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UNIVERSITY OF CALIFORNIA OBSERVATORIES/LICK OBSERVATORY
DEPARTMENT OF ASTRONOMY AND ASTROPHYSICS

March 14, 2005

Dr. Arden L. Bement, Jr., Director
National Science Foundation
4201 Wilson Blvd., Suite 1205
Arlington, VA 22230

Mr. Frederick D. Gregory, Acting Administrator
Office of the Administrator
NASA Headquarters
Washington, DC 20546-0001

The Honorable Sherwood L. Boehlert, Chairman
Committee on Science
House of Representatives
Washington, DC 20515

The Honorable Ted Stevens, Chairman
Committee on Commerce, Science and Transportation
United States Senate
Washington, DC 20510

The Honorable Mike Enzi, Chairman
Committee on Health, Education, Labor and Pensions
United States Senate
Washington, DC 20510

Dear Dr. Bement, Mr. Gregory, Chairman Boehlert, Chairman Stevens, and Chairman Enzi:

I am pleased to transmit to you the annual report of the Astronomy and Astrophysics Advisory Committee for 2004–5.

The Astronomy and Astrophysics Advisory Committee was established under the National Science Foundation Authorization Act of 2002 Public Law 107-368 to:

(1) assess, and make recommendations regarding, the coordination of astronomy and astrophysics programs of the Foundation and the National Aeronautics and Space Administration;

(2) assess, and make recommendations regarding, the status of the activities of the Foundation and the National Aeronautics and Space Administration as they relate to the recommendations contained in the National Research Council's 2001 report entitled Astronomy and Astrophysics in the New Millennium, and the recommendations contained in subsequent National Research Council reports of a similar nature;

(3) not later than March 15 of each year, transmit a report to the Director, the Administrator of the National Aeronautics and Space Administration, and the Committee on Science of the House of Representatives, the Committee on Commerce, Science, and Transportation of the Senate, and the Committee on Health, Education, Labor, and Pensions of the Senate on the Advisory Committee's findings and recommendations under paragraphs (1) and (2).

The attached document is the second such report. The executive summary is followed by the report, with recommendations for NSF, NASA and DOE regarding their support of the nation's astronomy and astrophysics research enterprise, along with detailed recommendations concerning specific programs.

I will be glad to provide you with a personal briefing if you so desire.

Sincerely yours, on behalf of the Committee,

Garth D. Illingworth
Chair, Astronomy and Astrophysics Advisory Committee

cc: Representative Bart Gordon, Ranking Member, Committee on Science, House of Representatives
Senator Daniel K. Inouye, Ranking Member, Committee on Commerce, Science and Transportation, United States Senate
Senator Edward M. Kennedy, Ranking Member, Committee on Health, Education, Labor and Pensions, United States Senate
Senator Richard Shelby, Chairman, Subcommittee on Commerce, Justice and Science, Committee on Appropriations, United States Senate

Senator Barbara Mikulski, Ranking Member, Subcommittee on Commerce, Justice and Science, Committee on Appropriations, United States Senate
Representative Frank R. Wolf, Chairman, Subcommittee on Science, State, Justice and Commerce, Committee on Appropriations, House of Representatives
Representative Alan B. Mollohan, Ranking Member, Subcommittee on Science, State, Justice and Commerce, Committee on Appropriations, House of Representatives
Senator Kay Bailey Hutchison, Chair, Subcommittee on Science and Space, Committee on Commerce, Science and Transportation, United States Senate
Senator Bill Nelson, Ranking Member, Subcommittee on Science and Space, Committee on Commerce, Science and Transportation, United States Senate
Representative Bob Inglis, Chairman, Subcommittee on Research, Committee on Science, House of Representatives
Representative Darlene Hooley, Ranking Member, Subcommittee on Research, Committee on Science, House of Representatives
Representative Ken Calvert, Chairman, Subcommittee on Space and Aeronautics, Committee on Science, House of Representatives
Representative Mark Udall, Ranking Member, Subcommittee on Space and Aeronautics, Committee on Science, House of Representatives
Dr. John H. Marburger, III, Director, Office of Science and Technology Policy, Executive Office of the President
Dr. J. Patrick Looney, Assistant Director, Physical Sciences and Engineering, Office of Science and Technology Policy, Executive Office of the President
Mr. David Radzanowski, Science and Space Branch Chief, The Office of Management and Budget
Mr. David Trinkle, Program Examiner, NSF, The Office of Management and Budget
Ms. Amy Kaminski, Program Examiner, NASA, The Office of Management and Budget
Mr. Rick Mertens, Energy Branch Chief, The Office of Management and Budget
Dr. Joel Parriott, Program Examiner, DOE, The Office of Management and Budget
Dr. Michael S. Turner, Assistant Director, Directorate for Mathematical and Physical Sciences, National Science Foundation
Dr. G. Wayne Van Citters, Division Director, Division of Astronomical Sciences, National Science Foundation
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Dr. Dana E. Lehr, Assistant Program Director, Division of Astronomical Sciences, National Science Foundation
Dr. Michael D. Griffin, Head, The Johns Hopkins University Applied Space Laboratory
Mr. Alphonso Diaz, Associate Administrator for Science, Science Mission Directorate, National Aeronautics and Space Administration
Dr. Anne Kinney, Director, Universe Division, Science Mission Directorate, National Aeronautics and Space Administration
Dr. Paul Hertz, Assistant Associate Administrator for Science, Science Mission Directorate, National Aeronautics and Space Administration

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Dr. Robin Staffin, Associate Director, Office of High Energy Physics, U.S. Department of Energy
Dr. Kathleen Turner, Program Manager, Office of High Energy Physics, U.S. Department of Energy
Mr. David Goldston, Chief of Staff, Committee on Science, House of Representatives
Dr. Chuck Atkins, Minority Staff Director, Committee on Science, House of Representatives

ANNUAL REPORT

ASTRONOMY AND ASTROPHYSICS ADVISORY COMMITTEE

MARCH 16, 2004 - MARCH 15, 2005

EXECUTIVE SUMMARY

Astronomy is in the midst of a period of extraordinary scientific discovery. The path ahead leads to the exploration of some of the most exciting aspects of our universe: the nature of dark matter and dark energy in the universe, the formation of galaxies at early times, the nature of massive black holes, the formation of stars and planetary systems, and the detection of planets like Earth around other stars. NASA, NSF, and increasingly DOE, together provide the opportunities for astronomical research that have allowed this nation to demonstrate its scientific and technological leadership worldwide. The framework that led to this leadership was established by the decade-long plan of the National Academy of Sciences (NAS) Astronomy and Astrophysics Survey Committee 2001 Decadal Survey, "Astronomy and Astrophysics in the New Millennium" (hereafter the "Decadal Survey"). The recommendations given in this report are intended to further the implementation of the Decadal Survey, and more recent NAS studies, such as "Connecting Quarks with the Cosmos" (CQC). These NAS studies herald a decade of remarkable scientific opportunities.

The diverse approach to astronomical research offered by NASA and NSF is key to the scientific success and public visibility achieved in astrophysics over the last several decades. It remains a central aspect of the future success of astronomy. Joint programs between NASA, NSF and DOE, implemented within a healthy scientific research budget, are also of great benefit to the nation's astronomy and astrophysics research enterprise. By drawing on the different strengths of the agencies' approaches to achieving the science goals of the astronomical community, the nation will realize greatly enhanced value from its investment in astronomy.

The NAS Committee on the Organization and Management of Research in Astronomy and Astrophysics (COMRAA) recommended in 2002 the establishment of an advisory committee to deal with the increasingly important interfaces between the agencies involved in supporting astronomy and astrophysics. Support for this by the Executive Branch and Congress led to the establishment of the Astronomy and Astrophysics Advisory Committee (AAAC) to: 1) assess, and make recommendations regarding, the coordination of astronomy and astrophysics programs of NSF and NASA; 2) assess, and make recommendations regarding, the status of the activities of NSF and NASA as they relate to the recommendations contained in the National Research Council's 2001 Decadal report, and the recommendations contained in subsequent National Research Council reports of a similar nature; and 3) issue an annual report to Congress and the agencies no later than March 15. This annual report is the second by the AAAC. The AAAC will formally include DOE for the 2005-6 report.

Recommendations for the agencies:

The recommendations of the AAAC for the agencies are developed in detail in the report. The recommendations are:

NSF: The NSF Division of Astronomical Sciences (AST) in the Directorate for Mathematical and Physical Sciences (MPS) is supporting a remarkably productive program in astronomical and astrophysical research using ground-based facilities. Major facilities like the Atacama Large Millimeter Array (ALMA), or the top-ranked, ground-based future project Giant Segmented Mirror Telescope (GSMT) in the Decadal Survey, are key aspects of the AST program. The Major Research Equipment and Facilities Construction (MREFC) process is key to implementing such projects. *The AAAC was very encouraged by the positive response of the NSF to the NAS Brinkman report "Setting Priorities for Large Research Facility Projects." The approach being discussed will add clarity to the MREFC process and provide the needed long-range planning. We recognize the challenges in establishing the detailed procedures for the many different components of the agency, but we recommend that the NSF take the next step and complete and adopt a detailed plan for MREFC projects. The AAAC recommends that this be followed by the development of an agency-wide long-range plan. Given the scale of this activity, it may require modifications in the future, but the adoption of a detailed plan would be a key next step. The AAAC commends the proactive efforts of AST and MPS to respond to the challenges of implementing and supporting ALMA, a major international MREFC project, and recommends that ways be found to move forward on the other very-highly ranked projects in the Decadal Survey and CQC. We also commend the AST for its willingness to take the difficult steps needed for the future vitality of the field.*

NASA: The current NASA space science program is returning excellent scientific results of great visibility to the public worldwide. The breadth of NASA's science program is a major factor in this visibility. The current program in the Science Mission Directorate (SMD) also includes a number of outstanding missions for the future, including the highest ranked large project in space in the Decadal Survey, the James Webb Space Telescope (JWST). However, the challenges for NASA are substantial. Within the current budget constraints, NASA is being asked to complete ISS and then ramp down the existing Shuttle program, and to initiate the Exploration Vision while retaining a vibrant, broadly-based science program. *The AAAC is concerned that the NASA space science program, while apparently healthy now, is at risk of becoming too narrowly focused, potentially leading to the loss of US pre-eminence in space science. The AAAC notes that NASA space science, through its Universe Division in the Science Mission Directorate (SMD), plays a key role in the national astronomy and astrophysics enterprise, and applauds SMD for its strong support of a forward-looking science program. The AAAC recommends that NASA make the elements of this highly productive and visible astronomy program a significant part of its Strategic Plan, along with similarly highly-ranked programs in other areas of space science. NASA should do so for its scientific returns, its inspirational value to the nation, and for its importance to NASA as a continuing everyday demonstration of NASA's value to the nation and to the world.*

DOE: The DOE Office of High Energy Physics (HEP) is contributing in a significant way to major projects that will explore a variety of forefront cosmological and astrophysical phenomena. Many of these are being done through inter-agency cooperation. The AAAC applauds this inter-agency collaboration, and hopes that DOE can continue to build on its collaborations with NSF and NASA in a number of areas. *The AAAC welcomes the upcoming more direct involvement of DOE* *and the Office of High Energy Physics with the AAAC in working to optimize the nation's astronomy and astrophysics enterprise.*

Recommendations for specific programs:

We identify a number of programs that present particular opportunities and/or raise issues for the vitality of the nation's astronomy and astrophysics enterprise as carried out by NSF, NASA and DOE. The rationale behind these recommendations is given in the report. The recommendations are:

HST: Astronomers and the public worldwide agree that the Hubble Space Telescope (HST) is one of the most productive research tools ever devised. Its contribution to public interest in science and its impact on science education have been stunning and unique. *The AAAC strongly recommends that NASA carry out Servicing Mission 4 (SM4) as originally planned as part of its overall effort to complete its current obligations and programs as the agency moves to focus on new capability as part of the Exploration Vision.*

GSMT: A giant 30-m class telescope (Giant Segmented Mirror Telescope - GSMT) is the highest-ranked, ground-based large project in the Decadal Survey. It is an extremely powerful scientific facility that would allow us to probe from the formation of planets around nearby stars out to galaxies forming in the most distant reaches of the universe. Significant scientific synergy could accrue from concurrent operation with future major space facilities, such as the James Webb Space Telescope (JWST). *The AAAC recommends that NSF begin its support for the GSMT technology development program through funding the proposal submitted last year jointly by two community groups, provided that it meets the standards set by the peer review process. The AAAC further recommends that the NSF evaluate its approach to major projects to see if incremental changes could allow it to take advantage of the opportunities provided by major levels of private funding, provided such programs meet the very high peer review standards set for major projects. The involvement of both OMB and relevant committees in Congress could help to bring this about. The AAAC reaffirms its view that operation of GSMT in the JWST era would provide major scientific synergies. The AAAC also believes that continued dialog with the Europeans regarding their plans for an extremely large telescope could be mutually beneficial as well, especially if it resulted in shared access for all-sky coverage to the next generation of very large telescopes in the north and the south.*

Dark Energy: The discovery of dark energy at the end of the 1990s is one of the great scientific surprises of our time. *The AAAC supports a vibrant, wide-ranging program of investigations leading to understanding of the impact of Dark Energy on the Universe. The Dark Energy Task Force (DETF) was set up at our suggestion with the strong support of the agencies. The DETF will help optimize a Dark Energy program that the science community and the agencies can utilize to make progress over the next decade quickly and cost-effectively.*

Beyond Einstein: The Beyond Einstein program entered a new phase with its formalization in late 2004. Some of the highest-priority space missions in the Decadal Survey and the CQC report, the Laser Interferometer Space Antenna (LISA), Constellation-X and the Einstein Probes, are part of the Beyond Einstein program, but the program remains severely underfunded. *The AAAC recommends that NASA look carefully at providing resources for moving ahead on the major scientific opportunities identified in the Beyond Einstein program, including funding for the Einstein Probes.*

CMB Task Force: Measurements of the polarization of the Cosmic Microwave Background (CMB) radiation have the potential to probe the first instants of time in the universe. This is extraordinarily challenging. *The AAAC will be presented with the full report from the CMB Task Force by its next meeting. The AAAC expects that the report, with its prioritized program, and the subsequent response from all three agencies, will provide a basis for moving forward on a broadly-based program in this exciting area of CMB polarization.*

GLAST: The Gamma-ray Large Area Space Telescope (GLAST) is the highest ranked space mission in the "moderate" category in the Decadal Survey. It is expected to launch in 2007. *The AAAC recommends that the cap in the President's FY06 budget request for DOE for GLAST be removed in the final budget so as to allow DOE and NASA to jointly resolve the fiscal issues with the Large Area Telescope LAT, allowing GLAST to move forward expeditiously to launch and operation.*

TPF-C: The Terrestrial Planet Finder (TPF) is an exciting scientific mission, with its goal of detecting and characterizing Earth-like planets around other stars. While significant technological developments have occurred in the last few years, the coronagraph implementation of TPF, TPF-C, is a highly challenging mission whose early implementation could significantly affect other highly-ranked missions in the Decadal Survey. *The AAAC recommends that the development of the TPF-C mission be the subject of a comprehensive independent review of both its scientific and technical readiness by the NAS before decisions are made to move TPF-C forward as a flight project.*

ATST: The Advanced Technology Solar Telescope (ATST) is a major ground-based solar observatory for the study of magnetic phenomena in the Sun. ATST and the NASA Solar Dynamics Observatory (SDO) together would provide powerful synergistic capability for tackling this important but challenging scientific question. SDO is progressing towards launch in 2008. *The AAAC applauds the progress that has been made on this important program and recommends that the NSF move ATST quickly through the MREFC process.*

Explorers: The Explorer line has provided many of NASA's most successful missions, including the Wilkinson Microwave Anisotropy Probe (WMAP) that revolutionized our knowledge of the structure of the universe. A key feature of the Explorer missions has been the ability to respond rapidly to new scientific opportunities. *The AAAC recommends that the NASA Explorer program be restored to its previous level to ensure its vitality and effectiveness.*

Theory: Theoretical studies are central to understanding the remarkable universe that we study with our telescopes and missions. *The AAAC recommends that the agencies build on the steps already taken and explicitly identify theory as an aspect of all major programs with some funding designated as part of the overall budget.*

NVO: The National Virtual Observatory (NVO) is the highest-priority small project in the Decadal Survey. It is a huge database that will provide a 'virtual sky' based on the enormous data sets from current and future observatories. *The AAAC strongly encourages the NVO team to continue its excellent work, especially its efforts to fully involve the community. The AAAC recommends that NSF and NASA carry out their plan to solicit proposals for the operation of the NVO and to implement that within the next year.*

Synopsis: The NAS Decadal Survey and the NAS report CQC set out an exciting, viable program for astronomical research that we heartily support. The diverse approach to astronomical research offered by NSF, NASA and DOE is an essential part of the scientific success and public visibility achieved in astronomy over the last several decades. We are encouraged by the effort to develop long-range plans for major facilities at NSF, though the budget situation poses a serious challenge for implementing the Decadal Survey recommendations. We are concerned about a potential steady erosion of US leadership in space science given the challenges for NASA within the current budget constraints: to ramp down the remnants of the past (Shuttle/ISS) and to initiate the Exploration Vision, while retaining a vibrant, broadly-based science program. By drawing on the different strengths of the three agencies, NSF, NASA and DOE, the nation will realize greatly enhanced value from its investment in astronomy.

COMMITTEE MEMBERS

Garth D. Illingworth, (Chair) University of California Santa Cruz/UCO/Lick Observatory
John Carlstrom, (Vice-Chair) University of Chicago
Neta Bahcall, Princeton University
Alan Dressler, Carnegie Observatories
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ANNUAL REPORT

ASTRONOMY AND ASTROPHYSICS ADVISORY COMMITTEE

MARCH 16, 2004 - MARCH 15, 2005

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ASTRONOMY AND ASTROPHYSICS ADVISORY COMMITTEE

MARCH 16, 2004 - MARCH 15, 2005

1.0 INTRODUCTION

1.1 CHARGE TO THE COMMITTEE

The federal research enterprise in astronomy and astrophysics is a remarkably productive activity with great visibility to the public, both in the nation and worldwide. It routinely demonstrates US scientific and technological leadership.

The organizational effectiveness of this enterprise was addressed in 2002 by the National Academy of Science (NAS) "Committee on the Organization and Management of Research in Astronomy and Astrophysics" (COMRAA). In their report, "U.S. Astronomy and Astrophysics: Managing an Integrated Program" COMRAA recommended the establishment of an advisory committee to deal with the increasingly important interfaces between the agencies involved in supporting astronomy and astrophysics. Support for this by the Executive Branch and Congress led to the establishment of the Astronomy and Astrophysics Advisory Committee (AAAC) under the National Science Foundation (NSF) Authorization Act of 2002, with the joint goals of:

1) assess, and make recommendations regarding, the coordination of astronomy and astrophysics programs of NSF and NASA, and
2) assess, and make recommendations regarding, the status of the activities of NSF and NASA as they relate to the recommendations contained in the National Research Council's 2001 Decadal report, and the recommendations contained in subsequent National Research Council reports of a similar nature. (See Appendix A for the full language.)

The AAAC's role will broaden in 2005 with the formal inclusion of DOE, following the submission of this 2004-2005 report.

1.2 CONTEXT AND ACTIVITIES

The National Academy of Sciences (NAS) Decadal reports play a critical role in evaluating and setting priorities for the nation's astronomy and astrophysics program funded by NSF, NASA and DOE. These reports are produced by the National Research Council (NRC) as the operating body of the National Academies in providing services to government. The 2001 NAS Decadal Survey "Astronomy and Astrophysics in the New Millennium" (hereafter called the Decadal Survey) followed by the NAS report "Connecting Quarks with the Cosmos" (CQC) set out an exciting, viable program for astronomical research that the AAAC heartily endorses. The recent NAS study by the "Committee to Assess Progress Toward the Decadal Vision in Astronomy and Astrophysics" reaffirmed the vitality and relevance of the program outlined in the Decadal Survey. The AAAC fully concurs with that NAS committee's recommendation that "the suite of projects recommended in the Decadal report provides the flexibility to explore the universe across a wide range of conditions. A broad portfolio of activities is a powerful tool for exploration."

The diverse approach to astronomical research offered by NASA and NSF is an essential part of the scientific success and public visibility achieved in astrophysics over the last several decades. It remains a key aspect of future success in the field of astronomy. Cooperation, collaboration, and joint programs between NASA, NSF and DOE bring further benefits to astronomy and astrophysics. Each agency has its own approach to supporting research. While this brings challenges, it also enables more efficient use of national resources for science through synergistic approaches. It is essential that each agency, NSF, NASA and DOE, retain a healthy scientific research budget, even in times of fiscal constraint.

The report of the NSF-NASA-DOE National Science and Technology Council (NSTC) working group, responding to the CQC, was released early in 2004. This report, "Physics of the Universe" (POU), is an excellent example of interagency cooperation for dealing with initiatives which are of mutual interest to several agencies.

The AAAC held four meetings between 16 March 2004 and 15 March 2005. Face-to-face meetings were held at the NSF on 21-22 June 2004, 26-27 October 2004, and 15-16 February 2005. A telephone conference was held to review the final report (9 March 2005). We greatly appreciate the efforts of the many agency staff and members of the astronomical community who provided support and information to us during our deliberations over the past year. The AAAC has also found the willingness of the agencies to engage in very open and direct dialog on a wide range of issues to be of great value in developing mutual understanding of the challenges of implementing an ambitious scientific program. We are very impressed with the professional, supportive approach that the agencies have taken in working with the community to realize the goals of the Decadal Survey and reports such as CQC.

2.0 NSF

The NSF plays a unique role in the Nation's science program. It provides resources for basic research that allows innovative, rapid and timely developments to be initiated from within the science community through a peer review process geared to excellence. Such programs can lead to rapid results. Astronomy and astrophysics share in this approach to research. Moreover, NSF is increasingly involved in major projects. Such projects play a key role in the science productivity of many Divisions of the agency. Astronomy is one area where this has been traditionally the case. It is certainly the case in the current decade, with the extremely powerful Atacama Millimeter Radio Array (ALMA) as a central element of the program of the Division of Astronomical Sciences (AST). The NSF's response to the NAS Brinkman report "Setting Priorities for Large Research Facility Projects Supported by the National Science Foundation" has been of great interest to the AAAC this past year. The AAAC is very supportive of the agency's efforts to respond to Brinkman, as is discussed further below.

The AAAC was greatly encouraged, as was the research community across the nation, at the foresight shown by the Administration and Congress in supporting an authorization to "double the budget" of the NSF. The research endeavor of the nation is one of its great strengths. We recognize that the budget situation has changed dramatically in the past year or so, and that it is now unrealistic to expect that the budget doubling will be implemented in the next few years. However, we were greatly disappointed to see an actual reduction for NSF in the final FY05 budget from the Congress. The FY06 President's budget request for NSF partly rectifies this decrease, but the increase is very small, especially when mandated activities are taken into account. Such changes do have a significant effect on the vitality of the research efforts across the nation and will become increasingly important for researchers funded by the NSF in academic institutions who are closest to students and the community.

Astronomical explorations using ground-based telescopes have yielded some of the most exciting discoveries in astronomy in recent times. These include, among others: the discovery of the existence of a mysterious dark-energy in the universe; detection of the fluctuation spectrum of the remnant cosmic microwave background radiation which revealed the seeds of all cosmic structure formation; the discovery of extra-solar planets; the mapping of the large-scale structure of the universe; the discovery of the "Kuiper Belt" region of the solar system that is populated by objects from the time of its formation; and the determination of the interior structure of the Sun from the seismic study of its internal sound waves. Many of these results have benefited from support from both NASA and NSF, exemplifying the benefit to astronomy and astrophysics of the support by both agencies. However, NSF remains at the heart of the ground-based effort. The NSF Division of Astronomical Sciences (AST) faces significant challenges in moving forward on the high priority projects advocated by the 2001 Decadal Survey and the CQC report. The AAAC is very encouraged by the steps being taken within AST to respond to evolving circumstances and the need for structural changes. Doing so will open up funding to respond to the Decadal Survey and to the programs outlined in the CQC and its companion report Physics of the Universe.

2.1 LONG-RANGE PLANNING AT THE NSF

The NSF is making good progress toward a more open and transparent process for the funding of major research facility projects that are developed under the purview of the Major Research Equipment Facilities Construction (MREFC) program. The process outlined to the AAAC offers an approach that should be reasonably appropriate across the Foundation and yet maintains sufficient flexibility to respond to the particular needs of different disciplines. Critical aspects include both the long forward-look (15-year time scale) of the annual facilities plan and the transparency offered via the development plans for individual projects. This ensures that project status and progress can be understood by all stakeholders. The possibility for funding design and development efforts for major, MREFC-level projects at the divisional level provides an important path to bring such projects to a stage of readiness for construction funding through the MREFC process. Theory challenges, and grant funding aimed at providing scientific as well as technical readiness for major initiatives, are both important during the development phase. The placement of projects under the auspices of the appropriate division during the design and development phase provides for better long-term planning and a stronger core program in the division. The plan also provides for "waystations" along the approval route for negotiation with potential international, multi-agency, or private partners. Such complexities have become the norm for major astronomy projects, and a recognition that these partnerships must be folded into the planning and approval process is an important step. The AAAC supports the direction of MREFC project planning under discussion and looks forward to the timely completion of the revised Facilities Management and Oversight Guide.

An important aspect of a more structured and open MREFC process for large projects will be the need to understand and identify the "lifecycle" aspects of major programs and their associated costs. "Lifecycle" is the term used to encompass the three well-defined components in the realization of major projects: the R&D phase (Research and Development); the construction (MREFC) phase; and then the operations and science return phase. The "lifecycle" analysis and cost-profiling approach has become the norm at NASA from their long experience with major projects, and it may be useful for NSF to look at the NASA experience to see what aspects might be appropriate for the NSF environment. The envisaged approach, as in the past, is that the divisions will usually find the resources for R&D and operations internally, with construction being done through the MREFC process.

Most major programs will have their R&D and operations funding identified from within the appropriate division, thus necessitating a major review of current obligations that would involve the relevant science community. However, some MREFC projects will likely be of a scale that funding increments to that division will be required for R&D and/or operations. This is an important aspect of taking a "lifecycle" planning approach to major projects. It is obviously not desirable to make a major investment in a program and then have that project not reach its design level of scientific return because the operating funding is too low. Nor is missing the opportunity to execute a major program that could provide "transformational" science because it cannot be fit into a division's current budget box. The "lifecycle" approach would allow the divisions and the agency to identify those projects which have broader budgetary implications beyond the MREFC-funded construction phase. For some programs significant budgetary enhancements may then be necessary in either the R&D or operations phase, or both, though this is expected to occur for only the very largest projects.

The first astronomy project likely to go forward under the new MREFC process is the Advanced Technology Solar Telescope (ATST - see §5.7). The committee is pleased to see this project move forward and views positively the effort to include a significant component of international participation. Another positive aspect is the possibility of Air Force involvement, given the close relationship that will likely develop at the Haleakala site in Hawaii. ATST, along with the more immediate need for ALMA operations, also sets an important precedent for planning for future operations funding within current budget levels.

Related to the development of NSF-wide planning for large projects is the emphasis on long-term planning within AST. The planning effort within the Division currently involves two activities, the roadmapping efforts underway for radio astronomy and for optical/infrared ground-based astronomy and the planned Senior Review of the AST program. Two committees have been formed for the long-range planning (roadmapping) effort. The radio astronomy roadmap is organized by the Associated Universities, Inc (AUI) and the optical/infrared roadmap is organized by the National Optical Astronomy Observatory (NOAO). Both committees have participation from a broad representation of the astronomical community. They will develop roadmaps guiding the development of major new facilities recommended through the Decadal Survey, with some preliminary discussion of longer-term initiatives. Both roadmaps are expected to be completed before summer and will define paths and decision points that could help provide a framework for the selection of initiatives proposed to AST for the MREFC process. These efforts are also expected to provide a broad, systemic view of how existing and upcoming facilities will support AST research activities. Such input will help in the Senior Review, which is the second major activity for long-range planning.

The Senior Review is scheduled for the summer of 2005. It is clear that moving forward on the facilities goals prioritized in the Decadal Survey will require funding for design and development at a level not currently available within the Divisional budget. At the same time, operations funding for ALMA, which will begin to ramp up within the 2005 budget, would clearly stress a flat or very slowly increasing AST budget. The goal of the Senior Review is to evaluate the distribution of funding within the Divisional portfolio and to identify strategies a) to provide for the U.S. share of operations funding for ALMA and b) to free up ~$20M of funding within the budget of AST that can be used for design and development funding for high-priority Decadal Survey and CQC projects such as GSMT and LST. The AAAC enthusiastically supports both the Senior Review and the roadmapping exercises initiated by AST, and congratulates the Division for its proactive stance towards long-range planning.

A major challenge for the NSF Directorate of Mathematical and Physical Sciences (MPS) and AST remains the implementation of the other large projects in the Decadal Survey. ALMA is a remarkably powerful radio observatory with unique capabilities, and its completion and proper support is essential. ALMA is also another example of a major international collaboration in astronomy. Such collaborations, whether international or with private foundations, are likely to become the norm for facilities of the scale of ALMA. As noted above ATST is moving forward and the AAAC hopes that it progresses rapidly through the MREFC process. A number of other programs remain in the queue, including GSMT (Giant Segmented Mirror Telescope), the EVLAII (a major upgrade to the Very Large Array), and LST (Large Survey Telescope). GSMT is the top-ranked ground-based project in the Decadal Survey, EVLAII is the highest-ranked large radio project, and LST is identified both in the Decadal Survey and CQC/Physics of the Universe (as the Large Synoptic Survey Telescope LSST, which is now proposed as one possible implementation of those recommendations). GSMT and LST are discussed below in §5.1 and §5.2. A significant challenge for the astronomy community and the NSF, particularly MPS and AST, is the timely implementation of these highly-ranked major projects.

A number of projects or programs involving NSF are discussed in §5, including GSMT in §5.1, Dark Energy §5.2, the CMB Task Force §5.4, ATST §5.7, Theory §5.9 and NVO §5.10.

NSF: The AAAC was very encouraged by the positive response of the NSF to the Brinkman report "Setting Priorities for Large Research Facility Projects." The approach being discussed will add clarity to the MREFC process and provide the needed long-range planning. We recognize the challenges in establishing the detailed procedures for the many different components of the agency, but we recommend that the NSF take the next step and complete and adopt a detailed plan for MREFC projects. The AAAC recommends that this be followed by the development of an agency-wide long-range plan. Given the scale of this activity, it may require modifications in the future, but the adoption of a detailed plan would be a key next step. The AAAC commends the proactive efforts of AST and MPS to respond to the challenges of implementing and supporting ALMA, and recommends that ways be found to move forward on the projects in the Decadal Survey and CQC.

We commend AST for its willingness to take the difficult steps needed for the future vitality of the field.

3.0 NASA

NASA has undergone a major restructuring in the past year. The Exploration Vision has provided an opportunity to move beyond the constraints of the past, namely a human transportation system, the Space Shuttle, that was developed some 30 years ago, and the International Space Station (ISS), a major orbiting facility that will not realize its full scientific potential. NASA's extraordinary successes over the last decade have resulted in large part from its challenging, ambitious science missions. NASA has demonstrated remarkable scientific leadership by implementing missions that have dramatically changed our understanding of the structure of the universe, the existence of massive black holes, when and how galaxies formed, and the birthplaces of star and planets. The excitement realized throughout the nation and the world from the Hubble Space Telescope, from the Mars Rovers, and from numerous other remarkable missions and projects have been both a unifying force for the nation and a driving force for its people, demonstrating time and time again that technology, driven by great science goals, can take us where no one has gone before. The value of these science missions for generating enthusiasm for science and engineering, and for evoking the interest of the youth of the nation in science and engineering education, is well-recognized.

With the current budget constraints, the challenge faced by NASA, is to ramp down the remnants of the past (Shuttle/ISS) and to initiate the Exploration Vision, while retaining a vibrant, broadly-based science program. Our deepest concerns lie with this latter area. The remarkable successes and visibility of NASA that have accrued from its science program are at risk. At first sight the President's FY06-FY10 budget, appears to be very good for science. Science increases from 33% to 38% of the total NASA budget. However, these very same budget projections show that the deep concerns of the science community, and of the AAAC, have some validity. A closer investigation reveals that much of the growth in the science program is related to the exploration of the Moon and Mars. For example, funding for the Universe Division, which contains essentially all fundamental studies related to astronomy and astrophysics and the astronomical aspects of the Physics of the Universe, is dropping, substantially so in inflation-adjusted dollars (by ~20%). Furthermore, the budget forecasts substantially impact even studies of our solar system outside the very limited destinations of the Moon and Mars. The impact of these developments on the breadth of the science program should be considered very carefully in the coming year. The leadership that NASA has shown worldwide, with the visibility that it brings to US technological and scientific achievements, is at risk. The breadth of NASA's science program is a major factor in this visibility.

3.1 NASA - THE EXPLORATION VISION AND SCIENCE

NASA is currently bringing its planning process into line with the goals of the Exploration Vision. This is a profound change within an agency that has had spectacular success over decades using a very different approach to develop its scientific program. The AAAC notes that the new approach starts from the top, with a set of goals for the agency, and all the programs within NASA have to articulate the way in which they support those goals. The risk is that this focus, while beneficial for moving the agency beyond the constraints of the past, could greatly impact those aspects, particularly its science missions, that have made it a world leader.

The voice of the scientific research community in formulating those goals has been diluted. In the past, NASA's science program was developed through a broad and sustained consultation with the scientific community. The National Academy of Sciences organized Decadal reports in astronomy and astrophysics with NASA's assistance (as in other areas such as the Solar System and Sun-Earth studies). This approach was long admired across the agencies, OMB and Congress as a model for how a scientific field should order its priorities. The Decadal reports helped NASA see where the scientific community put its priorities. Advisory committees helped segments of the space science program at NASA translate those broad goals into a program of action based on community consensus. What is so risky for NASA and US leadership in science is that its new approach compresses wide areas of science, where NASA has been the world leader, into narrow segments of the agency's agenda. The work being carried out in these segments are science topics of great interest to both the scientific community and the broad public. The myriad science discoveries of Hubble fall within one of these segments, for example.

There are great opportunities for NASA and US science to lead the world in exploring the great science questions of our time like dark energy, dark matter, the cosmos at its earliest times, planets around other stars, and the ubiquity of life. The risk of missing a good opportunity by being too segmented or, worse, of distorting the priority or nature of scientific investigations to suit the Exploration agenda could lead to NASA's rich and vibrant space science program becoming a barren enterprise. Grafting science on as an afterthought to justify a program is a flawed approach that ultimately is detrimental to both NASA and the nation.

NASA has a new strategic roadmapping process underway that will be carried out within the new framework. The AAAC was encouraged that the FY06 NASA budget contains a broadened version of NASA's Strategic Goals and Objectives that encompasses both the breadth of the science program carried out by NASA over the last decade and the science program in the most recent Strategic Plan. The strategic roadmapping is first taking place within the Divisions, after a substantial reorganization of the Science Mission Directorate, and it is being worked on a very short timescale. The legacy from previous roadmaps remains a significant aspect, and so the AAAC hopes that much of the scientific framework that was developed through extensive planning activities extending over many years remains in the new Strategic Plan. In particular, the recommendations of many NAS studies (e.g., the astronomy and astrophysics Decadal Survey and other like surveys) have been reflected in the strategic planning at the Science Mission Directorate (SMD) level in the past. We would encourage SMD to continue to do so in the current Strategic roadmapping activity.

However, the process for the final integration of the Division-level Strategic roadmaps into the "NASA Strategic Plan" remains unclear. The AAAC is concerned, as is the science community very broadly, that when this integration is done, the science community's priorities could be substantially modified from those in the many NAS studies that are input at the SMD level. The President's FY06 budget did give substantial support for a vibrant science program within NASA, but we recognize the challenge of fitting the ramp-up of the Exploration Vision, the return to flight of the Shuttle and completion of ISS, and of a broad program of scientific exploration, plus NASA's many other activities, into the budget box. Science may well suffer under the new planning approach, particularly if the long-standing support for science in NASA and the traditional "walling-off" of science from the Flight programs are weakened by choices made to deal with the above-mentioned challenges.

While there are concerns about the potential impact on NASA's ability to remain pre-eminent in the longer-term, we also recognize that the current program is returning excellent scientific results of great visibility to the public worldwide. The current program also includes a number of outstanding future missions in astronomy and astrophysics through the Universe Division in SMD. The support and efforts of SMD and the Universe Division in particular are commended by the AAAC. We applaud the excellent progress on JWST, the highest-ranked large program in space in the Decadal Survey, the progress on GLAST, the highest-ranked moderate-size program in space, the continuing scientific productivity and public visibility of the three Great Observatories, HST, Chandra and Spitzer, and the potential of many of the smaller missions that are being developed for launch later this decade. We discuss many of these in more detail below, noting our concerns regarding some particularly important programs, either in their rather slow ramp-up (the Beyond Einstein program), the unclear future for Hubble, or the rather premature efforts on TPF.

A number of projects or programs involving NASA are discussed in §5, including Dark Energy §5.2, Beyond Einstein §5.3, the CMB task force §5.4, GLAST §5.5, TPF §5.6, Explorers §5.8, Theory §5.9 and NVO §5.10.

NASA: The AAAC is concerned that the NASA space science program, while apparently healthy now, is at risk of becoming too narrowly focused, potentially leading to the loss of US pre-eminence in space science. The AAAC notes that NASA space science, through its Universe Division in the Science Mission Directorate (SMD), plays a key role in the national astronomy and astrophysics enterprise, and applauds SMD for its strong support of a forward-looking science program. The AAAC recommends that NASA make the elements of this highly productive and visible astronomy program a significant part of its Strategic Plan, along with similarly highly-ranked programs in other areas of space science. NASA should do so for its scientific returns, its inspirational value to the nation, and for its importance to NASA as a continuing everyday demonstration of NASA's value to the nation and to the world.

3.2 FUTURE OF THE HUBBLE SPACE TELESCOPE

Astronomers and the public worldwide agree that the Hubble Space Telescope (HST) is one of the most productive research tools ever devised. Its contribution to public interest in science and its impact on science education have been stunning and unique. The 2001 Decadal Survey in astronomy and astrophysics anticipated a Shuttle servicing mission (SM4) in the 2004-2005 time frame to install new instruments and to fortify Hubble's systems for a final scientific push lasting until around 2010. The new instruments would provide a dramatic increase in Hubble's scientific capability, like that which occurred in 2002 at the last servicing mission when the Advanced Camera for Surveys (ACS) was installed and the Near Infrared Camera (NICMOS) was brought back to life with a new cooling system. This long-planned last phase of Hubble's life would then be followed by controlled de-orbit or further lifetime extension without servicing. As with earlier servicing missions, the charges to the space science program at NASA were to be ~$300-400M, including engineering support, the cost of preparing and training for the mission, and the cost of the new instruments. It is the AAAC's judgment that, around this level, support for the continued servicing of Hubble with SM4 is undiminished since the 2001 Decadal Survey, consistent with our strong endorsement of the next servicing mission in the AAAC's 2004 Report.

The new instruments for HST, the Cosmic Origins Spectrograph (COS) and the Wide-Field Camera 3 (WFC3), have been built and could be installed as planned. Unfortunately, the Columbia accident led to an indefinite postponement of SM4; reinstatement appears to turn on a final evaluation of its risk compared to that of the ~25 planned flights to complete the Space Station. This is a controversial subject beyond our charge, but we note that several reports, from experienced groups and individuals well informed on these issues, have addressed this aspect over the last year. These include the thoughtful letter from Admiral Gehman to Senator Mikulski in March 2004, the Petition to the President from a group of former astronauts, and the recent NAS study "Assessment of Options for Extending the Life of the Hubble Space Telescope". The lack of a detailed risk assessment report from NASA made it difficult for those groups to assess NASA's concerns.

Within our purview is another question that was addressed at the recent House Science Committee hearing on the future of HST. The astronomy community is concerned about the effect on the rest of the astronomy program at NASA if the Science Mission Directorate (SMD) is forced to bear the additional flight cost for SM4 (that cost is unclear, but ~$1B was quoted at the hearing). This cost, over and above what was input to the Decadal process, would certainly have negative consequences on other highly rated programs. While NASA has not formally suggested that SMD be assessed these costs (it has in fact suggested the opposite - see below), the AAAC believes that congressional action concerning the SM4 mission should continue to isolate the flight costs outside the Science Mission Directorate, just as the budget of shuttle missions to the International Space Station are separately funded in the President's FY06 budget. Doing otherwise would be a change in the long-established ground rules in allocating costs. The NASA Administrator recognized this in a statement to the House Science Committee in 2002 as NASA moved to "full cost accounting." The Administrator explicitly noted that flight costs for HST SM4 were included in the budget of the Office of Space Flight in the 5 year NASA budget.

HST: The AAAC strongly recommends that NASA carry out SM4 as originally planned as part of its overall effort to complete its current obligations and programs as the agency moves to focus on new capability as part of the Exploration Vision.

4.0 DOE

The Department of Energy (DOE) Office of High Energy Physics (HEP) under the Office of Science is becoming increasingly involved in research efforts related to astronomy and astrophysics. DOE is contributing in a significant way to projects that will explore a variety of cosmological and astrophysical phenomena. These efforts address a number of basic questions of great interest to the astronomical and particle physics communities, with dark energy and dark matter being very visible examples, as highlighted in CQC and the Physics of the Universe report. The AAAC has discussed developments and issues with HEP routinely over the last year and was informed about the very comprehensive review from the Scientific Assessment Group For Experiments In Non-Accelerator Physics (SAGENAP). The AAAC is also involved directly with two activities of great interest to that office, namely the Cosmic Microwave Background (CMB) Task Force and the Dark Energy Task Force (DETF), which will report jointly to both AAAC and the High Energy Physics Advisory Panel (HEPAP). As examples for the area of dark energy, DOE is supporting R&D funding for the Supernova Acceleration Probe (SNAP) concept that could be a proposal for the Joint Dark Energy Mission (JDEM), while DOE involvement in the Large Synoptic Survey Telescope (LSST) is under consideration. DOE is a partner with NASA on the primary instrument for the Gamma-ray Large Area Space Telescope (GLAST). This program is moving forward, though some issues have arisen that will require further discussion to resolve (as outlined in more detail below in §5.5). Since many of these programs are some of the first examples of major inter-agency collaborations in a number of areas, they are excellent pathfinders for developing the processes and procedures that will enable enduring and effective joint missions of much larger scale in the future. The AAAC applauds this inter-agency collaboration and hopes that DOE can continue to build on its collaborations with NSF and NASA in a number of areas.

A number of projects or programs involving DOE are discussed in §5, including Dark Energy §5.2, JDEM §5.3, the CMB task force §5.4, and GLAST §5.5.

DOE: The AAAC welcomes the upcoming more direct involvement of DOE and the Office of High Energy Physics with the AAAC in working to optimize the nation's astronomy and astrophysics enterprise.

5.0 SPECIFIC PROGRAMS

The following sections deal with specific projects that raised issues and/or concerns for the AAAC during its deliberations over the last year. Some of these involve challenges for science programs in the agencies in the near-term that can affect the returns to the nation from its investment in science. Others raise issues explicitly for inter-agency cooperation or future return from initiatives that will be the focus of more than one agency. We have also taken particular note of concerns raised during the year by NAS committees such as the Committee on Astronomy and Astrophysics (CAA) and its associated panels, since they have a particular role to play as the custodians and champions of the Decadal Survey and other like NAS surveys.

5.1 GSMT

A giant 30-m class telescope (Giant-Segmented Mirror Telescope - GSMT) was the highest-ranked ground-based large project in the Decadal Survey, as was the James Webb Space Telescope (JWST) for space. GSMT can play a major role in some of the most ambitious goals of our time, namely understanding the formation and evolution of galaxies within the first 1-2 billion years after the Big Bang, and the formation of stars and planets. Just as the current generation of large telescopes has heralded unexpected discoveries through the breadth of their capabilities, so would a telescope with ~10 times the light gathering power of our current 8-m class telescopes. Furthermore, the experience of Hubble and the current generation of 8-m class ground-based telescopes have demonstrated that, working together, they synergistically provide scientific advances beyond even their enormous individual capabilities. This opportunity for enhanced synergistic capabilities led to the recommendation in our previous report: "Progress on these scientific objectives is heavily dependent on GSMT being developed on the same timescale as JWST. This requires initiation of an aggressive technology development program, ramping up if possible in 2005, with particular support in the FY06 budget".

To provide a more detailed scientific case for the synergies from concurrent operation of GSMT and JWST, the AAAC asked the GSMT Science Working Group (SWG) to develop a document in collaboration with the JWST SWG that would enunciate the science gains to be made with overlapping operation. The two SWG's agreed to do so, and their report will soon be completed.

Another aspect of the synergy between ground and space has surfaced as a result of developments over the last year. The focus on the search for other planets at NASA (see the TPF §5.6) has highlighted the scientific and public interest that is developing in the search for planets around other stars, their characterization and the broader issue of planetary system formation and evolution. Recent developments in adaptive optics (AO - and particularly the potential of what is now called Extreme AO - ExAO) have led to many researchers thinking about the great potential of large telescopes in the GSMT class for tackling these problems in the upcoming decade. The high resolution available in the infrared with 30-m class telescopes with AO enables observations of planets and disks closer to other stars than can be done with space telescopes with their smaller mirrors. Again, these ground-based capabilities will complement the space observatories under discussion and allow synergistic approaches to investigating how planetary systems develop around stars.

Significant effort towards realizing GSMT has begun in the community. Two concepts have surfaced, one the Giant Magellan Telescope (GMT) using a small number of large segments for the mirror, the other the Thirty Meter Telescope (TMT) using a large number of small segments. Given the technical challenges, the ideal approach, as demonstrated for JWST and for other large programs, is to support technology development to the point where the projects can submit proposals from which a selection can be made that will allow the NSF to move forward with a single project for a major investment through the Major Research Equipment and Facilities Construction (MREFC) process.

The astronomy community has come together with a joint proposal to the NSF for technology development that would, if funded, allow for the two programs to progress to the point where proposals for construction could be written and submitted to the NSF for review. Provided that peer review ranks the proposal as highly meritorious, the funding of this proposal would allow the technology development to move ahead. The AAAC is highly supportive of the GSMT program and recommends that funding be made available to begin the NSF's involvement in the technology development efforts.

There is another quite unusual aspect of the GSMT program that provides great opportunities for bolstering the research funding available to the nation as a whole, but which brings with it some interesting policy issues. The two candidate projects (at this point in time), the GMT and the TMT, expect to bring at least several hundred million dollars of private funding into the project from private foundations, individuals and universities. International partners are also likely (Canada is already a member of one project). Clearly investments of this scale for projects of very high priority in the Decadal Survey are of significant value to the nation's research enterprise. At first glance such investments, when combined with funding from the Federal Government, appear that they might solve a long-standing issue for privately funded facilities—namely, the problem of funding operations. Private foundations have shown a preference for supporting major construction expenditures over a limited period, with significantly less willingness to fund long-term operations. The agencies, while unable to make long-term commitments explicitly, have in fact been able to fund long-term operations in programs that are consistently returning high-value science results. Could procedures be found that would allow the agency, in this case the NSF, to make longer-term commitments for operations, while allowing the private foundations to bear the brunt of the early development and construction costs? Such arrangements may enable a project with a high level of private support to move more expeditiously once they have satisfied the readiness and review requirements.

The policy aspects of such an arrangement between the private and public sectors could be of interest to those in the agencies, OMB and Congress, who could potentially work together, possibly in discussions with some private foundations, to see what could be achieved in finding a way to utilize private resources at the level of $300M-$500M for funding very highly-ranked science projects. The appropriate review and management mechanisms would need to be implemented on all sides, but to do this successfully would be "win-win" for all concerned.

An even larger version of GSMT is under consideration by the Europeans through the European Southern Observatory. Their interest in extremely large telescopes (ELT) opens up the potential for future coordination or collaboration. AST has convened a group of international funding agency representatives to explore cooperation on the next generation telescopes. Continuing discussions with the European community could identify ways in which the two groups could develop their respective ELT facilities for mutual benefit (e.g., shared access; complementary instrumentation). This would be especially valuable if the result of these efforts is joint access to a next generation very large telescope in each of the Northern and Southern Hemispheres, giving all-sky coverage.

GSMT: The AAAC recommends that NSF begin its support for the GSMT technology development program through funding the proposal submitted last year jointly by the two community groups, provided that it meets the standards set by the peer review process. The AAAC further recommends that the NSF evaluate its approach to major projects to see if incremental changes could allow it to take advantage of the opportunities provided by major levels of private funding, provided such programs meet the very high peer review standards set for major projects. The involvement of both OMB and relevant committees in Congress could help to bring this about. The AAAC reaffirms its view that operation of GSMT in the JWST era would provide major scientific synergies. The AAAC also believes that continued dialog with the Europeans regarding their plans for an extremely large telescope ELT could be mutually beneficial as well, especially if it *resulted in shared access for all-sky coverage to the next generation of very large telescopes in the north and the south.*

5.2 DARK ENERGY - THE DARK ENERGY TASK FORCE

The discovery of dark energy at the end of the 1990's is one of the great scientific surprises of our time. Theory does not account properly for this mysterious stuff that makes up 2/3 of the Universe— either it is something like Einstein's cosmological constant with a ridiculously small value of the energy density or it is something else that is completely unaccounted for in physical theory. Either way, dark energy is very important and it poses the question: what is the best way to learn about it? Tracking the expansion of the universe with supernovae led to the discovery of dark energy. Ground-based supernova programs and observations with HST have built on their initial discovery of dark energy, and have led to significant improvements in measuring dark energy properties. But supernovae are not the only approach. A number of complementary approaches, such as weak gravitational lensing, the evolution of galaxy clusters, and the growth of structure in the matter of the Universe, have been articulated and are being analyzed for their potential in narrowing down the nature of the dark energy. A few preliminary results are in hand and they look promising for future work.

One of the initial agency responses to dark energy—a DOE-NASA Joint Dark Energy Mission (JDEM) —has progressed to the stage of a joint science definition team (SDT) that is working to define the scientific goals of a wide-field imaging telescope designed to study dark energy. That instrument would be used to obtain precise results on a large sample of distant supernovae. Another approach to the study of dark energy is to map the subtle distortions in the images of distant galaxies produced by the clumping of intervening matter. This could also be carried out by a wide-field imaging satellite or by telescopes on the ground. The AAAC is glad to see the evidence of interagency cooperation that should lead to a lively competition for the best mission concept and an excellent program in the years ahead. The only dark cloud is that there may be a great many years ahead before launch. The competitive selection, jointly by DOE and NASA, of the mission that would be JDEM is unlikely to occur before 2008. This would lead to a launch no earlier than 2012 in the best of circumstances. Given the lack of funding for the Einstein Probes (estimated to be about $600M each) in the current NASA budget, the launch date could well be even later. Currently DOE is vigorously supporting one particular implementation of JDEM, and the AAAC was encouraged to hear that NASA intended to provide an opportunity this year for all interested groups to propose for funding for studies that would help develop competitive approaches.

A second, complementary approach is being developed on the ground. A pilot project called the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS) is moving ahead in Hawaii with the goal of demonstrating that wide area surveys for dark energy studies, along with other science goals such as asteroid detection, can be done with a number of small, very wide-field telescopes operating together. Another project, the Large Synoptic Survey Telescope (LSST) is taking a comparably ambitious approach using a single large 8-m class ground-based telescope with similar goals. The LSST consortium has proposed to NSF for funding for technology development and is collaborating with DOE investigators who are proposing to develop the camera. The consortium is also pursuing a significant component of private funding.

The adopted approach to a major wide-field ground-based facility for the study of dark energy, generically known as the Large Survey Telescope (LST), will be determined by technological readiness through a peer-review selection. The likely timescale for completion of the construction of this project is also early in the next decade (2011-2012?), given the remaining technology development and the steps involved in moving through the NSF MREFC process. While not at the same cost level as JDEM, the LST program including its operations costs is likely to exceed \$300M. Thus even if LST is shared with DOE, the NSF contribution to LST is expected to require passage through the MREFC process.

The excitement engendered by the mystery of dark energy has, of course, led scientists across the nation (and around the world) to explore ways to tackle the problem using existing facilities with a variety of scientific approaches. As noted above, these include weak gravitational lensing, the evolution of galaxy clusters, and the growth of structure in the matter of the Universe, in addition to the established use of distant supernovae. Because these other promising approaches to learning about the dark energy are still being developed, it is not yet clear what the optimum strategy should be for the field as a whole. Moreover, the JDEM target launch date and LST completion are so far in the future that the agencies need guidance on what ought to be done in the near and intermediate term. A number of projects both within the US scientific community and internationally are actively being developed; some of these programs are likely to reveal aspects of the dark energy before JDEM is launched and LST completed.

To help sort out the best way forward in this important and exciting field, the AAAC recommended to the agencies last year that they form a task force to evaluate which initiatives to support in the near and intermediate term. The Scientific Assessment Group For Experiments In Non-Accelerator Physics (SAGENAP) also recommended in its 2004 report a roadmap study to provide context for this important area. The initiatives that will be evaluated by the task force will then set the stage for LST and JDEM. NASA, NSF, and DOE responded very positively to this request and established a Dark Energy Task Force (DETF) that will report to the AAAC and to the High Energy Physics Advisory Panel (HEPAP). The recommendations of the DETF will play a key role in helping the agencies respond to "Connecting Quarks with the Cosmos" (CQC) and to the Physics of the Universe report by providing a more detailed implementation plan. The AAAC fully endorses this approach and looks forward to receiving the report from the Task Force later this year.

Dark Energy: The AAAC supports a vibrant, wide-ranging program of investigations leading to understanding of the impact of Dark Energy on the Universe. The Dark Energy Task Force (DETF) was set up at our suggestion with the strong support of the agencies. The DETF will help optimize a Dark Energy program that the science community and the agencies can utilize to make progress over the next decade quickly and cost-effectively.

5.3 BEYOND EINSTEIN

In our 2004 report the AAAC highlighted our concern that a major aspect of the space science program for astronomy and astrophysics at NASA, the Beyond Einstein program, was progressing very slowly. This program included initiatives from both the Decadal Survey and from "Connecting Quarks with the Cosmos" (CQC). The major areas of concern were with the gravitational wave detector, the Laser Interferometer Space Antenna (LISA), the next-generation X-ray mission Constellation-X (Con-X), and the Einstein Probe program. We were pleased, therefore, to hear that the Beyond Einstein Formulation Authorization Document was signed in late 2004, formalizing the Beyond Einstein program, that LISA has been given Phase A status, and that some funding for Con-X was restored in the FY2006 budget request after its absence in the FY2005 budget. However, the projected launch date for Con-X has now slipped to no earlier than 2016, while as recently as two years ago, the expected launch date was projected to be 2013-14. LISA has also slipped about one year since 2003, with an anticipated launch now no earlier than 2012. The international collaboration with the European Space Agency (ESA) for LISA and the potential opportunity for such with Con-X are commendable, but significant fiscal challenges continue for these missions. Overall, the Beyond Einstein initiative remains severely underfunded, even though it is based on a science program that defined some of the highest-priority space missions in the Decadal Survey and the CQC report. Similar concerns were raised by the NAS Committee to Assess Progress Toward the Decadal Vision in Astronomy and Astrophysics, who noted that: "The Beyond Einstein roadmap (currently being updated), is an excellent implementation and synthesis of the Decadal Survey and CQC. For the program to fulfill its promise, support for the Beyond Einstein projects needs to be sustained."

A particular concern continues for the Einstein Probes program. This aspect of Beyond Einstein was discussed above (§5.3) in the context of the study of dark energy for one of its missions (JDEM). This program includes several potential missions of great interest, namely the Inflation Probe, the Black-Hole Finder and the Dark Energy Probe. While the program is still identified as part of the Beyond Einstein initiative, the President's FY06 budget request for NASA again provides zero funding, continuing the lack of funding that was in last year's FY05-FY09 budgets. The situation for the Einstein Probes mirrors that of the Beyond Einstein program as a whole: it has yet to receive significant fiscal traction.

Beyond Einstein: The AAAC recommends that NASA look carefully at providing resources for moving ahead on the major scientific opportunities identified in the Beyond Einstein program, including funding for the Einstein Probes.

5.4 CMB - CMB TASK FORCE

Measurements of the Cosmic Microwave Background (CMB) radiation have led to a remarkable series of discoveries of the universe. The CMB offers a pristine view of the universe when it was only 400,000 years old, a small fraction of its present age of 13.7 billion years. That the brightness of the CMB was found to be so uniform across the sky led to the inflation theory for the origin of the universe. After a long period of increasingly more sensitive measurements, anisotropy in the background was found at levels of only a few parts in a hundred thousand. Over the last few years, the careful measurements of the small CMB intensity fluctuations have shown that the spacetime of the universe is not curved—it is flat. For the first time, a full census of the makeup of the universe could also be made. We have learned that ordinary matter, the stuff of which the stars (and us) are made, can account for only a few percent of the universe, and that even the dark matter that holds galaxies together falls far short of that required to make the curvature of the universe flat as dictated by Einstein's equations. The remaining component is consistent with being made up of the dark energy that apparently now dominates the universe and is causing its expansion to accelerate. The measurements have also revealed that the first stars formed much earlier than previously thought. These measurements and results have been the result of a long program of careful detector development and testing through ground- and balloon-based telescopes that led to the recent spectacular success of the NASA Wilkinson Microwave Anisotropy Probe (WMAP) Explorer satellite mission.

As profound as these results have been, it has become clear that the minute variations in the polarization properties of the CMB radiation over large scales may be allow us to probe directly the first instants of time and test the inflation theory for the origin of our universe. Such a measurement would be one of the crowning scientific achievements of the century and of the utmost importance for our understanding of fundamental physics.

This ambitious goal of probing the first instants of the universe and testing inflation by definitive measurements of the polarization of the CMB was highlighted in CQC and POU. It builds directly on the remarkable progress in the last few years from observations of the CMB anisotropy. The definitive, foreground-limited, CMB polarization measurement will require an all-sky survey over several frequency bands and with sensitivity several orders of magnitude higher than ever achieved. That is the goal, and the great challenge, of the Inflation Probe of NASA's Beyond Einstein theme. A broad program supporting new technologies and techniques will need to be put in place to work toward achieving the definitive CMB polarization measurements. At the required sensitivity levels, systematics will be difficult to control and contamination from astronomical foregrounds will be severe. Several independent experiments using a variety of techniques will have to be explored. This will require the active involvement all three agencies.

The AAAC enthusiastically supported the effort to develop a joint NSF-NASA-DOE roadmap leading to definitive measurements of the CMB polarization. The CMB Task Force was set up early in 2004 and is nearing the end of its work. The CMB Task Force will report to both AAAC and HEPAP. The AAAC was presented with a draft of the CMB Task Force Executive Summary at its last meeting. The AAAC commended the task force on its very comprehensive study. The number and breadth of its recommended activities in the current funding environment were noted as a potential issue for its timely implementation, and so the AAAC asked that the task force clearly prioritize programs and areas for emphasis to help the guide the agencies if the full program could not be initiated in the near to intermediate term.

CMB Task Force: The AAAC will be presented with the full report from the CMB Task Force by its next meeting. The AAAC expects that the report, with its prioritized program, and the subsequent response from all three agencies, will provide a basis for moving forward in this exciting area on a broadly based program on CMB polarization.

5.5 GLAST

The Committee was pleased to hear that the Gamma-ray Large Area Space Telescope mission (GLAST) is now in the construction phase and is working toward a launch date of May 2007. GLAST is a very important gamma-ray space mission. It is the highest ranked space mission in the "moderate" category in the Decadal Survey. The primary instrument on GLAST, the Large Area Telescope (LAT), has been built in partnership between DOE and NASA. GLAST is the first such major program to be developed in partnership between the two agencies and the AAAC is particularly interested in how it develops. It is a pathfinder for future, even larger, joint efforts such as the Joint Dark Energy Mission (JDEM).

GLAST will survey the entire sky in high-energy gamma-rays over a wide field of view. The major instrument on GLAST, the Large Area Telescope (LAT) has encountered schedule and cost overruns. Previous cost overruns were successfully managed by the two agencies. However, due to substantial budget pressures, DOE has been unable to provide the proportional increase in funding needed to complete LAT and to launch GLAST on time. The committee strongly encourages NASA and DOE to work together to solve the current funding crisis. However, the committee is concerned that the cap in the President's FY06 budget request on DOE spending on GLAST will inhibit discussions needed to resolve the issues surrounding the current funding problem. The cap limits further spending by DOE HEP to just $3M for a total of $45M. We recommend that the cap be removed in the final budget so as to allow DOE and NASA to jointly solve the fiscal problems in a way that allows GLAST to move forward expeditiously to launch and operation. In doing so we would also recommend that the "lessons learned" from this experience be used to establish guidelines for how such programs would be jointly developed and managed in the future. The involvement of OMB and OSTP could be of value here in helping to identify policy issues and procedures that could be used for future such activities. A successful GLAST mission would bring great scientific progress, as well as being a successful working model for future NASA/DOE partnerships.

GLAST: The AAAC recommends that the cap in the President's FY06 budget request for DOE for GLAST be removed in the final budget so as to allow DOE and NASA to jointly resolve the fiscal issues with the Large Area Telescope LAT, allowing GLAST to move forward expeditiously to launch and science operations.

5.6 TPF: TPF-C and TPF-I

In response to the President's Vision, NASA elected to redefine the Terrestrial Planet Finder (TPF) into two missions, TPF-C and TPF-I. The near-term mission, TPF-C is a large optical space telescope with an optical coronagraph (the "C" in TPF-C), while TPF-I is an infrared interferometer (the "I") planned for longer-term implementation. TPF-I is akin to the European ESA Darwin project and could well become a major international program. TPF is an exciting mission scientifically, with its goal of detecting and characterizing earth-like planets around other stars. The scientific potential of TPF led to a recommendation for technology development in the

Decadal Survey. The changes to the TPF program early in 2004 were substantial—it now involves two major missions, and an accelerated development and implementation schedule for TPF-C leading to a launch in 2015. The NAS Committee on Astronomy and Astrophysics (CAA) was asked to provide a letter report on this change, which involved a significant departure from the Decadal Survey recommendations. The Decadal Survey recommendations were to initiate technology development for TPF and to establish the science framework based on missions like SIM and the others (e.g., the Discovery mission Kepler) with the expectation of a comprehensive review in the 2010 Decadal Survey. The CAA-led "Panel to Review the Science Requirements for the Terrestrial Planet Finder" raised concerns about the move to a very aggressive schedule for TPF-C, given the lack of scientific maturity (Kepler and SIM launch dates are around 2008 and 2011, respectively), and the potential impact of the technical and fiscal challenges on the priorities of the Decadal Survey. The CAA letter report noted that TPF is an exciting mission scientifically, but that, as a mission of at least the cost of the James Webb Space Telescope (JWST), significant impact could well occur on other highly-ranked missions in the Decadal Survey. The AAAC supports the concerns of the CAA. While significant technological developments have occurred in the last few years, TPF-C is a highly challenging mission. Thus, the risk to other programs is enhanced because of the potential for cost growth through the lack of technical maturity. The challenges of JWST were recognized early on and substantially mitigated by extensive development work that involved competitive sourcing. This approach greatly reduced the risk of cost growth in the program. The AAAC recommends that the experience from the JWST approach be considered for the development path of TPF-I and TPF-C.

TPF-C: The AAAC recommends that the development of the TPF-C mission be the subject of a comprehensive independent review of both its scientific and technical readiness by the National Academy of Sciences before decisions are made to move TPF-C forward as a flight project.

5.7 ATST

In last year's report, the AAAC reiterated one of the central findings of the Decadal Survey, and of the NAS study "The Sun to the Earth and Beyond": understanding the development of solar magnetic fields in space and time, and understanding how magnetic fields power flares and eruptive activity will require contemporaneous observations from the space-based Solar Dynamics Observatory (SDO) and the ground-based Advanced Technology Solar Telescope (ATST).

In this past year, both NASA and NSF have made steady progress toward this goal. SDO is progressing well. NASA held the SDO Confirmation Review in June 2004 and approved the mission to proceed to Phase C, with launch planned for early 2008.

After a comprehensive study and review, the ATST site selection was announced late in 2004. Site-specific planning for the chosen site on Haleakala on Maui in Hawaii is moving forward. The NSF Division of Astronomical Sciences (AST) conducted a thorough review of the ATST proposal for the construction phase. Based on that review, AST is carrying ATST forward in the MREFC process. The AAAC is pleased to see this project move forward and views positively the effort to include a significant component of international participation. The project did not achieve its goal of a FY2006 start, but the AAAC hopes that AST will continue to actively support ATST through the MREFC process to construction approval. The lag of ATST relative to SDO remains and will remain a concern of the AAAC. Potential involvement of the Air Force and international partners is being pursued. Collaboration between the Air Force and ATST would be an obvious benefit from siting ATST on Haleakala. A strong international component would add significant value to the program, both in the near-term development and construction, and in the long-term scientific effectiveness of the Observatory.

ATST: The AAAC applauds the progress that has been made on this important program and recommends that the NSF move ATST quickly through the MREFC process.

5.8 EXPLORERS

The AAAC notes with concern the continuation of diminished funding for the Explorer program. The Explorer line has provided many of NASA's most successful missions. The remarkable cosmological results from the Wilkinson Microwave Anisotropy Probe (WMAP) exemplify the power of Explorer missions. One of the Explorer program's key features has been the ability to respond rapidly to new scientific opportunities. The focused investigations enabled by Explorers provides early technology demonstration and scientific pathfinding for future missions. The competitive selection of Explorers, and their modest scale, provide an essential step in training the scientists and engineers who will build the larger missions in NASA's future. The funding shortfall has caused a substantial delay in the announcement of the next Explorer opportunity. The reduced rate of new missions under the current Explorer program limits the opportunities to exploit new technologies and scientific opportunities and to support the science goals of the Decadal Survey.

Explorers: The AAAC recommends that the NASA Explorer program be restored to its previous level to ensure its vitality and effectiveness.

5.9 THEORY

The AAAC is very encouraged that NASA is incorporating theory funding into its major programs, including those under development. Theory grants are now offered through each of the Great Observatory (Hubble, Chandra and Spitzer) General Observer programs. Two new Research and Analysis (R&A) programs, TPF Foundation Science and Beyond Einstein Foundation Science, provide significant opportunities for theoretical work.

We are encouraged also by the recent focus by NSF on responding to the recommendations of the Decadal Survey and the CQC Report with respect to support for theoretical work associated with all major projects. This past fall the NSF-MPS Theory Workshop focused attention on the challenge faced by the agency to fund theory appropriately. A number of recommendations are being made to NSF-AST and NSF-MPS by the steering committee of the NSF-MPS Theory workshop.

Theory: The AAAC recommends that the agencies build on the steps already taken and explicitly identify theory as an aspect of all major programs with some funding designated as part of the overall budget.

5.10 NVO

We are pleased with the excellent progress made by the joint NASA-NSF supported National Virtual Observatory (NVO) team. The NVO, recommended by the Decadal Survey as the highest-priority small project, will provide "a 'virtual sky' based on the enormous data sets being created now and the even larger ones proposed for the future. It will enable a new mode of research for professional astronomers and will provide to the public an unparalleled opportunity for education and discovery. The NVO will provide uniform access to numerous astronomical data archives and catalogs, obtained both from ground-based and space-borne telescopes and covering the entire wavelength spectrum from gamma-rays through X-rays, ultraviolet, visible, infra-red to radio wavelengths. Such data sets are orders –of magnitude larger, more complex, and more homogeneous than in the past. The NVO provides the ability to match and correlate data from such vastly different sources and thus empowers astronomers to mine the data archives to maximum benefit.

The NVO Framework development project, funded by the NSF through an ITR grant managed by the NSF Division of Astronomical Sciences, is now entering its 4^{th} year of a 5-year project, with $10M of funding over the 5 years. Seventeen organizations (from astronomy, computer sciences and information technology groups) are involved in the development, with discussions and collaborations currently being extended to additional groups (including the Gemini Science Archive, LSST, Keck, and Pan-STARRS). Extended community support and input has played a role through activities that include external advisory committees and a science steering committee. Related NASA activities include co-sponsoring the NVO Summer School, supporting NVO integration efforts at NASA data centers and various NVO-related R&D efforts. NVO is also co-founder of the International Virtual Observatory Alliance (IVOA), which now has 15 member projects. IVOA has adopted a standards process, and provides a forum for discussion and sharing of experience.

The NVO currently includes major archives and catalogs that are made available to the scientific community, with more archival data to come. The first archival tools and applications are now available for community use. The science prototypes of NVO provide science demonstrations that show capabilities of new infrastructure and motivate and guide technical developments of using the enormous collective data set of the Observatory. The first real applications were released in January 2005. The NVO team plans to engage the entire astronomical community in the immediate future. Data can now be examined in the NVO to discover and explore various astronomical objects in numerous data sets, cross-match data among numerous catalogs, upload images and cross-correlate them with selected surveys, and more. In addition, NVO is recognized as an excellent vehicle for education and public outreach (EPO). A second EPO workshop is planned for summer 2005.

The NVO provides access and tools for maximally utilizing archives, but is not itself an archive. NVO provides the tools that enable astronomers to collate material from all existing sources, which in turn increases the value of a single archive by placing it in the joint context of other archives. The AAAC hopes that the capabilities of the NVO will encourage and stimulate more widespread archiving of data by institutions and organizations that do not already have roadmaps to do so. The

AAAC would also be interested in seeing discussions develop with DOE regarding their future involvement in NVO.

NSF and NASA are working together to create a joint program for managing the NVO Observatory. A draft AO is expected within a year. The two agencies are working towards a strategy to allow for joint funding of US NVO work. Both agencies desire a fair and open competition, with peer-reviewed proposals. Good progress has been made on the long-range goals of the NVO through inter-agency discussions; an agreed philosophical framework exists. The AAAC is impressed with the excellent and thoughtful joint work of NSF and NASA in this important project, and with the progress made to date by the NVO team. This is an excellent example of a successful cross-agency teamwork to improve the scientific discovery and educational potential for the nation.

NVO: The AAAC strongly encourages the NVO team to continue its excellent work, especially its efforts to fully involve the science community. The AAAC recommends that the agencies, NSF and NASA, carry out their plan to solicit proposals for the operation of the NVO and to implement that within the next year.

APPENDIX A: ESTABLISHMENT OF THE AAAC UNDER THE NATIONAL SCIENCE FOUNDATION AUTHORIZATION ACT OF 2002

NATIONAL SCIENCE FOUNDATION AUTHORIZATION ACT OF 2002, Public Law 107-368, Dec.19, 2002

An Act To authorize appropriations for fiscal years 2003, 2004, 2005, 2006, and 2007 for the National Science Foundation, and for other purposes.

SEC. 23. ASTRONOMY AND ASTROPHYSICS ADVISORY COMMITTEE.

(a) Establishment.—The Foundation and the National Aeronautics and Space Administration shall jointly establish an Astronomy and Astrophysics Advisory Committee (in this section referred to as the “Advisory Committee”).

(b) Duties.—The Advisory Committee shall

(1) assess, and make recommendations regarding, the coordination of astronomy and astrophysics programs of the Foundation and the National Aeronautics and Space Administration;

(2) assess, and make recommendations regarding, the status of the activities of the Foundation and the National Aeronautics and Space Administration as they relate to the recommendations contained in the National Research Council's 2001 report entitled ``Astronomy and Astrophysics in the New Millennium", and the recommendations contained in subsequent National Research Council reports of a similar nature; and

(3) not later than March 15 of each year, transmit a report to the Director, the Administrator of the National Aeronautics and Space Administration, and the Committee on Science of the House of Representatives, the Committee on Commerce, Science, and Transportation of the Senate, and the Committee on Health, Education, Labor, and Pensions of the Senate on the Advisory Committee's findings and recommendations under paragraphs (1) and (2).

(c) Membership.—The Advisory Committee shall consist of 13 members, none of whom shall be a Federal employee, including

(1) 5 members selected by the Director;

(2) 5 members selected by the Administrator of the National Aeronautics and Space Administration; and

(3) 3 members selected by the Director of the Office of Science and Technology Policy.

(d) Selection Process.—Initial selections under subsection c shall be made within 3 months after the date of the enactment of this Act. Vacancies shall be filled in the same manner as provided in subsection c.

(e) Chairperson.—The Advisory Committee shall select a chairperson from among its members.

(f) Coordination.—The Advisory Committee shall coordinate with the advisory bodies of other Federal agencies, such as the Department of Energy, which may engage in related research activities.

(g) Compensation.—The members of the Advisory Committee shall serve without compensation, but shall receive travel expenses, including per diem in lieu of subsistence, in accordance with sections 5702 and 5703 of title 5, United States Code.

(h) Meetings.—The Advisory Committee shall convene, in person or by electronic means, at least 4 times a year.

(I) Quorum.—A majority of the members serving on the Advisory Committee shall constitute a quorum for purposes of conducting the business of the Advisory Committee.

(j) Duration.—Section 14 of the Federal Advisory Committee Act shall not apply to the Advisory Committee.

APPENDIX B: ACRONYMS

AAAC	Astronomy and Astrophysics Advisory Committee
AANM	Astronomy and Astrophysics in the New Millennium (2001 NAS report)
ALMA	Atacama Large Millimeter Array
AO	Adaptive Optics
AST	NSF Division of Astronomical Sciences
ATST	Advanced Technology Solar Telescope
CAA	Committee on Astronomy and Astrophysics
Chandra	Chandra X-ray Observatory
CMB	Cosmic Microwave Background (a.k.a. CMBR)
CMBR	Cosmic Microwave Background Radiation (a.k.a. CMB)
COMRAA	Committee on the Organization and Management of Research in Astronomy and Astrophysics
Con-X	Constellation X-Ray Observatory
CQC	Connecting Quarks with the Cosmos (2004 NAS report)
DOE	U.S. Department of Energy
ELT	Extremely Large Telescope
EPO	Education and Public Outreach
ESA	European Space Agency
EVLA	Expanded Very Large Array
EVLAII	Expanded Very Large Array Phase II
ExAO	Extreme Adaptive Optics
GLAST	Gamma Ray Large Area Telescope
GMT	Giant Magellan Telescope
GSMT	Giant Segmented Mirror Telescope
HEPAP	High Energy Physics Advisory Panel
HST	Hubble Space Telescope
ISS	International Space Station
IVOA	International Virtual Observatory Alliance
JDEM	Joint Dark Energy Mission
JWST	James Webb Space Telescope
LAT	Large Area Telescope
LISA	Laser Interferometer Space Antenna
LST	Large Survey Telescope
LSST	Large Synoptic Survey Telescope
MPS	NSF Directorate for Mathematical and Physical Sciences
MREFC	Major Research Equipment and Facilities Construction
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NRC	National Research Council
NSF	National Science Foundation
NSTC	National Science and Technology Council
NVO	National Virtual Observatory
OMB	Office of Management and Budget
Pan-STARRS	Panoramic Survey Telescope and Rapid Response System
R&A	Research and Analysis
R&D	Research and Development
SAGENAP	Scientific Assessment Group on Experiments in Non-Accelerator Physics

SDO	Solar Dynamics Observatory
SDT	Science Definition Team
SM4	HST Servicing Mission 4
SNAP	Supernova/Acceleration Probe
Spitzer	Spitzer Space Telescope
SWG	Science Working Group
TMT	Thirty Meter Telescope
TPF	Terrestrial Planet Finder
TPF-C	Terrestrial Planet Finder-Coronagraph
TPF-I	Terrestrial Planet Finder-Interferometer
UNESCO	United Nations Educational, Scientific and Cultural Organization
VLA	Very Large Array