partnerships. AST is also involved in strategic planning for the next generation of facilities. Over half (55%) of the Division's funding is directed at supporting the infrastructure of, and science from, these large facilities as well as impressive outreach and educational activities associated with each of the observatories. **Overall, the COV is impressed with the AST Division's management of its observatories and large facilities**. Before discussing them in turn below, however, we raise one concern.

The COV notes that there are routine performance reviews of grants and cooperative agreements for the management of large AST facilities every five years. This is sound procedure, although very labor intensive. We are concerned, that this process could steadily evolve into a routine re-competition of these facilities on relatively short intervals, e.g., every five years, regardless of the outcome of periodic reviews. This would create an overwhelming burden of work not just on the Foundation, but also on the astronomy community, segments of which must participate in both the preparation and the review of multiple proposals for each facility. This could result in a net decline in community scientific output, precisely the reverse of the motivation for routine, frequent re-competition.

Recommendation #13: The COV strongly cautions NSF against instituting a routine, five-year re-competition of the management of large AST facilities as this would create an overwhelming burden of work for the Foundation and the astronomy community, and would likely result in a net decline in the scientific output of these facilities.

E.2 National Optical Astronomy Observatory (NOAO)

The *Senior Review* has changed the landscape for many of the NSF-operated facilities. This is most certainly true for NOAO. Prior to the release of the SR, the long-term program plan for NOAO was defined largely by the content of the most recent decade survey in astronomy. This plan called for an increasing role for NOAO in the development of major telescope projects such as the LST and the GSMT, as well as a significant investment in the National Virtual Astronomical Observatory. Since the increasing involvement in these programs was occurring in a period of flat budgets for the facilities portion of the NSF portfolio, it required that cuts be made in other portions of the NOAO budget. NOAO was achieving budgetary balance by systematically divesting in the operation of telescopes on Kitt Peak and Cerro Tololo. The SR concluded that such a long-term plan would be unhealthy for the field and instead suggested a new vision where NOAO would continue to operate (and/or provide access to) well instrumented telescopes with a full range of apertures.

The course correction suggested by the SR has led to a dramatic change in the operations model for NOAO. This redefinition process has not come without significant pain, but AURA and the management of NOAO have made substantial progress on implementing the core recommendations of the report. In slightly more than a year, NOAO has managed to retool in a major way. AST has done an excellent job of stewardship during this difficult transition.

Key elements of the SR plan call for significant changes within the organization of NOAO. These include the reorganization and down-sizing of the instrumentation program, the divestiture of AURA/NOAO in the TMT project while assuming a leadership role on behalf of the US community in the development of a GSMT project, a modest reduction in the size of the scientific staff, and the reorganization and probable down-sizing of the Data Products division. Significant progress has already occurred in all but the last of these items.

With regard to addressing the key mandate of operating telescopes with a range of aperture sizes for the US community, NOAO (with helpful input from the NSF) created the ReSTAR panel to carry out a review of the needs of the entire US ground-based OIR community. The panel was charged with producing a prioritized, quantitative, science-justified list of capabilities appropriate to telescopes with apertures less than 6 meters, together with estimates of the number of nights needed to satisfy the needs of the community. The report of the panel, which was completed at the end of 2007, will be used by NOAO for guidance as they attempt to create a national system of telescopes that will best meet the needs of the US community. The COV hopes that the new path laid out for NOAO by the SR report will allow it to reverse the trend pointed out in the 2005 COV report concerning the reduction in the amount of merit-based community telescope time available.

We commend the NSF for taking such decisive action in implementing the suggestions made by the SR report regarding the program plan for NOAO. We urge that the full course of action proposed by the SR be carried through to completion. We note that the full implementation will likely require additional funds for upgrading and modernizing existing facilities, and/or in the investment in new facilities and instruments. We urge the NSF to give high priority to create the type of system of telescopes envisioned in the SR report. This is a unique point in time to fix a long-standing problem.

Recommendation #14: AST should complete the full course of action proposed by the *Senior Review* for the NOAO program.

Also, in this context and **in line with Recommendation #6**, the COV urges the NSF to facilitate federal-private partnerships that will result in the type of optical system of ground-based telescopes envisioned in the most recent decadal survey and reiterated in the *Senior Review*.

One constant at NOAO during the past decade has been the excellence of its education and outreach program. The NOAO EPO program has been a leader in innovation, creating a broad spectrum of programs to service a large and ever growing constituency: K-12 students, teachers at all levels, non-science college students, and astronomy graduate students. Programs such as the Astronomy Research-Based Science Education program (A-RBSE, formerly TLRBSE) have brought K-12 educators from around the country to Kitt Peak and involved them in hands-on research projects. These teachers then return home and involve their students to help make science more real and accessible for all. This is just one of many examples of the excellent work being carried out within the NOAO EPO program.

E.3 Gemini Observatory

The COV heard a detailed presentation on the status of the Gemini Observatory. We were pleased to learn that both telescopes not only perform superbly, but are now indisputably in routine use for research, with all commissioning tasks largely complete. Indeed, although such comparisons are always somewhat arbitrary, an examination of the current rate of scientific publication from

Gemini yields results quite comparable to those from other large telescopes at a similar post-commissioning stage, including Keck, Subaru, and CFHT.

In parallel to the growing excellence of the observing programs at both Gemini sites, the Gemini outreach program has grown and blossomed. At both locations the emphasis has been on reaching out to and serving the local community. In Chile, for example, Gemini South helped plan and organize AstroDay Chile, which attracted an estimated 7000 individuals in La Serena. The staff at Gemini North has continued to work closely with local schools in Hawaii, helping to train numerous teachers in order to bring the universe into the classroom.

The *Senior Review* noted that the operations cost of Gemini seems high by comparison with similar facilities. The NSF is currently conducting an independent review of facility administrative costs, and this should yield far more quantitative information on this issue. However, two rather unique factors were discussed that are surely at least a partial explanation: the telescopes are almost totally queue scheduled (a labor intensive procedure), and the facility follows a philosophy of "two telescopes, one observatory" regarding many issues of staffing and equipment. Both of these somewhat unusual points almost surely lead to improved science output, although at what quantitative level is unclear. Therefore it is possible that the science per dollar metric for Gemini is in fact quite parallel to that of other 8-10m class telescopes.

There are sobering challenges facing Gemini. Some are similar to those of other 8-10m class telescopes, especially in Chile. The cost of second-generation instruments is very high, yet these upgrades are essential to remain scientifically competitive; and the spiraling decline of the US dollar is making Chilean peso-denominated expenses steadily higher.

Clearly the most pressing challenge, however, is the recently announced intent of the UK to withdraw from the partnership. While the UK has backed off from its initial plan to withdraw immediately, the long-term prospects for their continuing in the international collaboration appear bleak. It is too early at the time of this writing to understand the full impact of the UK's stated intentions or the complete menu of possible onward strategies, so the COV cannot offer a great deal of cogent advice.

Despite all these challenges, it is important to recall that Gemini provides the majority of access to 8m class telescopes for US astronomers at institutions without their own facilities, and that this access has been embraced by the community. One outcome of an UK withdrawal could of course be an increase in US access. Such an increase, however, would come at an obvious price, and in a zero-sum AST budget already under great strain, this option will have to be carefully balanced against other lost opportunities across the Division.

The COV endorses the stewardship shown by the AST Division with regard to Gemini. We urge the NSF to utilize the results of the ongoing operations cost analysis to find ways to reduce the operations costs for Gemini. We further urge the Division with community input to develop plans now for the eventual withdrawal of the UK from the collaboration.

E.4 National Solar Observatory (NSO) & Advanced Technology Solar Telescope (ATST)

The National Solar Observatory (NSO) is functioning well and provides global leadership of ground-based O/IR solar astronomy. It enjoys a healthy relationship with the AST Division. Most significantly, NSO and AST have continued to work together to advance ATST through the MREFC approval process and a new line was created in the MREFC account for late stage design

and development for ATST. This is encouraging news for solar physics, but clearly continuing efforts are needed to advance the ATST to an approved MREFC project and to start its construction. Other NSO highlights include the commissioning of SOLIS, which is providing the first synoptic measurements of the vector magnetic field at the solar surface, an important measurement for a wide range of solar problems. A major challenge confronting NSO is the *Senior Review* recommendation to divest GONG++ one year after the successful deployment of the Solar Dynamics Observatory, scheduled for not earlier than December 2008. In addition, it is critical that NSO maintain technical expertise and provide adequate observing facilities for the community during the transition to a fully commissioned ATST.

NSO's education and outreach activities include a long history of training graduate and undergraduate students at the Sacramento Peak and Tucson facilities. A large number of professional solar astronomers are alumni of this program. NSO has conducted active REU (undergraduate) and RET (teacher) programs since their inception. They provide classroom and teaching materials for K-12 students, and work with Native Americans and underprivileged minorities. NSO operates a hands-on Visitors Center.

The Advanced Technology Solar Telescope (ATST) was highly recommended by the 2001 Decadal report. It will use state-of-the-art adaptive optics to provide revolutionary observations of the solar atmosphere and solar corona, including measurements of the magnetic fields responsible for solar activity ranging from coronal heating to solar flares to coronal mass ejections. The solar community has staked its future on ATST, which will be the first major ground-based solar observatory to be constructed by the US in four decades. It will replace the existing solar facilities on Sac Peak and Kitt Peak, which will be closed in view of limited budgets. ATST has passed all design, cost, and management reviews. The environmental impact study is nearing completion, with every precaution being taken to avoid further delay.

The COV commends AST for shepherding ATST to its current state. However, we are concerned that construction has not yet begun, and we encourage AST to continue to work aggressively to secure construction as soon as possible.

Recommendation #15: AST should make every effort to bring the ATST project into its construction phase as soon as possible.

E.5 National Astronomy and Ionosphere Center (NAIC)

NAIC, operated by Cornell University, operates one site at the Arecibo Observatory in Puerto Rico. Arecibo Observatory is a unique facility in terms of its unsurpassed collecting area and planetary radar capability. Instruments such as ALFA have allowed new and exciting survey work.

The observatory has an active and extensive Education and Public Outreach program. This includes a long-standing REU program, and the impressive Angel Ramos Visitor Center, which hosts 120,000 visitors per year, many of whom are school children. The Visitor Center receives the largest number of visitors of any other national observatory and is the only science museum in Puerto Rico.

During the period under review by this COV, there were major changes in the funding and resulting operation of NAIC as a result of the *Senior Review* process. While recognizing the value of its science program, the *Senior Review* recommended that NAIC seek other partners to help

provide financial support for operating Arecibo. In response to this new budget outlook, NAIC has cut 30 FTEs (25% of staff), modified astronomy observations to improve efficiency (to include more survey work), and maintained the radar facility, although it is used on a less frequent basis.

The continued operation of Arecibo Observatory requires securing additional partners. AST expects to provide $4M after 2011, which is half of the minimum feasible operating cost. The AST staff has helped lay the ground work for increased involvement on the part of Puerto Rico, and the Arecibo Observatory director is actively seeking outside funds to keep the observatory operational beyond 2011. The committee commends these efforts and strongly supports AST's further efforts to facilitate the transition within the context of the *Senior Review* so that astronomical community does not lose this valuable and unique facility.

The COV is concerned about the impact of the budget cuts on the morale of NAIC staff. We commend AST for monitoring this closely, and encourage continuation of this during transition period.

The *Senior Review* recommended an independent study to advise on the viability and cost of decommissioning the telescope should it become necessary. AST solicited such a report, and the report was completed just prior to the meeting of the COV. As a result, the report has not yet been reviewed by AST staff.

E.6 National Radio Astronomy Observatory (NRAO)

NRAO is managed by Associated Universities Inc (AUI) under a Cooperative Agreement with the NSF. NRAO headquarters in Charlottesville, VA are housed on the University of Virginia campus and include North American ALMA Science Center (NAASC). The NRAO Technology Center (NTC) is also housed in Charlottesville and includes the Central Development Lab and ALMA Electronics Division. The Array Operations Center (AOC), located on the campus of New Mexico Tech in Socorro, NM, houses scientific, engineering, technical, computer and support staff for both the VLA and VLBA.

NRAO operates several large, world-class telescope facilities and it heads the U.S. design, construction and science efforts for the international Atacama Large Millimeter Array (ALMA) project. The Green Bank Telescope (GBT) in Green Bank, WV is a relatively new, single 100m diameter, off-axis aperture radio telescope that currently operates from 0.3 GHz to 50 GHz, with limited tests at 90 GHz. The Very Large Array (VLA) consists of twenty-seven 25-meter diameter radio antennas in a Y-shaped configuration on the Plains of San Agustin in New Mexico. A significant activity funded by the AST Division is the VLA Upgrade through the Expanded Very Large Array (EVLA) project. The project is expected to be complete by 2011. The EVLA will maintain the same number of antennas, but with new receivers, electronics and fiber optic data transmission will increase its sensitivity enormously as well as open up new observing frequencies. The Very Long Baseline Array (VLBA) provides the highest resolution of any NRAO facility and is comprised of 10 VLA-like antennas spread from Mauna Kea to St. Croix.

The NRAO conducts significant education and public outreach activities. Green Bank Science Center (funded by appropriations from NASA) hosts ~ 40,000 visitors per year and has a rich variety of educational programs that benefit K-12 students, high school teachers, and amateur radio astronomers. Similarly, the VLA visitors center (funded by the state of New Mexico) hosts

~ 20,000 visitors per year. NRAO efforts in education and outreach include the GBT Student Support Program, Undergraduate Summer Research Program (funded through REU), Research Experience for Teachers, and K-12 outreach.

At part of the oversight responsibility of AST, AUI performance has been reviewed in several areas during the period under review by the COV. Progress in software development has been reviewed and found to be satisfactory. These software reviews were driven by previous reviews of AUI/NRAO and future needs for user support on ALMA. The EVLA upgrade was monitored by an informal review and found to be on budget and on schedule. A management review found that NRAO has flourished under AUI management. However, AST noted the need to improve diversity and made recommendations to AUI that are being implemented.

The Division expects to implement all of the *Senior Review* recommendations for NRAO and has planned future NRAO budgets around a base of facilities comprised of ALMA, EVLA, and GBT. AUI/NRAO has been directed by AST to seek non-NSF funding sources for half of VLBA operating budget ($3M) by 2011. The committee strongly supports AST's efforts to facilitate the transition within the context of the *Senior Review* recommendations. The committee was pleased to hear of the activity of NRAO, supported by NSF, to seek partners in VLBA operations, and the promising outlook.

E.7 Atacama Large Millimeter Array (ALMA)

Over the period of this review, NSF and the AST Division deserve tremendous credit for keeping ALMA – a complex, international billion-dollar class project – on track. The project is now at the height of construction, spending roughly $2M per week, with an expected completion in 2012.

ALMA will be the largest science facility NSF has ever participated in constructing or operating; it will also be the largest expenditure undertaken within the AST Division. Once fully operational, ALMA will be a first rate research facility for all astronomers world-wide for many years, rife with the promise of breakthroughs and discoveries. ALMA is a partnership between North America (the US and Canada), the European Southern Observatory, and Japan. This prominence in scope and importance of NSF role is well recognized, as evidenced by the personal interest of the Directorate and Foundation leadership. It is not an exaggeration to state that the success of ALMA is absolutely mandatory, not just for the health of astronomy, but also to maintain the reputation of the Foundation as the nation's premier federal sponsor of basic research.

ALMA is making good progress in construction, having successfully navigated its re-baselining in 2005, and established a reliable cost estimate. ALMA has also achieved a management and oversight structure adequate to support its development and operation. This structure is understandably complex given the multi-lateral international nature of the project, and the demanding technical and scientific requirements that ALMA must meet. Within these constraints, NSF and AST appear well positioned to monitor progress and cost effectiveness, to affect them as needed, and to serve the interests of the US scientific community.

The COV is concerned that only a single program officer within the Division is responsible for tracking this complex and fast moving project. This is another impressive performance given the scope and the many interfaces this one person needs to address. AST needs to constantly

reevaluate the resources it applies to oversight of ALMA; as noted above, it is critical that this high profile project succeed.

Several major challenges remain before ALMA starts delivering on its scientific promise, including completion of construction, operations planning and transition to operations, and bringing the data processing up to speed on time. Additional challenges specific to NSF include the fluctuating exchange rate, engaging the scientific community, funding its share of operations within the Division's budget envelope, and keeping the multi-national collaboration on a positive track.

The COV commends AST for helping the ALMA project proceed well into its development on a secure footing, and for continuing to meet the multiple challenges on ALMA in a constructive fashion. In the context of Recommendations #1 and #2, the COV recommends that the Division frequently reevaluate the resources it applies to oversight of ALMA to help ensure the success of this critical project.

E.8 Giant Segmented Mirror Telescope (GSMT)

The most recent *Decadal Survey* identified as its top major project recommendation the Giant Segmented Mirror Telescope – an optical and infrared telescope with an effective aperture of roughly 30 meters. The more recent *Senior Review* recommended that the NSF monitor carefully two such projects: the Thirty Meter Telescope (TMT) and the Giant Magellan Telescope (GMT). AST is actively pursuing this policy. The disparate cultures and management approach of the two projects and international participation create special challenges for the NSF, which will have to learn to work closely with private funding sources and new international partners.

The Foundation's approach has been to appoint NOAO as the project manager for this effort and to empower NOAO to lead community involvement in these projects. The committee approves of this approach and believes NOAO's involvement in both projects will enhance community representation and connection to these crucial facilities.

A major challenge ahead for these projects will be thorough and comprehensive analysis and understanding of their expected operational costs. The expected operational costs are significantly larger than any other optical/infrared telescope and are likely to be comparable to ALMA. **We urge NSF to take a leading role in the strategic planning for these expenses and distribute to the wider community lessons learned from ALMA. In line with Recommendation #5**, a goal for the Division should be to fully inform future *Decadal Surveys* on the need for realistic costs and timescales for these sorts of facilities.

E.9 Large Survey Telescope (LST)

A Large Survey Telescope (LST) specifically tuned to wide-field surveys and time-domain studies was one of the major recommendations of the last *Decadal Survey*. The Large Synoptic Survey Telescope (LSST) project is by far the most powerful LST project to be developed. It combines a monolithic 8.4 meter telescope with state-of-the-art advances in optics, detectors, and image processing into a powerful survey instrument. NSF, DOE, and a variety of private and university partners fund the project. The disparate nature of the funding and partnership creates special challenges for the NSF, which will have to create new, cooperative approaches to management and oversight of the project.

AST Division funding of the LSST is for design and development of the project ($14.2M over four years, see Mid-scale projects). The intent is to ready the project for a Preliminary Design Review in late 2008 and eventual inclusion for MREFC construction funds. This level of support and activity seems appropriate for the project, which the community has endorsed as a major new initiative. The level of management and oversight of the project at NSF also seems appropriate at this stage, but AST should expect to increase attention and personnel time as the project ramps up.

E.10 Square Kilometer Array (SKA)

The Square Kilometer Array (SKA) project is a transformative project for pursuing astronomy at long wavelengths (> 1 cm). It has several diverse and ambitious goals. SKA development funding was a major recommendation of the last *Decadal Survey* report. Although the level of community interest and involvement in the project should be defined by upcoming strategic planning exercises, such as the next *Decadal Survey*, it is clear that the project would be an important component of the community's future observational capabilities. The COV notes that the perception of the project varies widely in the community; in particular, the level of technology readiness of the project is not well agreed upon. It is agreed that the SKA will be a world-class project, consisting of more than one array of antennas, and with scientific and financial involvement across the globe. There is already considerable interest and investments in the SKA outside of the U.S.

The COV endorses the involvement of the AST Division in the SKA project at the level of participating in the current international discussions aimed at defining the project scope and organization. We recommend that AST representatives be actively involved in SKA planning meetings, which will likely require substantial travel costs and commitments. We also approve of the $12M funding awarded for SKA technology development (see mid-scale projects).

VII. Electromagnetic Spectrum Management (ESM)

Within AST, the ESM staff (1.5 FTE) works to protect the radio spectrum resource. This is of enormous value to the community that AST serves. The annualized commercial value of the bandwidth that ESM protects is nearly $1B, whereas the ESM budget is about $200k. Besides the commercial pressures, ESM must contend with other U.S. government agencies, observatories, and other nations. A consistent presence at meetings, conferences, working groups is needed and the travel budget should reflect the importance of ESM efforts.

ESM protects the Division's investment in NRAO, NAIC, ALMA, URO and several of the new Mid-size projects. It also is of direct interest to the NSF Office of Polar Program's Antarctic astrophysics program. ALMA represents $1.3B of construction investment that is vulnerable to degradation of performance from telecommunications. (ALMA is already impacted by satellite emission.) ESM offers a good return on investment if it protects radio telescope facilities and possibly mitigates existing problems. For example, commercial allocations above 275 GHz would be detrimental to ALMA observations of redshifted emission from molecular transitions and dust-continuum from evolving galaxies as early as $z \sim 10$ (one of the key science drivers for ALMA). **The COV applauds the AST's overall efforts in managing the electromagnetic spectrum.**

The importance of ESM to AST-funded facilities and grant awards is abundantly clear, but the COV is concerned about the visibility of ESM within the Foundation. As ESM activities are by definition global, substantial international travel is an absolute requirement for success of the enterprise. The COV was dismayed to learn that constraints on the AST travel budget have translated into significant limits on the Division's ESM activities. This constitutes a lack of thoughtful investment in an essential task not just for NSF, but for the entire scientific community.

Recommendation #16: NSF should consider moving responsibility for Electromagnetic Spectrum Management (ESM) to the MPS Directorate office, if not to the NSF Director's office, to increase the visibility of ESM within the Foundation and also to stress the Foundation's commitment to spectrum management to the global community.

VIII. Response to 2005 COV

The COV has considered the report of the previous (2005) COV carefully, as well as several iterations of the AST response to the report, the most recent dated January 2008.

As the AST response faithfully itemizes each of the 2005 recommendations, we will not repeat them here. The response speaks for itself, in that AST has carefully considered each of the items raised by the last COV, and acted on each of them to the greatest extent possible. Here we will highlight the subset of items from the 2005 report that may require continued visibility and/or actions. The response to the *Senior Review*, a major milestone in the history of AST and discussed at length by the 2005 COV, has been addressed elsewhere in this report.

Workload: The 2005 COV most strongly recommended provision of further staffing for AST, and it is most gratifying that MPS responded with three additional FTEs. However, our Committee remains gravely concerned about understaffing at AST. The number of proposals received by the Division is steadily growing, in part due to cuts in relevant individual investigator funding at NASA, as well as steadily increasing intellectual and technical opportunities in our field. The *Senior Review* was in our judgment a great success, but has also materially increased AST workload to implement these vital suggestions. Finally, AST is tasked with overseeing a number of capital projects which are huge and complex by any scale. ALMA, for example, is the largest capital project yet undertaken by the Foundation, and has a particularly arcane management structure imposed through no fault of the Foundation. Its success and budget discipline are both imperative, and cannot be jeopardized by the lack of a few extra FTE for oversight. Yet this is at the moment a real possibility. We urge in the strongest terms that MPS revisit again the staffing levels in AST.

ESM Program: The AST response to the last report makes it perfectly clear that the Division understands the crucial need to defend spectrum allocations for scientific research. However, the intrinsically international nature of this undertaking requires a modest amount of international travel, which if charged to the current Division blanket travel budget would quickly drain it. This issue impacts many disciplines in American science, not just astronomy, and it is completely unacceptable for the Division's response to these problems to be limited by travel allocations, especially when the need is comparatively modest.

Organization by Science Inquiry rather than Wavelength: AST has made great strides in reforming the organization of various grants programs to reflect the intellectual problem, rather than the instrumental technique, as strongly recommended by the 2005 COV. An additional area

where this integration could now be considered is in support of small to medium observatories. The University Radio Observatories (URO) program exists as a separate entity largely for historical reasons. The TSIP program and a variety of discrete programs provide comparable funding for university access to optical telescopes and instrumentation development. It is time to consider the pros and cons of removing the radio/OIR segregation. As this is a delicate funding ecology that has developed over many decades, the possibility of such change needs careful consideration and stakeholder input, to ensure that any change truly does increase the overall quality of AST science, and minimizes any unintended consequences.

Maintain the AAG Program: This point is so important that we cannot resist commending AST for its discipline in faithfully implementing this comment, despite huge pressures elsewhere for equally exciting opportunities. The COV was particularly pleased to note that most winning proposals were essentially fully funded, a difficult but we believe correct choice even as success rates decline due to budget pressures.

FY 2008 REPORT TEMPLATE FOR NSF AST DIVISION COMMITTEES OF VISITORS (COVs)

Date of COV: February 6-8, 2008
Program/Cluster/Section: All Division programs and activities
Division: AST
Directorate: MPS
Number of actions reviewed: 342 **Awards: 160** **Declinations: 172** **Other: 10**
Total number of actions within Program/Cluster/Division during period under review: **Awards: 935** **Declinations: 1493** **Other: 128**
Manner in which reviewed actions were selected: **COV members individually selected from list of 467 e-jackets provided by AST.**

PART A. INTEGRITY AND EFFICIENCY OF THE PROGRAM'S PROCESSES AND MANAGEMENT

A.1 Questions about the quality and effectiveness of the program's use of merit review process.

QUALITY AND EFFECTIVENESS OF MERIT REVIEW PROCESS	YES, NO, DATA NOT AVAILABLE, or NOT APPLICABLE[1]
1. Are the review methods (for example, panel, ad hoc, site visits) appropriate? Comments: **See discussion in main text of report.**	YES
2. Are both merit review criteria addressed a) In individual reviews? **YES** b) In panel summaries? **YES** c) In Program Officer review analyses? **YES** Comments: **Concerns in 2005 COV report regarding "Broader Impact" criterion were no longer found to be a significant problem. In almost all cases reviewed both criteria were addressed by the proposal.**	YES

3. Do the individual reviewers provide substantive comments to explain their assessment of the proposals? Comments: **In the most cases the reviewers did provide substantive comments, but the COV notes that the efforts were uneven. See discussion in main text of report.**	YES

4. Do the panel summaries provide the rationale for the panel consensus (or reasons consensus was not reached)? Comments: **The panel summaries could be improved to provide better feedback to the PIs. The COV notes that the PO review analyses are excellent. In their current form the PO analyses cannot be given to the PIs (confidentiality issues), but the COV discussed the possibility that key elements could be provided to the PI. It is clear, however, that this would add to the already heavy load carried by the POs.**	YES
5. Does the documentation in the jacket provide the rationale for the award/decline decision? (Note: Documentation in jacket usually includes context statement, individual reviews, panel summary (if applicable), site visit reports (if applicable), program officer review analysis, and staff diary notes.) Comments: **As noted above, the COV was greatly impressed with the PO review analysis, which clearly summarized the rationale for decisions.**	YES

6. Does the documentation to PI provide the rationale for the award/decline decision? (Note: Documentation to PI usually includes context statement, individual reviews, panel summary (if applicable), site visit reports (if applicable), and, if not otherwise provided in the panel summary, an explanation from the program officer (written or telephoned with diary note in jacket) of the basis for a declination.) Comments: **Yes, including follow up communication to the PIs, both written, in the form of telephone calls by the POs. The Review analyses are excellent, but the written panel summaries that the PIs receive could be improved**.	YES
7. Is the time to decision appropriate?	YES

Note: Time to Decision --NSF Annual Performance Goal: **For 70 percent of proposals, inform applicants about funding decisions within six months of proposal receipt or deadline or target date, whichever is later**. The date of Division Director concurrence is used in determining the time to decision. Once the Division Director concurs, applicants may be informed that their proposals have been declined or recommended for funding. The NSF-wide goal of 70 percent recognizes that the time to decision is appropriately greater than six months for some programs or some individual proposals. Comments: **The COV was impressed with the high rate of success in meeting this goal. Pressure to meet the 6 month time-to-decision, combined with the need to set up panels after receipt of the proposals, leads to a very short time to recruit panelists. The COV noted that this might contribute to the perceived lack of senior panelists on some panels. The COV does not suggest that the time to decision be increased. However, the COV discussed the possibility of starting the panel selection process before the receipt of proposals, although this requires AST to anticipate the mix of proposals eventually received.**	
8. Additional comments on the quality and effectiveness of the program's use of merit review process:	

A.2 Questions concerning the selection of reviewers

SELECTION OF REVIEWERS	YES , NO, DATA NOT AVAILABLE, or NOT APPLICABLE[2]
1. Did the program make use of reviewers having appropriate expertise and/or qualifications? Comments: **The COV recommends that continued attention be dedicated to the**	**YES**

issue of assembling diverse panels. While the COV supports efforts to broaden the base of participants on review panels, care should also be taken to ensure in all cases that the research activity of panelists remains high. Given that the pool of potential reviewers is filled with individuals whose calendars are very crowded, the COV suggests that an effort be made to recruit panelists as early as possible – even prior to the deadline for receipt of proposals – to facilitate the construction of panels with the most balanced distribution of research experience. To ensure the presence of necessary expertise, it may also at times be necessary to increase the size of a panel and/or obtain additional external reviews.	
2. Did the program use reviewers balanced with respect to characteristics such as geography, type of institution, and underrepresented groups? Note: Demographic data is self reported, with only about 25% of reviewers reporting this information. Comments: **The COV noted and commended the effort AST expended in balancing the panels. It also noted that the low number of women and other underrepresented groups on some panels (instrumentation related programs) almost certainly reflects the balance in the recruiting pool.**	**YES**
3. Did the program recognize and resolve conflicts of interest when appropriate? Comments:	**YES**

4. Additional comments on reviewer selection:

A.3 Questions concerning the resulting portfolio of awards under review.

RESULTING PORTFOLIO OF AWARDS	APPROPRIATE, NOT APPROPRIATE[3], OR DATA NOT AVAILABLE
1. Overall quality of the research and/or education projects supported by the program. Comments: **The COV was very impressed by the quality of the projects supported.**	APPROPRIATE
2. Does the program portfolio promote the integration of research and education? Comments: **This is a clear strength of the program.**	APPROPRIATE
3. Are awards appropriate in size and duration for the scope of the projects? Comments: **The COV supports the policy of funding proposals at or near 100% of the requested level.**	APPROPRIATE
4. Does the program portfolio have an appropriate balance of: • Innovative/potentially transformative projects? Comments:	APPROPRIATE
5. Does the program portfolio have an appropriate balance of: • Inter- and Multi- disciplinary projects? Comments: **This has always been a strength of the Division. The COV was pleased with the increased number of inter- and multi- disciplinary projects,**	APPROPRIATE

especially the new mid-sized projects which are directed at clear community needs.	

6. Does the program portfolio have an appropriate balance considering, for example, award size, single and multiple investigator awards, or other characteristics as appropriate for the program? Comments: **The COV recommends continuing efforts to encourage proposals for five years of support versus the three years that are currently the norm. The longer terms would allow PI's to better plan their research activities, as well as reduce overhead for the PI's, NSF personnel and reviewers.**	APPROPRIATE
7. Does the program portfolio have an appropriate balance of: • Awards to new investigators? NOTE: A new investigator is an investigator who has not been a PI on a previously funded NSF grant. Comments:	APPROPRIATE
8. Does the program portfolio have an appropriate balance of: • Geographical distribution of Principal Investigators? Comments:	APPROPRIATE
9. Does the program portfolio have an appropriate balance of: • Institutionnel types? Comments:	APPROPRIATE

10. Does the program portfolio have an appropriate balance: ▲ Across disciplines and sub disciplines of the activity? Comments: **A clear strength of the program.**	APPROPRIATE
11. Does the program portfolio have appropriate participation of underrepresented groups? Comments:	APPROPRIATE
12. Is the program relevant to national priorities, agency mission, relevant fields and other constituent needs? Include citations of relevant external reports. Comments: **Most definitely – it was clear to the COV that the NSF was well acquainted with the needs and priorities of the astronomical community, as represented by the AAMN Decadal report, the *Senior Review*, the Dark Energy and Cosmic Microwave Background Task Forces and similar reports. They are also guided by the OSTP "Physics of the Universe" report, the meetings and annual reports of the interagency Astronomy and Astrophysics Advisory Committee (AAAC), and the meetings and reports by the NRC Committee on Astronomy and Astrophysics (CAA).**	APPROPRIATE
13. Additional comments on the quality of the projects or the balance of the portfolio:	

A.4 Management of the program under review.

1. Management of the program. Comments: **We found, as did the previous COV, that the Division is very well managed. In addition to the more traditional grants program, the division is responsible for managing a number of complex, national and international projects with numerous collaborators from other agencies and countries.**

2. Responsiveness of the program to emerging research and education opportunities.

Comments: **The pilot "mid-scale" program was singled out by the COV as an example of responsiveness to emerging research. The handling of proposals to the individual-investigator grant programs also was found to be very responsive to emerging research and education opportunities.**

3. Program planning and prioritization process (internal and external) that guided the development of the portfolio.

Comments: **The community has done well prioritizing their needs, but perhaps not so well containing costs. The Division, especially with the *Senior Review*, has helped the community make hard but necessary decisions in the latter regard.**

4. Responsiveness of program to previous COV comments and recommendations.

Comments: **The Division has been responsive to all previous COV comments and recommendations. These are discussed in the text of this report.**

5. Additional comments on program management:

PART B. RESULTS OF NSF INVESTMENTS

B.1 OUTCOME GOAL for Discovery: "*Foster research that will advance the frontier of knowledge, emphasizing areas of greatest opportunity and potential benefit and establishing the nation as a global leader in fundamental and transformational science and engineering.*"

Comments: See general comments, examples and award numbers below.

B.2 OUTCOME GOAL for Learning: "*Cultivate a world-class, broadly inclusive science and engineering workforce, and expand the scientific literacy of all citizens.*"

Comments: See general comments, examples and award numbers below.

B.3 OUTCOME GOAL for Research Infrastructure: "*Build the nation's research capability through critical investments in advanced instrumentation, facilities, cyberinfrastructure and experimental tools.*"

Comments: See general comments, examples and award numbers below.

B1: Outcomes in the area of Discovery

First Terrestrial Planet Found Around Normal Star
A major step forward in the search for Earth-like planets beyond our solar system was made when astronomers announced the discovery of the first of a new class of rocky terrestrial planets orbiting a normal star. The team estimates the mass of the planet, orbiting the star Gliese 876, at about 7.5 Earth masses, or about half that of the of the least massive planets previously discovered around other stars (all of which are larger than Uranus). Of special importance is the development of the tools and techniques that allowed the team to detect the tiny wobble the planet induces in the star - which can now be measured to within one meter per second (human walking speed) instead of the previous precision of three meters per second. This improved sensitivity will allow the planet-hunting team to detect the gravitational effect of an Earth-like planet within the habitable zone of other cool dwarf stars like Gliese 876. This gives astronomers confidence that they will be able to detect even smaller rocky planets around other stars in orbits more hospitable to life.
NSF Award Numbers:
0307493
Award Title: Continuation of a Survey of Nearby Stars for Extrasolar Planets
PI Name: Steven Vogt
Institution Name: University of California-Santa Cruz
9988087
Award Title: A Southern Hemisphere Search for Extra-Solar Planets

PI Name: R. Paul Butler
Institution Name: Carnegie Institution of Washington
9520443
Award Title: Detecting Extra-Solar Planets: Crossing the Jupiter Threshold
PI Name: Geoffrey Marcy
Institution Name: San Francisco State University

An Ancient Star Raises Questions on the Origin of Chemical Elements
Astronomers led by Michael Rich at UCLA have discovered a most unusual star, possibly one of the first stars to have formed in the Universe following the Big Bang. Using the W.M. Keck telescope in Hawaii, Rich and colleagues Jon Fulbright and Sandra Castro have determined that the star Draco 119, in the relatively small Draco Dwarf galaxy, has only 1/1000 of the iron found in the Sun, but more strikingly has no elements with nuclei heavier than that of iron.
Because iron, and all elements heavier than helium, are produced by nuclear burning in stars, such an unusual star must have formed from very ancient material, when the Universe was young. Elements heavier than iron have up to now been found in all stars, even those with 1/10,000 the chemical abundance found in the Sun, so their absence in Draco 119 is most puzzling. Large surveys aimed at finding other genesis stars are underway.
NSF Award Numbers:
0098739
Award Title: Collaborative Research: Chemical Composition of the Galactic Bulge
PI Name: R. Michael Rich
Institution Name: University of California-Los Angeles
0098612
PI Name: Andrew McWilliam
Institution Name: Carnegie Institution of Washington

Chemical signatures provide clues to galaxy formation
The current theories for galaxy formation suggest that galaxies are formed from smaller structures such as the dwarf galaxies found around our own Milky Way. Extensive surveys around our galaxy and nearby Andromeda galaxy, in fact, show evidence of the accretion or merger of dwarf galaxies going on even today. As a result, we expect that many of the stars of our galaxy, particularly those oldest objects in the galactic halo, should look like the stars in dwarf galaxies. And one of the best ways to compare stars and relate their birthplaces and history is to look at their chemical compositions. Dr. Matthew Shetrone, of University of Texas at Austin, and his colleagues Verne Smith at UT, El Paso, and CAREER awardee Kim Venn of Macalaster College, have done just that, and uncovered a major mystery. They have analyzed the chemical composition of stars in a sample of local dwarf galaxies, and compared them to published datasets for stars in the Milky Way. They find distinctive differences in the abundances of key elements such as calcium and titanium between the stars of the dwarf galaxies and those of any component of the Milky Way. If most of the Milky Way stars came from the accretion of dwarf galaxies, these abundances should look similar. The contrasting abundance patterns indicate that either our knowledge of the formation of galaxies is seriously flawed or that the remaining local dwarf galaxies are nothing like the original building blocks that formed the Milky Way. In either case, these results pose a challenge to our understanding of one of the most fundamental processes in astrophysics - the assembly of galaxies.
NSF Award Numbers:
0306884
Award Title: Collaborative Research: Chemical Evolution Beyond the Milky Way
PI Name: Matthew Shetrone
Institution Name: University of Texas at Austin

0307534
Award Title: Collaborative Research: Chemical Evolution Beyond the Milky Way
PI Name: Verne Smith
Institution Name: University of Texas at El Paso
9984073
Award Title: CAREER: The First Stellar Abundances in Local Group Galaxies
PI Name: Kimberley Venn
Institution Name: Macalester College

Astronomers Use Lasers to Image the Remarkable Neighborhood of the Supermassive Black Hole at the Center of the Milky Way
UCLA astronomer Andrea Ghez and colleagues have taken remarkably clear pictures of the center of our Milky Way galaxy, including the region containing its supermassive black hole. The data were obtained using a new laser virtual star at the W.M. Keck observatory in Hawaii. The images represent a breakthrough that will help scientists to better understand the black hole's environment and physics. A laser virtual star, created using the Keck telescope itself, was used to correct the atmosphere's distortions and clear up the images. The new technology, called Laser Guide Star adaptive optics, will lead to important advances for the study of planets in our solar system and outside of our solar system, as well as galaxies, black holes, and how the universe formed and evolved.
NSF Award Numbers: **0406816**
Award Title: Probing the Remarkable Neighborhood of the Galactic Center's Supermassive Black Hole with Diffraction-Limited Studies of Stars, Dark Matter, and Accreting Gas
PI Name: Andrea Ghez
Institution Name: University of California-Los Angeles

3-D Map of the Nearby Universe
An international team of astronomers, which includes NSF-supported researcher Professor John Huchra of Harvard University, has released maps from the largest full-sky, three-dimensional survey of galaxies ever conducted. The precise measurements and analyses were made as part of a collaboration between American, Australian and British researchers. The results include detailed maps of the cosmos out to a distance of 600 million light years, identifying all of the major superclusters of galaxies and voids. Within this vast volume, the most massive supercluster is 400 million light years away and was named after its original identifier, the American astronomer Harlow Shapley. However, Shapley is not the only nearby massive supercluster, because the Great Attractor supercluster, three times closer, plays a bigger role in the motion of our Galaxy than Shapley. The current team also established that the Great Attractor is indeed an isolated supercluster and not part of Shapley. This extraordinarily detailed map will act as a benchmark against which to test theories for the formation of structure in the Universe. In the near future, predicted motions from this map will be compared with measurements by the 6dF Galaxy Survey, providing a new and stringent test of cosmological models.
NSF Award Numbers: **0406906**
Award Title: The Nearby Universe with 2MASS
PI Name: John Huchra
Institution Name: Harvard University

Cosmic Sound Waves from the Early Universe
The Universe today is marked by a vast array of galaxies which are not distributed randomly throughout the cosmos but organized into clusters and super-clusters, with empty voids between them. One of the major goals in cosmology is to understand how these structures and the galaxies

within them came into existence. The young Universe was much hotter and denser than it is today, forming a plasma of ionized material capable of trapping light itself. At a moment only some 400,000 years after the Big Bang, the plasma cooled, the matter recombined, and the light was released. That light is the well-known cosmic microwave background, our picture of the way the Universe was in its infancy. But that's not the only thing the plasma left behind.

The trapped light causes a varying pressure in the plasma just like sound waves in air. All sorts of oscillations exist, but in the same way that the length of an organ pipe selects just one note, so the 400,000-year scale of the Universe selects a single resonant cosmic pitch, spreading out through the cosmos from many sources, like a handful of gravel thrown into a pond creating multiple ripples. By now, those ripples have all spread to the same size, but because of overlap and interference we do not see a clear set of rings on the sky. However, amazingly enough, careful analysis can still show a small excess bump in the structure of the Universe at today's expected ripple scale. Detecting this imprint of ancient sound waves is not only a spectacular confirmation of our current cosmology, but the scale of the bump confirms in a completely independent way the amazing discovery that the expansion of the Universe is accelerating and helps constrain theories for the accelatation mechanism, the so-called Dark Energy. These are exciting times for cosmology.

The work by NSF-supported researchers used data from the Sloan Digital Sky Survey, funded by the Sloan Foundation, universities, and the NSF, and confirms the value to science of public-private partnerships.
NSF Award Numbers:
0098577
Award Title: Luminous Elliptical Galaxies in the Sloan Digital Sky Survey: Large-Scale Structure and Galaxy Evolution
PI Name: Daniel Eisenstein
Institution Name: University of Arizona
0407200
Award Title: Luminous Red Galaxies in the SDSS and Beyond: Large-Scale Structure, Dark Energy, and Galaxy Evolution
PI Name: Daniel Eisenstein

Micro Volcanoes on Enceladus
Enceladus, a satellite of Saturn, is one of the brightest objects in our Solar System. Covered in water ice that reflects sunlight like freshly fallen snow, Enceladus reflects almost 100 percent of the sunlight that strikes it. Because Enceladus reflects so much sunlight, the surface temperature is extremely cold, about -201 C. About as wide as Arizona, Enceladus displays at least five different types of terrain. Parts of the satellite show craters no larger than 35 kilometers (about 22 miles) in diameter. Other areas show regions with no craters indicating major resurfacing events in the geologically recent past. There are fissures, plains, corrugated terrain and other crustal deformations. All of this indicates that the interior of the satellite may be liquid today, even though it should have been frozen eons ago. Enceladus' surface is believed to be geologically "young," possibly less than 100 million years old. In a laboratory study of surface processes on icy Solar System objects, Dr. Raul Baragiola, at the University of Virginia, has discovered a mechanism for producing micro volcanoes that could explain some of the features, such as plumes, that are observed on Enceladus.
NSF Award Numbers: **0506565**
Award Title: Surface Processes in Icy Solar System Objects
PI Name: Raul Baragiola
Institution Name: University of Virginia Main Campus

Stellar Birth Rings
Eugene Chiang and graduate student Linda Strubbe, University of California at Berkeley, developed a comprehensive theory to explain the surface brightness profiles of debris disks around stars, like the one surrounding the 10-million year-old M dwarf, AU Microscopii. Dust originates from a ring of parent bodies (the "birth ring") that undergoes collisional attrition. Chiang and Strubbe derive analytically and verify by numerical simulations the optical depth of dust grains as a function of distance from the star. Application of their theory to the AU Mic disk reveals that its birth ring bears a striking resemblance to the Kuiper Belt in our Solar System. The Kuiper Belt is that area of the Solar System extending from the orbit of Neptune out to 50 astronomical units from the Sun. The objects within the Kuiper Belt, together with the members of the scattered disk extending beyond, are collectively referred to as trans-Neptunian.
NSF Award Numbers: **0507805**
Award Title: Dynamics of the Kuiper Belt: From Planetesimal Formation to Planetary Migration
PI Name: Eugene Chiang
Institution Name: University of California-Berkeley

Simulations Explore Solar Magnetism
The Sun possesses magnetic fields that impact our technological society in myriad ways: solar coronal mass ejections and flares can disrupt power grids, interrupt satellite communications, and pose a danger to astronauts on spacewalks. These powerful outbursts come about as part of the 22-year cycle of solar magnetic activity, which is thought to arise from the action of a "magnetic dynamo" operating deep within the Sun. That dynamo is believed to build strong magnetic fields through a combination of several key processes, crucially involving both turbulent motions in the convection zone (which occupies the outer 30% of the Sun) and a strong shear layer at the base of that zone, called the "tachocline," which stretches, amplifies, and organizes the magnetism.

In 2006 NSF Astronomy and Astrophysics Postdoctoral Fellow Matthew Browning and collaborators Mark Miesch (HAO/NCAR), Sacha Brun (CEA Saclay), and Juri Toomre (University of Colorado) published the first global numerical simulations of the solar dynamo that include penetration into the tachocline of shear. Their computational models solved the full three-dimensional equations of fluid motion and magnetism using massively parallel supercomputers. Although their simulated flows are not as turbulent as in the real Sun, the models still show that strong magnetic fields akin to those in the Sun can be built efficiently by solar convection and differential rotation. In their calculations, the tachocline is found to play a major role in generating the magnetism, yielding mean (large-scale) fields that are much stronger and more organized than in prior simulations that modeled only the convective envelope.
NSF Award Numbers: **0502413**
Award Title: Simulations of Convection and Dynamo Activity in Low-Mass Stars
PI Name: Matthew Browning

Portrait of a Star on the Edge
While many people think of stars as round like our Sun, astronomers at Georgia State University's Center for High Angular Resolution Astronomy (CHARA) have shown that this isn't always the case - especially when the star's equator is moving at 700,000 miles per hour. Using the recently completed array of optical telescopes atop California's Mount Wilson, the CHARA astronomers have measured Regulus' size and shape, the temperature difference between its poles and equator, and the orientation of its spin axis - a remarkable feat given that Regulus is more than 30 light years away. Regulus' frenetic spin gives the star its grossly bulging mid-section; its equatorial diameter is one-third larger than its north-south diameter. But almost as striking is the "gravity

darkening" in the midsection: Regulus' rotation lowers the pull of gravity at the equator, which in turn lowers the temperature there and dims the light output. CHARA researchers have found that Regulus is five times brighter at the poles, where the temperature is 27,200 degrees Fahrenheit, than it is at the equator, where the temperature is 18,000 degrees Fahrenheit. While gravity darkening has been theorized for decades, this is one of the first direct measurements of the effect.

NSF Award Numbers: **0307562**
Award Title: Fundamental Stellar Parameters from the CHARA Array
PI Name: Harold McAlister
Institution Name: Georgia State University Research Foundation, Inc.

Pre-Supernova White Dwarf Star Discovered

Direct radiation has now been detected from the surface of a white dwarf doomed to become a supernova. The white dwarf star, trapped in orbit around a companion, is part of a rare binary system known as an AM Cvn star - currently the strongest candidates for the progenitors of Type Ia supernovae which in turn are key cosmological distance indicators (it was Type Ia supernovae that provided the first evidence that the expansion of the universe is accelerating). The white dwarf star itself is obscured by a spinning helium-rich disk of material pulled from the companion. But by subtracting off the light from this disk, astronomers were able to uncover the radiation from the underlying white dwarf star. They found the pre-supernova white dwarf star to be much cooler than predicted by theory as well as rotating more slowly. The surface abundances of heavy elements were also greater than expected. While it remains to be seen if this system is typical (about 10 AM Cvn stars are known), it is critical that we understand the underlying properties of Type Ia supernovae progenitors if they are to be used as cosmological indicators. The direct detection of radiation from the white dwarf in this AM Cvn system is a critical first step.

NSF Award Numbers: **0507514**
Award Title: RUI: White Dwarfs in Cataclysmic Variables: Probes of Evolution and Accretion Physics
PI Name: Edward Sion
Institution Name: Villanova University

Sound Waves Rock a Star to Death

A long standing theoretical problem in astronomy has been "how do massive stars explode at the ends of their lives?" These events, called supernovae, occur only among the most massive stars (10-25 times the mass of our Sun). And, while it is understood that tremendous amounts of energy are released at the moment of death, it has not been clear how the energy gets out. Previous simulations suggested the layers of gas surrounding the core were just too dense for the energy to escape. The simulated blast wave would stall and die before it reached the star's surface, and observers on the outside would see nothing at all. University of Arizona astronomer Adam Burrows and his colleagues have developed techniques that allow a more natural modeling of the flow of material and radiation, especially in the central regions of the star. These new simulations show that the initial energy release at the core pulsates the surrounding layers of gas (an acoustic wave). Within a fraction of a second these waves grow so violent they tear the star apart, blowing its outer layers into space.

NSF Award Numbers: **0504947**
Award Title: Multi-Dimensional Simulations of Core-Collapse Supernovae
PI Name: Adam Burrows
Institution Name: University of Arizona

A Vast Stellar Web Spun by Colliding Galaxies

Case Western Reserve University astronomers have captured the deepest wide-field image ever of the nearby Virgo cluster of galaxies, directly revealing for the first time a vast, complex web of 'intracluster starlight' - nearly 1,000 times fainter than the dark night sky - filling the space between the galaxies within the cluster. The streamers, plumes and cocoons that make up this extremely faint starlight are made of stars ripped out of galaxies as they collide with one another inside the cluster, and act as an 'archaeological record' of the violent lives of cluster galaxies. The Virgo image was captured through Case's newly refurbished 24-inch Burrell Schmidt telescope, located at the Kitt Peak National Observatory in Arizona. Working from the deepest image ever obtained of this galaxy cluster, the PI's have provided direct evidence of the fundamental processes of galaxy formation. This work was carried out by two CAREER awardees and an NSF Astronomy and Astrophysics postdoctoral fellow.

NSF Award Numbers:

9876143

Award Title: CAREER: The Dynamical Evolution of Galaxies and Galaxy Clusters

PI Name: Chris Mihos

Institution Name: Case Western Reserve University

0098435

Award Title: Collaborative Research: The Structure and Origin of the Galactic Halo

PI Name: Heather Morrison

Institution Name: Case Western Reserve University

0302030

Award Title: The Study of Intracluster Starlight and Demystifying the Scientific Process

PI Name: John Feldmeier

Dissecting Distant Galaxies

Using the new W. M. Keck Observatory Laser Guide Star Adaptive Optics System (created with partial NSF support) and the OSIRIS integral field spectrograph (built with substantial NSF contributions), it has become possible to obtain information on galaxies more than 10 billion light years away that are in the process of formation. The adaptive optics system, in which a laser beacon is used as an "artificial star" to sense turbulence in the earth's atmosphere, allows astronomers to obtain spatial resolution that is even higher than that of the Hubble Space Telescope. The images of three distant galaxies are shown in the figure; the grayscale images show the appearance of the galaxies in the light of Hydrogen alpha, an indicator of intense star formation activity. The OSIRIS instrument actually obtains a spectrum of each "pixel" in the image, so that accurate measures of the speed at which the material in the galaxies is moving is obtained at every point. The color coded panels show the "velocity field" (middle) and velocity dispersion (a measure of the spread of velocities) at each point. Note that in the 3rd panel, labeled C2, there is evidence for elongation and rotation, much as would be expected for ancient disks of gas, dust, and stars, whereas in the other two galaxies, there is no evidence for ordered rotation. These observations illustrate the new capabilities of large telescopes coupled with state-of-the-art adaptive optics systems and instruments on ground-based telescopes. For the first time, it is possible to measure the chemistry, mass, and distribution of star formation activity in galaxies in the early universe, providing clues to the processes that govern their formation. This is primarily the work of graduate student David Law, who is fully supported by PI Charles Steidel's NSF award.

NSF Award Numbers:

0606912

Award Title: Galaxies, AGN, and the IGM During the Peak Epoch of Galaxy Formation

PI Name: Charles Steidel

Institution Name: California Institute of Technology

0307263
Award Title: Galaxies and the Intergalactic Medium at z=1.5-3.5
PI Name: Charles Steidel

Galaxy Collisions Dominate the Local Universe
More than half of the largest galaxies in the nearby universe have collided and merged with another galaxy in the past two billion years, according to a new study using hundreds of images from two of the deepest sky surveys ever conducted. The idea of large galaxies being assembled primarily by mergers rather than evolving by themselves in isolation has grown to dominate cosmological thinking. However, a troubling inconsistency within this general theory has been that the most massive galaxies appear to be the oldest, leaving minimal time since the Big Bang for the mergers to have occurred.

CAREER awardee Pieter van Dokkum of Yale University led the study that found these common massive galaxies do form by mergers. It is just that the mergers happen quickly, and the features that reveal the mergers are very faint and therefore difficult to detect. The paper uses two recent deep surveys done with NSF's 4-meter telescopes at Kitt Peak National Observatory and Cerro Tololo Inter-American Observatory. Known as the NOAO Deep Wide-Field Survey and the Multiwavelength Survey by Yale/Chile, these surveys covered an area of the sky 50 times larger than the size of the full Moon. Van Dokkum used images from the two surveys to look for telltale tidal features around 126 nearby massive galaxies in the local universe. These faint tidal features turn out to be quite common, with 53 percent of the galaxies showing tails, broad fans of stars trailing behind them or other obvious asymmetries. This implies that there is a galaxy that has endured a major collision and subsequent merger event for every single other 'normal' undisturbed field galaxy.
NSF Award Numbers:
0449678
Award Title: CAREER: The Formation Epoch of Massive Galaxies
PI Name: Pieter van Dokkum
Institution Name: Yale University
0244680
Award Title: Cooperative Agreement for the Management, Operation and the Maintenance of the National Optical Astronomy Observatories (NOAO)
PI Name: William Smith
Institution Name: AURA/National Optical Astronomy Observatories

B2: Outcomes in the area of Learning

The Division has strongly encouraged a high level of educational activities associated with all of its awards. For example, the Astronomy and Astrophysics Postdoctoral Fellowship (AAPF) program requires a strong outreach component. The Research Experiences for Undergraduates (REU) program does an excellent job of promoting undergraduate education. All of the major observatories and facilities funded by the Division have strong educational programs. Lastly, the many graduate students and postdoctoral scholars supported by PI research grants are receiving excellent education. Below we list a few specific examples.

Astronomy and Astrophysics Postdoctoral Fellowships (AAPF)

High School Student Uncovers Young Brown Dwarf Stars

Working with NSF Astronomy and Astrophysics Postdoctoral Fellow Kelle Cruz, Bellmore-JFK High School senior Adam Solomon has earned third place in the Siemens-Westinghouse Competition and a finalist slot in the Intel Science Talent Search by identifying several young, planetary-mass brown dwarf stars through the analysis of their near-infrared spectra. Brown dwarf stars are star-like objects that are not massive enough to sustain the core nuclear engine that keeps typical stars burning for billions of years. As a result, brown dwarf stars gradually cool with time and are akin to giant planets. Objects similar to those identified by Solomon have previously been identified in young stellar clusters, but those brown dwarf stars are so young that they are still in the process of gravitational collapse, and thus their physical properties are difficult to determine. These newly uncovered objects represent the first discoveries of an intermediate-age population of brown dwarf stars. Their properties will put strong constraints on the atmospheric, formation, and evolutionary models of these very low-mass objects. Mr. Solomon presented his findings at the January 2006 meeting of the American Astronomical Society.

NSF Award Numbers: **0401418**
Award Title: Measuring the Luminosity and Mass Functions of Low-Mass Stars and Brown Dwarfs
PI Name: Kelle Cruz

Geysers or Volcanoes on Titan?

Using images obtained during the past two years by adaptive optics systems on the Gemini North and the W. M. Keck telescopes on Mauna Kea in Hawaii, NSF Astronomy & Astrophysics Postdoctoral Fellow Henry Roe and his colleagues have provided the first explanation for a long standing mystery about Saturn's largest moon, Titan. Titan's atmosphere contains copious amounts of methane gas, yet the sun's ultraviolet rays should have removed all of Titan's atmospheric methane billions of years ago. Roe and his colleagues conclude that geologic activity on the surface of the moon is replenishing the gas, forming telltale clouds.

Their high resolution images, taken on 82 nights, showed methane clouds located within a relatively narrow band at around 40 degrees south latitude, with most clustered tightly near 350 degrees west longitude. Both the clouds' sporadic appearance and their specific geographic location led the researchers to conclude that the clouds were not arising from the regular convective overturn of the atmosphere due to its heating by the sun (which produces the cloud cover across the moon's southern pole) but, rather, that some process on the surface was creating the clouds. Exactly how the methane is being injected is still unknown. It may seep out of transient cracks on the surface, or bubble out during the eruption of icy cryovolcanoes.

NSF Award Numbers: 0401559
Award Title: Titan's Methane Meteorological Cycle
PI Name: Henry Roe
0233706
Award Title: Gemini Operations and Maintenance
PI Name: William Smith
Institution Name: AURA/National Optical Astronomy

Local Dwarf Galaxies Provide Clues to Galaxy Evolution

NSF Astronomy and Astrophysics Postdoctoral Fellow Jessica Rosenberg and her collaborators have been studying the dust properties of star-forming dwarf galaxies in the local universe. These galaxies have remained relatively unchanged by stellar evolution; as a result, they may serve as nearby analogs to galaxies in the distant, early universe as well as provide a way to study star formation in relatively pristine environments. Rosenberg and her colleagues have found that, contrary to expectations, some of these star-forming dwarf galaxies contain significant amounts

of dust. The observations also indicate that those galaxies that contain fewer by-products of stellar evolution generally have less dust, which suggests either that these galaxies are very young or that their interstellar environments are hostile to dust. These observations have already proved to be important in trying to understand the properties of distant galaxies. The properties of star-forming dwarf galaxies have been compared with so-called "blue" Lyman break galaxies to show that the latter systems could be low-mass galaxies in the distant universe.
NSF Award Numbers: **0302049**
Award Title: Using Lyman-Alpha Absorbers as Probes of Galaxy Halos
PI Name: Jessica Rosenberg

Undergraduate Student Research Activities

The Most Distant Explosion Ever Seen
Scientists, including two UNC Chapel Hill undergraduate students, using the NASA Swift satellite and several NSF-supported ground-based telescopes have detected the most distant explosion yet, a gamma-ray burst from the edge of the visible Universe. This powerful burst, likely marking the death of a massive star as it collapsed into a black hole, was detected on September 4. It comes from an era soon after stars and galaxies first formed, about 500 million to 1 billion years after the Big Bang. The orbiting Swift satellite detected GRB 050904 and relayed its coordinates to scientists around the world within minutes. Gamma-ray bursts disappear quickly, which is why Swift was designed to autonomously detect and locate bursts and notify the science community via e-mail, Web sites and even cell phone.

Dan Reichart's team at the University of North Carolina, Chapel Hill was one of the first groups to respond to the alert. The team discovered the afterglow with the SOAR telescope (Southern Observatory for Astrophysical Research, an NSF-supported facility) atop Cerro Pachon, Chile. Over the next several nights, the team used SOAR and the Gemini South telescope, also on Cerro Pachon, to calculate a redshift of greater than 6 via a light filtering technique. Reichart also searched for the afterglow with PROMPT (six Panchromatic Robotic Optical Monitoring and Polarimetry Telescopes), located near SOAR. PROMPT didn't see the afterglow, providing further evidence that this was a very distant burst redshifted to an infrared energy below PROMPT's range in visible light. Similarly, Dr. Derek Fox of Caltech searched with the Palomar 60-inch in southern California and saw nothing. The PROMPT and Palomar "non-detections" were key to deciding how to interpret SOAR and Gemini data.

Building upon all this information, a team led by Nobuyuki Kawai of the Tokyo Institute of Technology used the Subaru Observatory on Mauna Kea, Hawaii, to confirm the distance and fine-tune the redshift measurement to 6.29, placing the object at a distance of about 13 billion light-years from earth. This result is described in a paper published in Nature. It is remarkable that the two first authors of the paper (which has more than 30 authors), Josh Haslip and Melissa Nysewander, are undergraduate students at UNC, Chapel Hill.

The PROMPT array has been funded by NSF through awards to Reichart under the CAREER, MRI, and PREST programs. UNC-Chapel Hill is the lead partner in the PROMPT project, with research collaborators at Appalachian State University, Elon University, Fayetteville State University, Guilford Technical Community College, N.C. Agricultural and Technical State University, UNC-Asheville, UNC-Charlotte, UNC-Greensboro, UNC-Pembroke and Western Carolina University, as well as Hampden-Sydney College in Virginia. The telescopes in Chile also will open fields of study for undergraduate and high school education statewide, thanks to a consortium of 11 N.C. colleges and universities and remote operating technology available online and at UNC-Chapel Hill's Morehead Observatory. In addition, 10 percent of the observing time

on the telescope array will be made available to members of the astronomical community at large through the NSF's Program for Research and Education with Small Telescopes.
NSF Award Numbers:
0420868
Award Title: Acquisition of PROMPT: Gamma-Ray Bursts as Probes (MRI Program)
PI Name: Daniel Reichart
Institution Name: University of North Carolina at Chapel Hill
0440793
Award Title: PROMPT Phase II: Gamma-Ray Bursts as Probes (PREST Program)
PI Name: Daniel Reichart
Institution Name: University of North Carolina at Chapel Hill
0449001
Award Title: CAREER: Multi-wavelength Research and Educational Experiences for Graduate, Undergraduate, and High School Students across North Carolina
PI Name: Daniel Reichart
Institution Name: University of North Carolina at Chapel Hill

REU Student Mines for Methanol in our Galaxy
As part of a Research Experiences for Undergraduates (REU) project at the MIT Haystack Observatory in the summer of 2004, Cara Battersby from the University of Massachusetts conducted a search for "masers" (the microwave analog of lasers) in several regions of star formation. She used the Haystack 37-meter telescope, under the guidance of Dr. Preethi Pratap of MIT. Methanol masers have been detected in star forming regions, and are thought to provide a critical link in detecting very early star formation in regions of our Galaxy. The student found that the relative appearance and strength of masers varied depending on whether the masers were associated with known star formation or not, and also that the methanol masers are sometimes found in areas with no apparent star formation. These results were presented by the student at the annual meeting of the American Astronomical Society, and are being prepared for publication in a peer-reviewed journal.
NSF Award Numbers: **0138506**
Award Title: The Haystack Observatory as an REU Site for Astronomy and Atmospheric Science
PI Name: Joseph Salah
Institution Name: Massachusetts Institute of Technology

Flickering Red Giants a Surprising Find
A significant number of red giant stars, whose light output varies on timescales as short as 10 minutes, has been found in the nearby Ursa Minor dwarf galaxy by an astronomer at the National Optical Astronomy Observatory (NOAO), and summer Research Experiences for Undergraduates (REU student Ian Roederer from Indiana University in Bloomington). This surprising variability occurs on a much shorter timescale than previously thought possible for such mature, giant stars. Red giants are used as calibrations for many kinds of observations in astronomy, so it is important to understand errors that the flickering might induce into other research. This discovery was made by comparing individual frames of observations of the Ursa Minor dwarf galaxy, obtained with the Hubble Space Telescope (HST) in 1995 and 1999. The observations were retrieved from the HST archives. The cause of these rapid luminosity variations is not yet known, but they could result from sunspots (i.e., starspots), stellar flares, or a partner star that is tearing mass off of the red giants as part of an interacting binary system. Follow-up observations are being planned with the WIYN 3.5-meter telescope at Kitt Peak National Observatory.
NSF Award Numbers: **0243875**
Award Title: Research Experiences for Undergraduates (REU) Site Program at Kitt Peak

National Observatory
PI Name: Todd Boroson
Institution Name: AURA/National Optical Astronomy Observatories

REU student provides key analysis tools
Undergraduate student Kyle Momenee (Milwaukee School of Engineering) participated in the summer 2005 Research Experiences for Undergraduates (REU) program at the National Solar Observatory (NSO). He analyzed the heat transfer and thermal control of the Advanced Technology Solar Telescope (ATST) primary mirror using a software package know as "MATLAB". The ATST mirror will be made of glass in a thin shape rather like a large contact lens. The thin nature of the glass (about 100 mm) and its poor thermal conductivity result in a system that has a large lag time between controling inputs on the back of the mirror and the sun-side surface temperature, which must be kept within 1-degree C of the surrounding temperature. Kyle designed an automatic control system and tested it on historical data from the proposed ATST site to produce predictions for the future ATST system. His work helped define the utility of decreasing the mirror thickness and the relative tradeoffs of potential types of glass to be used for the mirror. Dr. Nathan Dalrymple was Kyle's advisor.
NSF Award Numbers: **0243912**
Award Title: Research Experiences for Undergraduates (REU) / Research Experiences for Teachers (RET) Site Program at the National Solar Observatory
PI Name: K. Balasubramaniam
Institution Name: AURA/National Optical Astronomy Observatories

Educational Activities at the National Observatories

Teachers Discover Unexpected Disks around Interacting Stars
New Spitzer Space Telescope observations of an unusual class of interacting binary stars detected excess amounts of infrared radiation, suggesting that these odd objects are surrounded by large disks of cool dust. The results were produced by one of six teams of professional astronomers and high school teachers participating in a unique program co-sponsored by the National Optical Astronomy Observatory (NOAO) and NASA's Spitzer Science Center.

The type of variable star system being studied by the team consists of a highly magnetic white dwarf star and a very low mass, cool object similar to a brown dwarf star. The two objects orbit so closely - about the distance from Earth to the Moon - that they make a complete revolution about each other in only 80-90 minutes. The high mass of the white dwarf and the closeness of the companion result in mass exchange between the two stars. The gravitational influence of the white dwarf squeezes the companion star into a teardrop shape, and matter squirts from its pointed end toward the white dwarf. This material eventually falls onto the white dwarf, causing tremendous heating of its atmosphere and the emission of a large amount of energy from X-rays to the far infrared. To their surprise, the team found excess infrared emission around all four systems that they studied. The team's current best model for its origin is that a large, cool dust disk with a temperature of about 800-1,200 Kelvin surrounds the orbiting stars.

The research team also included Carolyn Brinkworth of the Spitzer Science Center, and physics teachers Howard Chun from Cranston High School in East Cranston, Rhode Island; Beth Thomas of Great Falls Public Schools in Great Falls, Montana; and, Linda Stefaniak of Allentown High School, Allentown, New Jersey. Chun, Thomas and Stefaniak are graduates of NOAO's Teacher Leaders in Research Based Science Education (TLRBSE), a teacher professional development program funded by the National Science Foundation. Twelve TLRBSE teachers were

competitively selected in the fall of 2004 to work in six teams that were awarded three hours of Directors discretionary observing time with Spitzer
NSF Award Numbers: **0244680**
Award Title: Cooperative Agreement for the Management, Operation and the Maintenance of the National Optical Astronomy Observatories (NOAO)
PI Name: William Smith
Institution Name: AURA/National Optical Astronomy Observatories

Hilo Students Observe Comet Break-up with Gemini
A new educational outreach program at the NSF's Gemini Observatory is pairing local students with astronomers to do cutting-edge astronomy with an 8-meter telescope. The first observations from this program were executed early on the morning of May 13 2006 when three Hilo High School students observed the disintegrating comet 73P/Schwassmann-Wachmann 3, and observed the comet in both visible and infrared light. The observations show the classic head and tail of the comet as well as multiple pieces of the comet's body breaking off.

Hilo High School student Nicholas Higa and classmates Keane Nakatsu and Ken Oyadomari began working with Gemini astronomer Scott Fisher in March, 2006 when it was first announced that Gemini would be offering this unique opportunity for local students. "We looked at a whole bunch of possible things to observe, including exploding stars but once we saw that this comet was behaving so strangely it was obvious what we should observe," said Higa.

"We have already done a preliminary reduction of this data," said Dr. Fisher. "Now it is up to the students to work with us to do the final, more detailed reduction of the data and determine exactly how the nucleus is breaking apart. We will also find out how warm the dust in the tail is and we may even be able to tell how much dust is being released in the disintegration." The observations have already been sent to the International Astronomical Union Bulletin service and will likely be included in work by other astronomers studying the comet around the world.
NSF Award Numbers:
0233706, 052580
Award Title: Gemini Operations and Maintenance
PI Name: William Smith
Institution Name: AURA/National Optical Astronomy Observatories

Citizen-scientists measure light pollution
More than 18,000 citizen-scientists in 96 countries submitted observations of the darkness of their local night skies during the 10-day GLOBE at Night event. The GLOBE at Night program is a collaboration of five international institutions that includes the National Optical Astronomy Observatory. Conducted during March 22-31, 2006, the GLOBE at Night program was designed to help students, families, and the general public observe and record how the constellation Orion looked from different locations, as a means of measuring the brightness of the sky at a variety of urban and rural sites. The program was designed to aid teaching about the impact of artificial lighting on local environments, and the ongoing loss of a dark night sky as a natural resource for much of the worlds population. Observers reported their results online by comparing the number of stars they could see in Orion with a set of template images on the program's Web site, which showed the number of stars in the constellation for a range of visibilities from bright skies to very dark. Scientific analysis of the GLOBE at Night data set has begun, including cooperation with experts in analysis of worldwide satellite data related to artificial lighting.

Participation was open to anyone - anywhere in the world - who could get outside and look

skyward in the early evening. The GLOBE at Night Web site received data from all 50 U.S. states and from every continent except Antarctica (where the constellation used for the project was not visible!) At least 399 of the participants were under age 12, with another 949 between the ages of 12-14 years old.
NSF Award Numbers: **0244680**
Award Title: Cooperative Agreement for the Management, Operation and the Maintenance of the National Optical Astronomy Observatories (NOAO)
PI Name: William Smith
Institution Name: AURA/National Optical Astronomy Observatories

Outreach by AST PI's

Jamieson Telescope Will Light Infrared Universe for Amateur Astronomers
University of Arizona (UA) astronomer Laird Close provided a new telescope dome and modern computerized infrared camera controller as part of his NSF Faculty Early Career Development Award. Given the NSF's heavy investment in professional infrared astronomy, Close said, "It will be a great asset to U.S. astronomical outreach and education efforts to have at least one dedicated 'research class' infrared telescope fully devoted to outreach." The infrared telescope is unique because it will be used primarily by students and those in UA Astronomy Camps. The UA Astronomy Camps are popular with youngsters and adults who include Girl Scout leaders from around the nation. They will study the universe using a truly professional 'research class' infrared telescope available to them for the first time on Mount Lemmon in the Santa Catalina Mountains about 45 miles north of the UA campus in Tucson, Ariz. Close's NSF award supports his research to directly detect planets around young, nearby stars.
NSF Award Numbers: **0349360**
Award Title: CAREER: Direct Detection of Extrasolar Planets With Very High Contrast Adaptive Optics Imaging
PI Name: Laird Close
Institution Name: University of Arizona

B3: Outcomes in Research Infrastructure.

As discussed in the COV report, a substantial fraction of the Divisions funds (55%) are directed at major observatories and facilities used by the astronomical community. The Division provides excellent stewardship of these facilities, taking care to ensure the research infrastructure is robust and at the cutting edge. Below we give specific examples of- and results from- these research infrastructure investments.

National Optical Astronomy Observatory

Distant Young Galaxy Hints at Gradual End to the Dark Ages
Astronomers have peered into the fog of the early universe and discovered a young and extremely distant galaxy at a time when the Universe was only about six percent of its present age. When compared with other recent findings about the "dark ages" of the early universe, this discovery suggests that this murky era could have lasted the better part of a billion years.

The newly detected galaxy, designated LALA J142442.24+353400.2, was discovered in the constellation Bootes using data from the Large Area Lyman Alpha (LALA) survey, led by James Rhoads and Sangeeta Malhotra of the Space Telescope Science Institute, Baltimore, MD. This

survey takes advantage of observations of the same portions of the northern and southern skies as the NOAO Deep Wide-Field Survey, led by Buell Jannuzi and Arjun Dey of the National Optical Astronomy Observatory. Both surveys have been conducted using the NSF's 4-meter Mayall telescope at the Kitt Peak National Observatory and 4-meter Blanco telescope at the Cerro Tololo Inter-American Observatory. The nature of the newly discovered galaxy was confirmed using a spectrum obtained at the international Gemini North 8-meter telescope on Mauna Kea, Hawaii.

These "dark ages" began about a million years after the Big Bang, when most ordinary matter had condensed into a pervasive 'fog' of neutral hydrogen. They ended when the first stars formed in the earliest galaxies and ionized the gas. However, much remains mysterious about this transitional period in the cosmic history - when it took place, how it occurred, where and when the first stars were formed, and what became of them. The new observations suggest that the transition from the dark ages to the modern Universe was a gradual and complex process.
NSF Award Numbers: **0132798, 0244680**
Award Title: AURA Management and Operations of the National Optical Astronomy Observatory and the National Solar Observatory
PI Name: William Smith
Institution Name: AURA/National Optical Astronomy Observatories

Cleaning Out an Entire Galaxy
New observations from the WIYN 3.5-meter telescope on Kitt Peak show striking visual evidence for a galaxy being stripped bare of its star-forming material by its violent ongoing encounter with the hot gas in the center of the galaxy cluster of which it is a member. This extremely disruptive process is believed to be a major influence on the evolution of galaxies and their star-forming ability over time, but direct observational evidence has been more circumstantial than incontrovertible. A new three-color composite image of spiral galaxy NGC 4402, taken as the galaxy falls into the Virgo galaxy cluster, shows several key lines of evidence of an ongoing interaction.

The galaxy, denoted NGC 4402, is located more than 50 million light years from Earth, in the midst of the relatively nearby Virgo cluster. As the galaxy moves toward the center of the cluster (located out of the image toward the bottom left), it experiences a "wind" from the hot cluster gas, which can reach temperatures of millions of degrees. This hot wind strips out the much cooler gas and dust in the galaxy. This is important because the gas is raw material for new stars, and once this gas is stripped, the galaxy can no longer form new stars and becomes "dead" in a sense.

This imaging data was obtained with the help of the WIYN Tip-Tilt module, an adaptive optics device that uses a movable mirror to compensate for the jittery motion of the incoming image caused by variable atmospheric conditions and telescope vibrations. The result of this compensation is an improvement of the sharpness of the image.
NSF Award Numbers: **0132798, 0244680**
Award Title: AURA Management and Operations of the National Optical Astronomy Observatory and the National Solar Observatory
PI Name: William Smith
Institution Name: AURA/National Optical Astronomy Observatories

Gemini Observatory

Gemini Obtains First High-Resolution Image of Dust Around SN1987A

Infrared observations of Supernova 1987A made as part of the ‘checkout’ of the new Thermal-Region Camera Spectrograph (T-ReCS) instrument on Gemini South have revealed dust emissions at a wavelength of 10 microns, corresponding to a temperature of only 150 degrees Kelvin. The T-ReCS data and images demonstrate the tremendous sensitivity of the instrument when combined with the infrared optimized Gemini South Telescope. The detection of the ejecta is among the faintest radiation ever detected from the ground at this wavelength regime. The emission is coming from a cool dust ring that is surprisingly luminous. It co-exists with hot gas components left over from the relic equatorial ring. This gas was lit up by the flash of the explosion, and now that the supernova has faded, astronomers can clearly see a complex structure around the explosion site, shaped by relic wind from the star. The "circumstellar envelope" or bipolar nebula is now about three light-years across and is expanding at 10 kilometers per second at the equator and 25 kilometers per second at the poles, moving into a diffuse medium that has accumulated into a dense 13-light-year-wide shell.
NSF Award Numbers: **0233706**
Award Title: Gemini Operations and Maintenance
PI Name: William Smith
Institution Name: AURA/National Optical Astronomy Observatories

Gemini Uncovers 'Lost City' of Stars
Like archaeologists unearthing a 'lost city,' an international team of Australian and U.S. astronomers using the Gemini South telescope have revealed that the galaxy NGC 300 has a large, faint extended disk made of ancient stars, enlarging the known diameter of the galaxy by a factor of two or more. The finding also implies that our own Milky Way Galaxy could be much larger than currently thought. Images from Gemini went more than ten times deeper than any previous images of this galaxy and measured out to double the previously known radius of the disk. Surprisingly, the team found no evidence for truncating, or an abrupt ‘cutting-off' of the star population as seen in many galaxies further from the central regions. It is difficult to understand how such an extensive stellar disk that falls off so smoothly and gradually could have formed.
NSF Award Numbers: **0233706**
Award Title: Gemini Operations and Maintenance
PI Name: William Smith
Institution Name: AURA/National Optical Astronomy

Adaptive Optics - Straightening Bent Starlight
Two advances in adaptive optics at the Gemini North telescope have opened up new capabilities for imaging. Adaptive optics (AO) technology uses deformable mirrors to remove distortions to starlight caused by turbulence in Earth's atmosphere. Using this technology, astronomers can improve near-infrared images to rival the resolution of space-based observations. Technologies such as laser guide stars and 3-dimensional turbulence mapping (multi-conjugate AO) are making the technique, and our instruments, even more powerful.

For example, the recent addition of a new field lens in the Altair adaptive optics system that corrects for turbulence close to the ground has resulted in a significant improvement in near-infrared imaging capabilities at Gemini North. A laser guide star system installed on Gemini North in late 2005 expands the reach of the telescope to much fainter observational targets. By creating an artificial star on the sky, the laser provides a bright source that can be monitored to remove the atmospheric turbulence, even in parts of the night sky where no natural bright stars are available.
NSF Award Numbers: **0233706**
Award Title: Gemini Operations and Maintenance

PI Name: William Smith
Institution Name: AURA/National Optical Astronomy Observatories

National Solar Observatory

Adaptive optics produces ultrasharp images of sunspot
Advanced technologies now available at the NSF's Dunn Solar Telescope at Sunspot, NM, are revealing striking details inside sunspots and hint at features remaining to be discovered in solar activity. This image, spanning an area on the Sun's surface more than three times wider than Earth, was made possible by the Dunn's recently completed advanced adaptive optics image correction system and a new high-resolution electronic camera.

The dark cores of penumbral fibrils and bright penumbral grains are seen as well in the sunspot penumbra (the fluted structures radiating outward from the spot). These features hold the key to understanding the magnetic structure of sunspots and can only be seen in ultra high-resolution images such as this one. Magnetism in solar activity is the "dark energy problem" being tackled in solar physics today.

Normally such features are beyond the grasp of ground-based solar telescopes because of blurring by Earth's turbulent atmosphere. The Dunn's new adaptive optics system compensates for much of that blurring by reshaping a deformable mirror 130 times a second to match changes in the atmosphere and refocus the incoming light. This allows the Dunn to operate at its diffraction limit (theoretical best) of 0.14 arc-second resolution, rather than the 1.0 to 0.5 arc-second resolution normally allowed by Earth's atmosphere.
NSF Award Numbers: **0132798, 0244679**
Award Title: Support of the Management, Operations, and the Maintenance of the National Solar Observatory (NSO)
PI Name: William Smith
Institution Name: AURA/National Optical Astronomy Observatories

Virtual Solar Observatory now available for one-stop data shopping
The first working version of a "one-stop shopping" service for solar data is now on line, giving scientists a much easier way to search for data on specific solar phenomena and even to confirm the results of earlier research. The Virtual Solar Observatory or VSO makes it possible to access data from multiple sources, using one web service enabled by a collaboration between NASA and NSF's National Solar Observatory.

At the VSO's core are decades of data and images from the National Solar Observatory Digital Library (ground-based solar telescopes) and NASA's Solar Data Archive Center (spacecraft observations), which is being transformed into the VSO. Most of the data cover the entire solar disk over long periods of time, but the collection may grow to include more high-resolution observations that focus on small parts of the Sun such as sunspots and other regions of solar activity.

The VSO is open to anyone and anyone can make data sources available. It is analogous in intent to nighttime astronomy's National Virtual Observatory. Both will make huge volumes of data available to researchers, educators and students at all levels, free of charge.
NSF Award Numbers: **0132798, 0244679**
Award Title: AURA Management and Operations of the National Optical Astronomy Observatory and the National Solar Observatory

PI Name: William Smith
Institution Name: AURA/National Optical Astronomy Observatories

NAIC Arecibo Observatory

A Galaxy with Atomic Hydrogen Gas, Dark Matter, and No Stars?
Most disk galaxies in the cosmos such as our Milky Way galaxy have a total mass of approximately 100 billion times the mass of the sun. The bulk of this mass is in stars and the mysterious quantity referred to as 'dark matter' because it interacts gravitationally with stars and gas, but does not emit light at any wavelength. Less than 10% of the mass of the Milky Way is interstellar gas. Observations at the NAIC Arecibo Observatory demonstrate that not all disk galaxies fit this description.

The new Arecibo L-band Feed Array, ALFA, is giving astronomers a view of disk galaxies in the universe near the Milky Way. ALFA is an innovative multi-beam imaging receiver mounted on the 305-m Arecibo radio/radar telescope that facilitates large-area imaging of the sky. Among the large imaging projects being undertaken by ALFA are two programs studying the gas content in disk galaxies. Both surveys have made the surprising discovery that there are galaxies beyond the Milky Way that consist of atomic hydrogen gas and dark matter but no stars. These dark galaxies were undiscovered heretofore because, having no stars, they emit no visible or ultraviolet light. The mass of hydrogen gas detected in the cloud is much less than the total mass of the cloud deduced from its kinematics. The 'missing mass' must be dark matter because there are no stars to provide the gravitational 'glue' needed to hold the gas cloud together.
NSF Award Numbers: **9809484**
Award Title: Operation of the National Astronomy and Ionosphere Center, 1999-2004
PI Name: Robert Brown
Institution Name: Cornell University

Exploring the Hydrogen Gas in the Milky Way
The Milky Way is filled with atomic hydrogen gas, the most abundant element in the universe. The distribution and structure of that gas provides astronomers with a wealth of information regarding the energy input to the galaxy, the structure of the spiral arms in the Milky Way, and the role of magnetic fields in the Galaxy. In 2004 mapping the structure of the hydrogen gas became easier with the advent of a new imaging receiver on the 305-m Arecibo radio telescope. The new 7-beam receiver, the Arecibo L-Band Feed Array (ALFA), detects radio emission from hydrogen at seven places in the sky simultaneously allowing astronomers to build up images of the interstellar gas quickly and in great detail. One of the first ALFA maps of the hydrogen in the Milky Way is shown below. Ultimately, thousands of maps such as this spread across the sky will greatly improve our understanding of our Galaxy.
NSF Award Numbers: **9809484, 0431904**
Award Title: Operation of the National Astronomy and Ionosphere Center
PI Name: Robert Brown
Institution Name: Cornell University

NRAO Green Bank Telesscope
No Ice on the Moon?
Using the highest resolution radar-signal images ever made of the moon - images from the NSF's Arecibo Telescope in Arecibo, P.R., and Robert C. Byrd Telescope in Green Bank, W.Va. - planetary astronomers have found no evidence for ice in craters at the lunar south pole. Cornell University, Smithsonian Institution and Australian scientists report the findings in the 19 October 2006 issue of Nature. "These new results do not preclude ice being present as small grains in the

lunar soil based on the Lunar Prospector's discovery of enhanced hydrogen concentrations at the lunar poles," said Donald Campbell, Cornell professor of astronomy and a principal investigator. "There is always the possibility that concentrated deposits exist in a few of the shadowed locations not visible to radars on Earth, but any current planning for landers or bases at the lunar poles should not count on this."

NSF Award Numbers: **0223851, 0226933**
Award Title: Cooperative Agreement for the Management, Operation of the National Radio Astronomy Observatory and Support of Other Scientific Activities
PI Name: Ethan Schreier
Institution Name: Associated Universities Inc/National Radio Astronomy Observatory
0431904
Award Title: Management and Operation of the National Astronomy and Ionosphere Center (NAIC), Arecibo Observatory (AO) 2005-2010
PI Name: Robert Brown
Institution Name: Cornell University

Fastest-Spinning Neutron Star ever found
Astronomers using the NSF's Robert C. Byrd Green Bank Telescope have discovered the fastest-spinning neutron star ever found, a 20-mile-diameter superdense pulsar whirling faster than the blades of a kitchen blender. Their work yields important new information about the nature of one of the most exotic forms of matter known in the Universe.

"We believe that the matter in neutron stars is denser than an atomic nucleus, but it is unclear by how much. Our observations of such a rapidly rotating star set a hard upper limit on its size, and hence on how dense the star can be," said Jason Hessels, a graduate student at McGill University in Montreal. "Neutron stars are incredible laboratories for learning about the physics of the fundamental particles of nature, and this pulsar has given us an important new limit," explained Scott Ransom, an astronomer at NRAO and one of Hessels' collaborators on this work. The scientists discovered the pulsar, named PSR J1748-2446ad, in a globular cluster of stars called Terzan 5. The newly discovered pulsar is spinning 716 times per second. The object's fast rotation speed means that it cannot be any larger than about 20 miles across.
NSF Award Numbers: **0223851, 0226933**
Award Title: Cooperative Agreement for the Management, Operation of the National Radio Astronomy Observatory and Support of Other Scientific Activities
PI Name: Ethan Schreier
Institution Name: Associated Universities Inc/National Radio Astronomy Observatory

NRAO Very Long Baseline Array

Blazar Jets Push Closer to Cosmic Speed Limit
Astronomers using the NSF's Very Long Baseline Array (VLBA) have discovered jets of plasma blasted from the cores of distant galaxies at speeds within one-tenth of one percent of the speed of light, placing these plasma jets among the fastest objects yet seen in the Universe. "This tells us that the physical processes at the cores of these galaxies, called blazars, are extremely energetic and are capable of propelling matter very close to the absolute cosmic speed limit," said Glenn Piner of Whittier College in Whittier, California. Piner, who worked on the project with student Dipesh Bhattari, also of Whittier College, Philip Edwards of the Japan Aerospace Exploration Agency, and Dayton Jones of NASA's Jet Propulsion Laboratory. According to Einstein's Special Theory of Relativity, no object with mass can be accelerated to the speed of light. To get even close to the speed of light requires enormous amounts of energy. "For example, to accelerate a

bowling ball to the speed newly measured in these blazars would require all the energy produced in the world for an entire week," Piner said, "and the blobs of plasma in these jets are at least as massive as a large planet".
NSF Award Numbers:
0223851, 0226933
Award Title: NRAO Management, Operations and Maintenance
PI Name: Ethan Schreier
Institution Name: Associated Universities Inc/National Radio Astronomy Observatory

University Radio Observatory: CARMA

Atoms and Molecules in an External Galaxy
The molecule carbon monoxide (CO) is a trace constituent in clouds of molecular hydrogen that have condensed from the more diffuse atomic gas, and the work described here demonstrates this connection between atoms and molecules in space. Molecular clouds are essential in the lifecycles of stars and galaxies in that they are the nurseries where new stars are formed. The accompanying image is a mosaic of 48 pointing centers obtained over a few nights with CARMA, the Combined Array for Research in Millimeter Astronomy. The region surveyed lies in the nearby grand design spiral galaxy M33 and covers an area on the sky of a 6 x 4 arc minutes or 1.5 x 1 kiloparsec at the distance to the galaxy. The angular resolution is 6 arcsececonds, which corresponds to a linear resolution of 25 parsecs. Contours show the intensity of the radio signals emitted by molecules of carbon monoxide, overlaid on a gray-scale image of the emission from atomic hydrogen. Note how the molecular clouds appear only in regions of strong hydrogen emission, implying that the molecular gas has formed from the atomic gas around it. The smallest molecular clouds in this image have masses approximately 25,000 times the mass of the Sun, slightly higher than the mass of the nearby Taurus star forming region.
NSF Award Numbers: **0540567**
Award Title: Collaborative Research: Astronomy with CARMA - Raising our Sites
PI Name: Leo Blitz
Institution Name: University of California-Berkeley

University Radio Observatory, CSO

Star Forming Galaxies in the Early Universe
A ultrasensitive map of a region of sky taken through the Lockman Hole, a clear window out of our galaxy with very little confusing dust emission, made with the radio camera Bolocam on the Caltech Submillimeter Observatory. Bolocam is a 144-pixel array of "spider web" bolometers (heat sensing elements) for detection and mapping of radio emission at a wavelength of about 1 mm. The map represents a blind search for submillimeter galaxies, which are dusty galaxies in the distant universe forming stars at a prodigious rate. The light reaching us from these galaxies has taken most of the age of the Universe to reach us and it is possible that these galaxies are the progenitors of modern-day massive galaxies. The Lockman Hole was chosen because there is relatively little dust in our own Milky Way along the line of sight to the Lockman Hole that could confuse the observations. The submillimeter galaxy candidates appear as bright spots and are circled to highlight them.
NSF Award Numbers: **0229008**
Award Title: Astronomical Studies with the Caltech Submillimeter Observatory
PI Name: Thomas Phillips
Institution Name: California Institute of Technology

Cyberinfrastructure

Computing dark energy
The recent surprising result that the expansion of the Universe appears to be accelerating has sparked renewed interest in Einstein's cosmological constant, and in the possibility of exotica from high energy physics severally dubbed "dark energy". Measuring the parameters of dark energy, including that set which would confirm that Einstein was right about his constant, has rapidly become a major activity.

The light and the matter, both bright and dark, in the Universe, are connected in many ways, both obvious and subtle. To this mix must now be added dark energy. Small effects require large samples: fortunately, we have surveys both of galaxies and of the cosmic microwave background, the relic light. Unfortunately, the calculation of their relationship required massive amounts of time on the largest computational facilities.

New fast algorithms developed with support from NSF's Information Technology Research (ITR) program have enabled application of NSF-sponsored computer resources to this new generation of large scale astrophysics surveys. Calculation of one subtle signature, known as the Integrated Sachs-Wolfe effect (ISW), has provided another independent confirmation of our current characterization of the dark energy. Perhaps more importantly in the long run, these algorithms are a valuable new way to investigate correlations between any massive data sets, and to leverage the NSF investments in the TeraGrid and other cyberinfrastructure initiatives.
NSF Award Numbers:
0121671
Award Title: ITR/IM: Statistical Data Mining for Cosmology
PI Name: Andrew Moore
Institution Name: Carnegie-Mellon University
0312498
Award Title: ITR: Searching for Correlations in a High Dimensional Space
PI Name: Andrew Connolly
Institution Name: University of Pittsburgh

The National Virtual Observatory sees First Light
Breakthroughs in telescope, detector, and computer technology allow astronomical surveys to produce terabytes of images and catalogs. These datasets cover the sky in different wavebands, from gamma- and X-rays, through optical and infrared to radio wavelengths. Funded under the Information Technology Research Program, the National Virtual Observatory project has worked for several years to make astronomical data easier to use by federating astronomical databases, creating and adopting standards, and developing tools for analysis.

In January 2005, at the meeting of the American Astronomical Society, the NVO released a first set of software tools and applications that make it easy to locate, retrieve, and analyze data from archives and catalogs worldwide. These tools provided 'first light' for the NVO, turning it from a concept to a set of practical tools for astronomers, teachers, students and the public. These tools are based upon international standards developed in collaboration with the International Virtual Observatory Alliance. All are available at http://us-vo.org/apps/.
NSF Award Numbers: 0122449
Award Title: ITR/IM: Building the Framework of the National Virtual Observatory
PI Name: Alexander Szalay
Institution Name: Johns Hopkins University

PART C. OTHER TOPICS

C.1. Please comment on any program areas in need of improvement or gaps (if any) within program areas.

There were no perceived gaps in the scientific programs.

C.2. Please provide comments as appropriate on the program's performance in meeting program-specific goals and objectives that are not covered by the above questions.

C.3. Please identify agency-wide issues that should be addressed by NSF to help improve the program's performance.

A problem that surfaced frequently throughout the three day COV meeting was the need for additional travel funds to support the oversight and management activities of the Division and its Program Officers. This need is acute, and has been mentioned in previous COV reports with only modest effect.

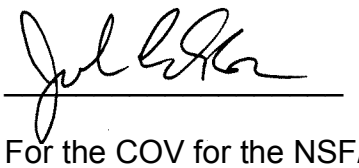
The COV is concerned that current processes and practices concerning the Foundation's Major Research Equipment and Facilities Construction (MREFC) account are becoming a significant impediment to timely and cost-effective completion of certain high priority projects. The largest projects will almost surely be too expensive for any one stakeholder, be it the Foundation or any community entity, to finance when both capital and operating costs are included. The COV encourages NSF to investigate possible modifications to the MREFC procedures that would provide sufficient flexibility to allow NSF to work with private and institutional investments in funding the design, construction and operations of large facilities.

The COV applauds the Division's efforts in Electromagnetic Spectrum Management (ESM). The COV recommends NSF consider moving responsibility for Electromagnetic Spectrum Management (ESM) to the MPS Directorate office, if not to the NSF Director's office, to increase the visibility of ESM within the Foundation and also to stress the Foundation's commitment to spectrum management to the global community.

C.4. Please provide comments on any other issues the COV feels are relevant.

C.5. NSF would appreciate your comments on how to improve the COV review process, format and report template.

SIGNATURE BLOCK:



For the COV for the NSF/MPS Division of Astronomical Sciences
John Carlstrom and Bruce Margon, Co-Chairs

Commonly Used Acronyms

AAAC – Astronomy and Astrophysics Advisory Committee
AAG – Astronomy and Astrophysics Research Grants
AAPF – Astronomy & Astrophysics Postdoctoral Fellowship Program
ACT – Approaches to Combat Terrorism program (MPS-wide program)
ACT – Atacama Cosmology Telescope
ADVANCE - Increasing the Participation and Advancement of Women in Academic Science and Engineering Careers (NSF-wide program)
AFOSR/AEOS – Air Force Office of Scientific Research / Advanced Electro-Optical System
ALMA – Atacama Large Millimeter Array
AODP – Adaptive Optics Development Program
AST – Division of Astronomical Sciences, NSF
ATA – Allen Telescope Array (in URO program)
ATI – Advanced Technologies and Instrumentation
ATM – Division of Atmospheric Sciences in the Geosciences Directorate, NSF
ATST – Advanced Technology Solar Telescope
AUI – Associated Universities, Inc
AURA – Association of Universities for Research in Astronomy, Inc
BFA – NSF's Office of Budget, Finance and Award Management
BIMA – Berkeley – Illinois – Maryland Array (in URO program)
CAA – NRC Committee on Astronomy and Astrophysics
CAREER – Faculty Early Career Development (NSF-wide program)
CARMA – Combined Array for Research in Millimeter Astronomy (in URO program)
CI – CyberInfrastructure
CISE – Computer and Information Sciences and Engineering Directorate, NSF
CMB – Cosmic Microwave Background
COV – Committee of Visitors
CSA – Cooperative Support Agreement (in a Cooperative Agreement)
CSO – Caltech Submillimeter Observatory (in URO program)
CTIO – Cerro Tololo InterAmerican Observatory
DACS – Division of Acquisition and Cooperative Support, NSF
DGA – NSF's Division of Grants and Agreements
DOE – Department of Energy
EHR – Education and Human Resources Directorate, NSF
EPSCoR – Experimental Program to Stimulate Competitive Research
ESM – Electromagnetic Spectrum Management
ESP – Education and Special Programs
EXC – Extragalactic Astronomy and Cosmology
GAL – Galactic Astronomy
GBT – Green Bank Telescope
GEO – Geosciences Directorate, NSF
GMT – Giant Magellan Telescope
GONG – Global Oscillation Network
GPRA – Government Performance and Results Act
GSMT – Giant Segmented Mirror Telescope
IGERT – Integrated Graduate Education and Research Traineeships (NSF-wide program)
IPA – Intergovernmental Personnel Act
ITR – Information Technology Research (NSF-wide program)
JAO – Joint ALMA Office
KPNO – Kitt Peak National Observatory

LFP, LFPO – NSF's Large Facilities Project Office
LMT – Large Millimeter Telescope
LST – Large Survey Telescope
LSST – Large Synoptic Survey Telescope
MPS – Directorate of Mathematical and Physical Sciences, NSF
MPS-DRF – MPS International Distinguished Postdoctoral Research Fellowships
MPS-IPSE – MPS Internships in Public Science Education
MREFC – Major Research Equipment and Facilities Construction (account)
MRI – Major Research Instrumentation (NSF-wide program)
MSPA – Math Sciences Priority Area (NSF-wide program)
MWA – Murchison (Mileura) Widefield Array
NAIC – National Astronomy and Ionosphere Center
NOAO – National Optical Astronomy Observatory
NRAO – National Radio Astronomy Observatory
NSB – National Science Board
NSO – National Solar Observatory
NVO – National Virtual Observatory
OGC – NSF's Office of General Council
OISE – Office of International Science and Engineering, NSF
OLPA – Office of Legislative and Public Affairs, NSF
OMA – Office of Multidisciplinary Activities (in MPS)
OPP – Office of Polar Programs, NSF
OVRO – Owens Valley Radio Observatory
PA – Particle Astrophysics
PAT – Project Advisory Team
PECASE – Presidential Early Career Awards for Scientists and Engineers
PHY – Division of Physics, MPS
PLA – Planetary Astronomy
POU – Physics of the Universe
PREST – Program for Research and Education with Small Telescopes
R&RA – Research and Related Activities Account
RET – Research Experiences for Teachers
REU – Research Experiences for Undergraduates
ROA – Research Opportunity Award
RUI – Research in Undergraduate Institutions
SAA – Stellar Astronomy and Astrophysics
SDSS – Sloan Digital Sky Survey
SGER – Small Grant for Exploratory Research
SKA – Square Kilometer Array
SOAR – Southern Astrophysical Research Telescope
SPO – Scientific Program Order (in a Cooperative Agreement)
STC – Science and Technology Center (NSF program)
TMT – Thirty Meter Telescope Project
TSIP – Telescope Systems Instrumentation Program
URO – University Radio Observatory
VLA – Very Large Array
VLBA – Very Long Baseline Array
VSEE – Visiting Scientist, Engineer, and Educator program
WIYN – Wisconsin-Indiana-Yale-NOAO Telescope