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

March 15, 2007

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

Dr. Michael D. Griffin, Administrator
Office of the Administrator
NASA Headquarters
Washington, DC 20546-0001

Dr. Samuel W. Bodman, Secretary of Energy
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

The Honorable Bart Gordon, Chairman
Committee on Science and Technology
House of Representatives
Washington, DC 20515

The Honorable Daniel K. Inouye, Chairman
Committee on Commerce, Science and Transportation
United States Senate
Washington, DC 20510

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

Dear Dr. Bement, Dr. Griffin, Secretary Bodman, Chairman Gordon, Chairman Inouye, and Chairman Kennedy:

I am pleased to transmit to you the annual report of the Astronomy and Astrophysics Advisory Committee for 2006–2007.

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, and the Department of Energy;
(2) assess, and make recommendations regarding, the status of the activities of the Foundation and the National Aeronautics and Space Administration, and the Department of Energy 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, the Secretary of Energy 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 fourth 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 projects and programs.

I would 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 Ralph Hall, Ranking Member, Committee on Science and Technology, House of Representatives
Senator Ted Stevens, Ranking Member, Committee on Commerce, Science and Transportation, United States Senate
Senator Michael Enzi, Ranking Member, Committee on Health, Education, Labor and Pensions, United States Senate
Senator Barbara Mikulski, Chairwoman, Subcommittee on Commerce, Justice, Science, Committee on Appropriations, United States Senate
Senator Richard Shelby, Ranking Member, Subcommittee on Commerce, Justice and Science, Committee on Appropriations, United States Senate
Senator Bryon Dorgan, Chairman, Subcommittee on Energy and Water Development, Committee on Appropriations, United States Senate

Senator Pete Domenici, Ranking Member, Subcommittee on Energy and Water Development, Committee on Appropriations, United States Senate
Senator Bill Nelson, Chairman, Subcommittee on Space, Aeronautics and Related Agencies, Committee on Commerce, Science and Transportation, United States Senate
Senator Kay Bailey Hutchison, Ranking Member, Subcommittee on Space, Aeronautics and Related Agencies, Committee on Commerce, Science and Transportation, United States Senate
Representative Alan B. Mollohan, Chairman, Subcommittee on Commerce, Justice, Science, and Related Agencies, Committee on Appropriations, House of Representatives
Representative Rodney Frelinghuysen, Ranking Member, Subcommittee on Commerce, Justice, Science and Related Agencies, Committee on Appropriations, House of Representatives
Representative Peter J. Visclosky, Chairman, Subcommittee on Energy and Water Development, Committee on Appropriations, House of Representatives
Representative David L. Hobson, Ranking Member, Subcommittee on Energy and Water Development, Committee on Appropriations, House of Representatives
Representative Brian Baird, Chairman, Subcommittee on Research and Science Education, Committee on Science and Technology, House of Representatives
Representative Vernon Ehlers, Ranking Member, Subcommittee on Research and Science Education, Committee on Science and Technology, House of Representatives
Representative Mark Udall, Chairman, Subcommittee on Space and Aeronautics, Committee on Science and Technology, House of Representatives
Representative Ken Calvert, Ranking Member, Subcommittee on Space and Aeronautics, Committee on Science and Technology, House of Representatives
Dr. John H. Marburger, III, President's Science Advisor, Director, Office of Science and Technology Policy, Executive Office of the President
Dr. Kathryn Beers, Senior Policy Analyst, Physical Sciences and Engineering, Office of Science and Technology Policy, Executive Office of the President
Mr. Paul Shawcross, Science and Space Branch Chief, The Office of Management and Budget
Ms. Amy Kaminski, Program Examiner, NASA, The Office of Management and Budget
Dr. Joel Parriott, Program Examiner, NSF, The Office of Management and Budget
Mr. Kevin Carroll, Energy Branch Chief, The Office of Management and Budget
Mr. Leo Sommaripa, Acting Program Examiner, DOE, The Office of Management and Budget
Dr. Kathie Olsen, Deputy Director, National Science Foundation
Dr. Tony Chan, 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
Dr. Eileen Friel, Executive Officer, Division of Astronomical Sciences, National Science Foundation
Dr. Dana Lehr, Associate Program Director, Division of Astronomical Sciences, National Science Foundation
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Dr. Colleen Hartman, Acting Associate Administrator for Science, Science Mission Directorate, National Aeronautics and Space Administration
Dr. Paul Hertz, Chief Scientist, Science Mission Directorate, National Aeronautics and Space Administration

Dr. Richard Howard, Acting Director, Astrophysics Division, Science Mission Directorate, National Aeronautics and Space Administration
Dr. Eric Smith, Astrophysics Division, Science Mission Directorate, National Aeronautics and Space Administration
Dr. Michael Salamon, Astrophysics Division, Science Mission Directorate, National Aeronautics and Space Administration
Dr. Ray Orbach, Director, Office of Science, U.S. Department of Energy
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
Dr. Charles Elachi, Director, NASA Jet Propulsion Laboratory
Dr. Edward Weiler, Director, NASA Goddard Space Flight Center
Mr. Chuck Atkins, Chief of Staff, Committee on Science and Technology, House of Representatives
Ms. Janet Poppleton, Ranking Chief of Staff, Committee on Science and Technology, House of Representatives

Astronomy and Astrophysics Advisory Committee Members:

Dr. Neta Bahcall, Princeton University
Dr. John E. Carlstrom, (Vice-Chair) University of Chicago
Dr. Bruce Carney, University of North Carolina at Chapel Hill
Dr. Scott Dodelson, Fermi National Accelerator Laboratory
Dr. Wendy Freedman, Observatories of the Carnegie Institution of Washington
Dr. Katherine Freese, University of Michigan
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Dr. E. Sterl Phinney, California Institute of Technology
Dr. Marcia Rieke, University of Arizona
Dr. Keivan G. Stassun, Vanderbilt University
Dr. Alycia Weinberger, DTM, Carnegie Institution of Washington

ANNUAL REPORT

ASTRONOMY AND ASTROPHYSICS ADVISORY COMMITTEE

MARCH 16, 2006 - MARCH 15, 2007

REPORT STRUCTURE

This report covers many topics. The Executive Summary includes section numbers on the individual items that correspond to the supporting text in the main body of the report.

The Table of Contents can be found on page XVII in the front section. The main body of the report follows page XVIII. The committee members are listed on page XV and acknowledgements are on page XVI. The charge to the committee and the context for the AAAC's activities is given in the Introduction (page 1).

NSF starts on page 3 as §2, NASA on page 16 as §3, and DOE on page 29 as §4. More detailed discussions of individual issues, missions and programs are in §5 (Decadal) on page 33 and §6 (Interagency) on page 48.

EXECUTIVE SUMMARY

The nature of dark matter and dark energy in the universe, the formation of galaxies at early times, the nature of massive black holes, and the formation and life of stars and planetary systems are part of the fabric of our extraordinary scientific quest in astronomy. Together, the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), and the U.S. Department of Energy (DOE) Office of Science are providing opportunities for astronomical research that have allowed the nation to demonstrate its scientific and technological leadership.

The framework for this leadership is built on the decade-long plans of the National Research Council (NRC) Astronomy and Astrophysics Survey Committees, the most recent of which is the 2000 *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 of more recent NRC studies such as *Connecting Quarks with the Cosmos* (*CQC*).

The diversity that flourishes under the three agencies is central to the scientific success and public visibility achieved in astrophysics over the last several decades. Joint programs between NASA, NSF and DOE, implemented within a healthy scientific research budget, are increasingly 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 realizes greatly enhanced value from its investment in astronomy.

In response to the need to address the increasingly important interfaces among the agencies that support astronomy and astrophysics, the Astronomy and Astrophysics Advisory Committee (AAAC) was established in 2002 (and updated in 2005 to include DOE) by the Executive Branch and Congress to: 1) assess, and make recommendations regarding, the coordination of astronomy and astrophysics programs of NSF, NASA and DOE; 2) assess, and make recommendations regarding, the status of the activities of NSF, NASA and DOE as they relate to the recommendations contained in the National Research Council's 2000 Decadal report, and the recommendations contained in subsequent National Research Council reports of a similar nature. This annual report is the fourth by the AAAC.

The AAAC has dealt with many issues over the last year. The impact of the NASA Space and Earth Science FY07-11 budget cuts was given considerable attention by the Committee. The NASA Astrophysics program has many powerful missions in operation and more are coming, but serious challenges lie ahead. Of particular concern is the challenge of supporting a broad-ranging scientific program with a balanced suite of missions from the small Explorers to the large and rare flagship missions. The focus of our attention for NSF was on major new facilities and the Major Research Equipment and Facilities Construction (MREFC) process used for their construction, and on the Senior Review in the Division of Astronomical Sciences (AST). We devoted attention to the question of "lifecycle" costing of mqajor projects at NSF and the implications for the funding profile of large, high-technology projects that are of critical importance to the future of astronomical research. A serious concern is funding of the operations of major facilities. We appreciate the NSF's support for the Atacama Large Millimeter Array (ALMA) construction budget increase, hope that the Advanced Technology Solar Telescope (ATST, a project that is in MREFC Readiness), moves forward expeditiously, and are interested in the progress on a Giant Segmented Mirror Telescope (GSMT) and the Large Synoptic Survey Telescope (LSST). The discussions with DOE have centered on joint programs with NASA and NSF, including the excellent progress on the Gamma-ray Large Area Space Telescope (GLAST), and developments in dark-energy and dark-matter searches.

The AAAC has used several Task Forces to evaluate the scientific approaches that will best enable progress in key areas. The first was the Task Force on CMB Radiation (TFCR), which produced a comprehensive and exciting report in 2005. The excellent Dark Energy Task Force (DETF) report was accepted and transmitted to the agencies in mid-2006. The Dark Matter Scientific Assessment Group (DMSAG) is finalizing its draft report, which also looks excellent. The recently chartered ExoPlanet Task Force (ExoPTF) has begun work on its development of a framework for extra-solar planet detection and characterization both on the ground and in space.

The continuation of the American Competitiveness Initiative (ACI) into the FY08 budget request for NSF and DOE science (and NIST) was widely acknowledged as a key step in building a robust R&D base in the physical sciences. Congressional support for NSF research and DOE science in the FY07 Joint Funding Resolution was welcomed as a further key step in strengthening science and technology through its Innovation and Competitiveness effort. The omission of NASA science from ACI, where there are many parallels with research done at NSF and DOE, seems inconsistent, and even runs counter to the goals of ACI – the cuts in NASA science (after inflation) will negate some of the gains at NSF and DOE. It is a challenge for NASA to retain a healthy science program while it transitions to a new launch and transportation capability without additional funding. The AAAC is very concerned that the NASA science program has been seriously impacted and that further stresses lie ahead for a science program that has been such an effective demonstration of U.S. science and technology leadership.

The AAAC's strongest recommendation this year is that NASA's science funding outlook be restored.

Doing so would be entirely consistent with the commitment to innovation and competitiveness already demonstrated by the Administration and Congress for the NSF and the DOE Office of Science.

A) Findings and Recommendations for the Agencies

The AAAC's findings and recommendations for the agencies are shown in bold below and discussed in detail in the report.

2. NSF

A). The AAAC was very encouraged by the NSF budget increase in the FY07 budget request and its continuation in the FY08 budget request as steps towards the long-awaited budget "doubling" for research through the ACI. The Congressional FY07 Joint Funding Resolution support for an increased NSF research budget ensured that the momentum was not lost. Such increases are key to a future cutting-edge science and technology research program in the nation, and greatly encourages the commitment of young researchers to a science career. **The AAAC strongly supports the effort to further strengthen R&D through ACI increases at NSF. Significant innovation and competitiveness gains will accrue.**

B). The MREFC program continues to be of great interest to the AAAC, since major facility projects play such a central role in astronomy and astrophysics. The release of NSB-05-77 provides more structure to the MREFC process, as does the release of the first Facility Plan. However, the value of the Facility Plan for current and potential MREFC projects would benefit from the inclusion of likely timelines, phasing and key milestones for each project. **The MRFEC process is of great interest to the astronomy community since major facility projects are essential for progress in astronomy and astrophysics. The AAAC fully supports efforts to improve the MREFC process and to refine the Facility Plan.**

C). The AAAC also recommends that consideration be given to a phased management approach and "lifecycle" costing approach that recognizes the very different funding and management requirements of the different phases of large, high technology projects. A crucial phase that is not well supported by the current Divisional and MRFEC approaches is the pre-construction phase, in which key technologies and processes are demonstrated and the detailed construction plans developed. We also note that the immediate post-construction commissioning phase is a particularly critical period requiring adequate funding. By managing and funding these phases as an agency-level activity, the NSF should be able to reduce the risk of cost growth during construction and should ensure that high science returns are achieved more rapidly after construction ends. **The multi-stage process for major, high technology projects recommended by the AAAC will make the MREFC program more robust, lessen cost growth and risk during construction and enhance science return during operations.**

D). The AAAC commends AST for carrying out the Senior Review as a broad-ranging NSF astronomy "portfolio" review, and the Senior Review committee members for their effort on behalf of the community. The effort to obtain community input via solicitations and "Townhall" meetings was particularly appreciated. The Senior Review was a key step in moving forward on several very powerful new astronomy facilities, since the MREFC investments in major facilities like the Atacama Large Millimeter Array (ALMA), the Advanced Technology Solar Telescope (ATST), the Giant Segmented Mirror Telescope (GSMT), and the Large Synoptic Survey Telescope (LSST), will require significant operations funds to realize their full potential. **The AAAC commends AST for initiating and supporting the Senior Review and for fully involving the astronomy community through its solicitations of input and its "Townhall" meetings.**

E). A growing concern for major projects is the support of operations, maintenance, and upgrades (new instrumentation). For example, a single $0.5B project with a typical 10% annual budget for operations, maintenance and upgrades would alone consume a major fraction of the AST facility operations budget. In addition to the savings realized from closing or reducing operations of current facility operations in AST, as recommended by the Senior Review, the need for additional operations funding for next-generation facilities should be considered as future budgets are developed for MPS and AST. **The AAAC recommends consideration of the operations funding needs of major projects as an integral part of a thorough "lifecycle" cost assessment, and planning for the likely required additional funding.**

F). A number of remarkably powerful astronomy facilities from the Decadal Survey are under development or construction. The continued support by NSF for ALMA during the re-assessment of its construction budget is greatly appreciated, as was the transition of ATST to Readiness in MREFC. The AAAC hopes that the site issues will not delay ATST's transition to a New Start – or if delays become significant that consideration is given to other locations. The Expanded Very Large Array (EVLA) Phase 1 will be completed by 2010. The submission of an LSST proposal to the NSF as a proposed joint NSF/DOE program was welcomed. The development of GSMT, the top-ranked, large ground-based program in the Decadal Survey, continues, but largely by utilizing private funds at this time. Discussions regarding the Federal role are underway. Science community input is needed on any potential change in the ranking of GSMT and LSST. The AAAC suggests that the next Decadal Survey provides a suitable mechanism for doing this as part of its broad re-assessment of unfinished projects, without impacting progress on either facility in the near-term. **The AAAC appreciated the NSF support for the revised ALMA budget, and hopes that ATST can be moved forward as a New Start. The AAAC welcomes the continuing development of LSST and GSMT, and recommends that the next Decadal Survey be used to assess the ranking of these facilities for Federal support, without impacting their near-term efforts.**

G). A 2003 NSB report (02-190) highlighted the need for mid-scale instrumentation funding. Such funding (~$5M to ~$20M) is at levels above the $2M MRI cost cap, but is too small for MREFC. The AAAC concurs with the NSB report recommendation and further recommends that the NSF and MPS give added consideration and visibility to mid-scale instrumentation funding, as it is becoming an increasing critical aspect of the research framework for astronomy and astrophysics. **The AAAC recommends that NSF, MPS and AST respond to the need for mid-scale instrumentation funding.**

H). GSMT is the top-ranked large ground-based program in the 2000 Decadal Survey. Two projects, the Giant Magellan Telescope (GMT) and the Thirty Meter Telescope (TMT), which would be largely funded privately (with private funding that could exceed $500M in total), are under development. The timescale for private funding is potentially much shorter than Federal funding and so the Federal role and mechanism for funding remains unclear. This is discussed in some detail in §5.4. **The AAAC recommends that NSF, AST and MPS, along with the projects, explore mutually-beneficial (and likely innovative approaches) for funding the Federal component of GSMT, with OSTP help if need be.**

I). The Senior Review identified a number of programs for which closure or reduced cost operations are required. The AAAC will hear more this coming year about the impacts of those recommendations on other agencies. Other recommendations concerned operational efficiency improvements at national centers and also improvements in the balance between science return from current facilities *vs.* future projects. Particular attention was given to the National Optical Astronomical Observatory (NOAO) in this context, though the operational costs at Gemini were identified as a concern. The role of NOAO in LSST, and as the GSMT "program manager" for the NSF, makes operational efficiencies of particular interest to the AAAC. **The AAAC recommends that further consideration be given to any efficiencies that could accrue in the longer-term by improved linkages between the major national optical-IR facilities, NOAO and Gemini.**

3. NASA

A). The AAAC remains deeply concerned about the impact on the NASA space science program of removing more than $3B from the Science Mission Directorate (SMD) budget in the next 4-5 years. Science has been the most visible and productive element of NASA. NASA's extraordinary successes over the last decade have resulted in large part from its challenging, ambitious science missions, combined with continuing, broadly-based research support that produces stunning science return from a diverse portfolio of programs. The challenges of transitioning within the current NASA budget to a new generation of space capabilities in the framework of the Exploration Vision, with no new funding, have become obvious. The balance among the needs of Space Shuttle (STS) operations and ramp-down, International Space Station (ISS) completion and operation, Exploration Systems development and a robust Space and Earth Science program has come under great strain as the real costs of the transition to a new human spaceflight structure have been recognized. Yet no additional funds have been identified. **The lack of growth in the NASA budget to respond to the Exploration Vision is stressing all the agency's activities. The AAAC is deeply concerned about the growing impact on the space and earth science program.**

B). The added stress on the agency of the FY07 Joint Funding Resolution was largely alleviated for science by the explicit funding level and only a small (~1.5%) decrease for SMD. While this was welcome, a very serious near-term concern for the AAAC is whether the FY07 Joint Resolution budget for NASA will become the new baseline on top of which a modest increase might be applied, or whether the FY08 Congressional budget for NASA will be at least the FY08 request level. If the FY07 funding level becomes the new baseline for future budgets, further substantial cuts to science could well occur. **The AAAC is concerned that the appropriation for FY08 and beyond may lead to a further cut by using the FY07 appropriation as the base for future budgets, and recommends that the FY08 request be the base to preclude added impacts on science at NASA.**

C). The American Competitiveness Initiative (ACI) recognized the challenges faced by the nation in staying at the forefront of scientific and technological development. Research is essential to innovative activities and underpins a technologically-competitive society, as highlighted in the NRC report *Rising Above the Gathering Storm*. The exclusion of NASA science from the ACI, in contrast to the inclusion of DOE science, is inconsistent. There is no question that NASA is at the cutting-edge of science and technology research. This exciting and highly visible research contributes to the vitality of the national skill set and has encouraged young people to move into science and engineering. The Congressional interest in Innovation and Competitiveness enables a fresh opportunity for enhancing NASA science. **The AAAC strongly encourages Congress to consider enhancing the support for science at NASA explicitly to improve innovation and competitiveness, as has been done for NSF and DOE science.**

D). The last three Astronomy and Astrophysics Decadal Surveys have all emphasized the need for a balanced program of small, medium and large missions – and have given particular emphasis to the Explorer program and to a healthy program of research support (Data Analysis – DA, and Research and Analysis – R&A). However, the program is currently dominated by large missions. The cuts in the research and analysis budget have an immediate and significant impact and seem inconsistent with the broad goals of the ACI. The very infrequent Explorer opportunities (six years between mission proposals instead of the more typical three years) are indicative of a program on life-support. The DA/R&A funds and smaller-scale missions each serve a critical role in supporting the broad fabric of research needed for realizing the science from future missions and in enabling the development of the necessary personnel and skills. The Astrophysics program should be rebalanced as a part of any increase for science, or at the least when funds become available as the major astrophysics missions pass their spending peaks. **The balance between small, medium and large programs in the NASA Astrophysics Division has been undermined. The**

AAAC recommends that the funding "wedge" in FY09/10 be used to add some funding for R&A and small missions, to rebalance the program.

E). The AAAC welcomed the Administrator's announcement regarding the HST SM4 servicing mission. The new camera and spectrograph will again renew HST. The recent JWST Technology Non-Advocate Review (T-NAR) was very successful, and combined with the larger levels of contingency allocated to the program gives confidence that JWST is on a much more stable track to launch. The progress towards launch for GLAST, Kepler, WISE, Herschel and Planck is very encouraging, and will provide a considerable resource of new data. The potential for a first Beyond Einstein mission to be initiated in 2010 is also encouraging. SOFIA has been re-instated, and while it faces considerable challenges, we look forward to a successful flight and science demonstration. The Navigator program is under stress, but we expect the recently formed ExoPlanet Task Force to provide broad guidance on how to move forward on the ground and in space in this exciting area. A major concern develops when we view the science missions launch rate in 2009 and beyond for space science. It decreases significantly compared to recent times. **The AAAC welcomes the support and progress on many missions as they move towards launch and operations over the next few years, but notes that a significant drop in the number of science mission launches occurs after 2009, and views this dearth of new science opportunities as a major concern for the long-term productivity of the science program.**

F). Most missions now have lifecycle costs that are $2B or more. The exceptions are the cost-capped programs like Discovery and Explorer, and the future Probes like JDEM. It is crucial that programs under consideration for implementation by the Decadal Survey process reach a level of maturity that is characterized by a well-defined architecture with formally vetted costs. The AAAC emphasized last year that consistent support, roughly at the $10M level, would make a significant difference in the robustness of the mission selections in the next Decadal Survey. The improvements in early phase development funds in the FY08 budget for the major missions in Beyond Einstein (Con-X, LISA) and in Navigator (TPF) should be continued if possible until the Decadal Survey re-evaluates the mission suite in the Astrophysics arena. **The AAAC welcomes the support for conceptual and technological development for Con-X, LISA, and TPF in the FY08 budget and recommends that such support be continued through the next Decadal Survey.**

G). The AAAC greatly appreciated NASA's support for two interagency activities. (1) ExoPlanets: With the substantial advances on the ground and the recognition of the challenges and cost of major space missions for planet search projects like SIM and TPF, the AAAC recommended last year that NSF and NASA constitute a Task Force to develop a strategic framework for how to move forward on the detection and characterization of planets around other stars. The AAAC greatly appreciates that the agencies responded positively and quickly; the ExoPlanet Task Force (ExoPTF) has been formed and has begun its deliberations. Its report is expected later in 2007. (2) Beyond Einstein: The AAAC has been concerned for some time about the slow progress on the Beyond Einstein program. We welcomed the decision by SMD last year to ask the NRC to carry out a study to determine which Beyond Einstein mission should go forward if funding became available in a possible FY09/10 funding "wedge" as HST SM4 is completed and JWST passes the peak of its spending curve. The selection of three JDEM mission concept studies for conceptual development by NASA Astrophysics, and the joint support of the NRC Beyond Einstein Program Assessment Committee (BEPAC) study by DOE were also highly welcomed by the AAAC. **The AAAC welcomed NASA's support with NSF of the ExoPlanet Task Force (ExoPTF), and the developments in Beyond Einstein leading to a jointly funded NRC study with DOE HEP, the Beyond Einstein Program Assessment Committee (BEPAC). The selection of JDEM concept studies by NASA was also welcomed.**

H). The AAAC expressed great concern last year in our report about the lack of an advisory process at NASA. We were very encouraged when the new NASA advisory committees were established. The new structure does differ from that used previously, providing a clearer path for advice to the Administrator. The new structure has, however, lost a valuable role that was once provided by the Space Science Advisory Committee (SScAC). That structure encouraged dialogue, on wide-ranging issues that cut across the SMD divisions, between SMD and a broadly-representative group from the science community. An improved interface with SMD is in the best interests of both NASA and the science community to restore this important two-way communication link that has contributed to the success of NASA science in the past. **The AAAC welcomed the re-establishment of the advisory structure at NASA last year, but notes that dialogue between SMD and a broadly-representative group from the science community is missing in the new structure.**

4. DOE

A). The DOE Office of Science, primarily through the Office of High Energy Physics (HEP), is playing an increasing role in the nation's astronomy and astrophysics enterprise. DOE HEP is contributing in significant ways to projects that will address a number of fundamental scientific questions that explore the physics of the Universe. The NRC report, Elementary Particle Physics in the 21st Century (EPP2010), recommended action by DOE HEP in several areas of astrophysics: dark matter, CMB research and dark energy. These fields lie at the boundary of astrophysics and particle physics and promise great insights. The AAAC is encouraged by the progress towards the late-2007 launch of the joint DOE/NASA project Gamma-Ray Large Area Space Telescope (GLAST). The AAAC appreciates the support of HEP (and the NSF Physics Division) for the Task Force on CMB Research (TFCR), the Dark Energy Task Force (DETF) and the Dark Matter Scientific Assessment Group (DMSAG) and looks forward to the agencies' response to these activities. The recent increases for the DOE Office of Science from the ACI program and from Congressional action on the FY07 Joint Funding Resolution provide opportunities to significantly enhance the science program at DOE, though the AAAC was concerned that the increase in the FY08 budget request for HEP was small (<1%). **The AAAC appreciates the growing interest in astrophysics within DOE HEP and recommends that HEP continue to enhance their support of programs at the interface of astronomy and particle physics in response to the recommendations in EPP2010. The AAAC hopes that DOE-HEP shares in the ACI-led increase for DOE-science and that the FY08 request increase of <1% does not represent a trend for HEP funding.**

B). The AAAC welcomed the HEP solicitation for dark energy R&D, in addition to continuing DOE support for the Supernova Acceleration Probe (SNAP) R&D. The AAAC expects that the DETF report will provide guidance for the optimization of near- and intermediate-term activities, as well as for the Joint Dark Energy Mission (JDEM) and Large Survey Telescope (LST), and we hope that DOE, NASA and NSF will work together to utilize the DETF recommendations in their planning and review processes. The AAAC considers support of the DETF near-term (Stage III) activities to be particularly valuable at this time, and the AAAC recommends that HEP give particular attention to supporting Stage III projects as a means of making progress quickly and providing a framework for the much more expensive Stage IV projects (JDEM and LST). The AAAC notes that the Dark Energy Survey DES (Stage III) was recommended by HEPAP for the start of fabrication. Similarly, the DMSAG report is expected to provide very valuable guidance on how to optimally focus resources on the direct detection of dark matter. This field is poised to make significant advances with a modest increase in funding that would ensure the continuation of US leadership. The AAAC strongly endorses increased support for the dark-matter direct-detection efforts. **The AAAC recommends that the HEP further develop their support for R&D and programs in the areas of dark energy and dark matter, giving particular attention to supporting DETF Stage III near-term projects that provide a framework for the much more expensive Stage IV projects (JDEM and LST). The AAAC strongly endorses increased support for the dark matter direct detection efforts.**

B) Astronomy and Astrophysics Decadal Survey and Other NRC Reports: Findings and Recommendations

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 within the framework of the astronomy and astrophysics 2000 Decadal Survey and similar NRC reports (e.g., CQC). The rationale behind these findings and recommendations is given in the report at the listed section number.

5.1 Research and Analysis (R&A) and Mission Operations and Data Analysis (MO&DA) at NASA

R&A/MO&DA: The mission-specific science data analysis (the DA in MO&DA) funds are an important NASA innovation that has resulted in great science return from missions, benefiting both NASA and the science community. R&A is a complementary program that also benefits both NASA and the community. Funds from R&A complement mission-specific data analysis support, train the next generation of researchers, develop and demonstrate new technologies, and provide broad scientific underpinning for the space and earth science enterprise. The impact of the R&A budget cuts has been substantial. Even modest cuts have a dramatic impact since they result in a major reduction in near-term opportunities in a multi-year program. Recovery from such cuts is difficult since the options are few for substitute funding in an academic environment. **The AAAC strongly recommends a restoration of R&A funding at NASA, particularly if new funding is added in the FY08 appropriation, or utilizing part of the FY09/10 funding "wedge" in Astrophysics.**

5.2 Hubble Space Telescope (HST)

HST: The AAAC recognizes the scientific value of HST and the gains in capability that will be achieved through Servicing Mission 4 (SM4); thus, we support a carefully-managed program to maintain and upgrade HST, and we welcomed the NASA Administrator's announcement last fall that HST SM4 would be carried out in 2008. The new Wide-Field Camera 3 (WFC3) and Cosmic Origins Spectrograph (COS) will provide powerful new scientific capabilities. The new camera in particular will continue the extraordinary images from Hubble that have captured the public's imagination. **The AAAC welcomed the decision to carry out SM4, but recognizes the significant cost to SMD and the Astrophysics Division of preparing for the servicing mission and hopes that no further delays occur in SM4 beyond Fall 2008.**

5.3 James Webb Space telescope (JWST)

JWST: JWST is the highest-priority Major Initiative in the Decadal Survey. The realization of the high lifecycle cost of JWST in 2004-5, the disconnect between the current mission lifecycle costs and the budget estimates used in the previous Decadal Survey, and the budget cuts for SMD led to great concern about JWST's impact on Astrophysics/SMD. Considerable concern exists that JWST is still 6 years from launch and could develop problems that would further impact the balance of programs in the Astrophysics Division. The AAAC shares the view in the community, as reflected in the Decadal Survey, that a balanced program from R&A through moderate missions to "flagships" is essential. The recent very successful Technology Non-Advocate Review (T-NAR) and the identification of added contingency for JWST in FY08 and FY09 indicate a more stable path to launch and a more stable budget. **The AAAC reaffirms the high scientific value of JWST that led to its Decadal Survey ranking, and more generally the value of "flagship missions" like JWST for the overall science program. The AAAC hopes that JWST progresses to launch without further cost growth.**

5.4 Giant Segmented Mirror Telescope (GSMT)

GSMT: The AAAC greatly appreciates that NSF MPS and AST continue to support GSMT technology development through funding for the two community groups, the Giant Magellan Telescope (GMT) and the Thirty Meter Telescope (TMT). The next step is less clear. The options for Federal involvement in the GSMT project are unclear given both the potentially different timescales for GMT and TMT and the likely need for construction funding for either project more rapidly than can be provided through the MREFC process. TMT and GMT and their private donors are likely to be ready to commit hundreds of millions of dollars to construction well before a MREFC New Start could be reached. Federal involvement through an MREFC proposal for a set of instruments that are matched to each telescope's optimization could be a very effective mechanism for the national "GSMT" role, along with archive and operations support. The early commitment of operations support for the Federal partnership poses a challenge. The involvement of OMB and OSTP, and of committees in Congress, could help develop this unusual model. The role of the National Optical Astronomy Observatory (NOAO) as the national interface for GSMT is a welcome development. 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. **The AAAC recommends that NSF, AST and MPS, along with the projects, explore options for funding other aspects of GSMT, including major upgrades through MREFC (e.g., a set of second-generation instruments and archives). Developing mutually-beneficial approaches for funding operations could encourage progress on the projects with private donors, who will likely invest at least several hundred million dollars into GMT and/or TMT for construction. The AAAC recommends OSTP involvement if broader policy issues arise and encourages Congressional interest if the current mechanisms challenge the use of private funding.**

5.5 Large Synoptic Survey Telescope (LSST)

LSST: LSST is a ground-based 8-meter telescope project, whose goal is a deep survey of the sky accessible from Northern Chile. LSST was the third-highest-ranked large ground-based project in the Decadal Survey and would be a unique resource of data for the science community. LSST has a broad range of exciting science goals, including deep galaxy surveys, measurement of dark matter and dark energy, time-resolved surveys, and detection of Near Earth Objects. A central aspect of LSST is the rapid availability of data through a publicly-accessible archive. The LSST consortium submitted a construction proposal to NSF in February 2007 with a proposed cost of $467M in actual year dollars. The proposed approach for LSST is a joint NSF and DOE-HEP program (led by the NSF), along with private funding (~13%). **The AAAC is very supportive of LSST, but notes that consideration needs to be given to the consequent change in the Decadal prioritization if LSST precedes GSMT. The AAAC recommends that the next Decadal Survey be used to provide an assessment of the two projects – while NSF and DOE-HEP evaluate the LSST proposal and GSMT approaches are being worked.**

5.6 The Explorer Program

Explorers: The Explorer program has been identified as a high-priority activity in each of the last three Decadal Surveys. There remains strong community support for small-to-moderate scale programs within Astrophysics, and so the decision in 2006 to identify some funding for the Wide-Field Infrared Survey Explorer (WISE) was appreciated. The current frequency of missions is now about one every 6 years, roughly half the previous rate. The AAAC recommends that the NASA Explorer program be restored to a level of support adequate to ensure its vitality and effectiveness with frequent announcements of opportunity (every few years) as funding becomes available. **The AAAC recommends that the Explorer program, along with R&A, have high priority when additional funds become available, possibly through the funding "wedge" in FY09/10.**

5.7 The Beyond Einstein Program

Beyond Einstein: The AAAC has been concerned for some time that the Beyond Einstein program, with its missions from both the Decadal survey and *Connecting Quarks with the Cosmos* (CQC), and the potentially very rewarding Einstein Probes, has not been able to move forward. The decision to carry out an NRC study through the Beyond Einstein Program Assessment Committee (BEPAC) to identify a mission for a potential funding opportunity ("wedge") that opens up in FY09-FY10 was viewed very favorably by the AAAC. Of particular interest to the AAAC was the decision by DOE HEP to share in the cost of that study because of their interest in the Joint Dark Energy Mission (JDEM). In addition, the AAAC was very encouraged by the selection of three JDEM concepts for study funding by NASA Astrophysics over the next two years. **The AAAC is encouraged that these activities represent very real progress in the Beyond Einstein program.**

5.8 Einstein/Origins Probes

Einstein/Origins Probes: The Einstein/Origins Probes (similar to the New Frontiers program in the Planetary Science Division) would lie in cost between the ~$300M Explorer and ~$420M Discovery missions and the very infrequent flagship missions, and can address scientific questions that cannot be done within the cost envelope of the Explorer and Discovery missions. **The AAAC recommends that the NASA Science Mission Directorate (SMD) and the Astrophysics Division further refine the conceptual development of the Probes (~$600M missions) to where the "Probes" concept could be presented to the next Decadal Review as a potential option for mid-scale missions that could address specific science questions within the Astrophysics Division.**

5.9 Major Mission Technology and Conceptual Development

Conceptual Development for Flagship Missions: The AAAC recommended in its 2006 report that NASA provide resources for continuing a modest level of technology development for likely Major Initiatives identified in the 2000 Decadal Survey up through the next Decadal Survey. A useful level of such support was estimated to be about $10M/yr and would enable a much better understanding of the technological readiness and the likely performance, as well as improved cost estimates. The missions identified for this support were Constellation-X (Con-X), the Laser Interferometer Space Antenna (LISA) and the Terrestrial Planet Finder (TPF). **The AAAC was encouraged to see that the Astrophysics Division has been trying to increase the funding for Con-X, LISA and TPF and has identified funds in the FY08 budget request. The AAAC recommends that this be continued up through the next Decadal Survey.**

5.10 Stratospheric Observatory for Infrared Astronomy (SOFIA)

SOFIA: The SOFIA program underwent some dramatic changes in the last year. After an initial plan that would have reduced SOFIA to $0 and terminated the program, SOFIA underwent a recovery and is now part of the Astrophysics budget. SOFIA has had a troubled and costly development history and will not reach full operations until 2013, more than 15 years after the project began. SOFIA has a distinctly different operational model, akin to ground-based telescopes, in that its instruments can be developed to take advantage of ongoing technological developments. SOFIA is a major mission, with a lifecycle cost for 15 years of operations that exceeds $2B. From FY09 on its yearly cost is estimated to be $90M, including Institutional costs, broadly comparable to HST (excluding servicing costs) and similar to that expected for JWST, though an operations review is underway to assess the operations model and to see if any savings can be found. When fully operational, SOFIA is estimated to provide ~900 hours of on-target time per year for science observations. SOFIA provides for new instruments with the latest technology, and so the science opportunities can be high. However, as outlined in §5.10 the cost per hour of on-target operation is comparable to HST and JWST. **Given its cost and limited on-target time, the AAAC considers that it is crucial that SOFIA operates as efficiently as possible and fully involves the science community to provide high science returns.**

5.11 Considerations regarding the next Decadal Survey

Next Decadal Survey: The AAAC's tactical role, providing advice on the implementation of the Decadal Survey recommendations, provides it with some "front-line" experience on how well these very important NRC studies achieve their goals. Our collective experience suggests that there are several areas where the Decadal Survey process could be improved. These include (i) careful re-consideration and ranking of the unfinished projects and missions ("carry-over" projects), (ii) development of a more explicit science framework, (iii) consideration of the tradeoffs between continuing to support missions with high levels of annual operation costs *vs*. using those resources to initiate new small, intermediate or large missions, (iv) developing a process that might allow iteration on the Decadal Survey recommendations during the decade, and (v) establishing better cost estimates and better review of the cost estimates. **The AAAC recommends that the NRC and the agencies consider these issues during their discussions on the next Decadal Survey.**

C) Interagency Coordination: Findings & Recommendations

The programs and activities discussed here involve interagency coordination for DOE, NASA and NSF. The rationale behind these findings and recommendations is given in the report at the listed section number.

6.1 Research and Analysis (R&A) and Workforce Development

R&A: The AAAC notes that a central goal of the American Competitiveness Initiative (ACI) is to improve basic research in the physical sciences and in so doing excite and train young researchers and technologists. The AAAC noted in its 2006 report that cuts at NASA in R&A run counter to that ACI goal and that R&A funding should be restored at NASA. The cuts at NASA are leading to increased pressure on the smaller R&A (grants) program at NSF. Given its role in advising on the optimization of the astronomy and astrophysics enterprise in the nation, the AAAC is quite concerned that decreases in R&A budgets overall will lead to less-than-effective utilization of current facilities, reduced productivity, slower progress on major scientific issues of great public interest, and slower development of new facilities to address cutting-edge science questions. Many examples can be enunciated where R&A cuts damage a much larger and broader research community's productivity (e.g., detector development, laboratory astrophysics, data analysis tools, numerical modeling, etc). **The AAAC recommends that OSTP consider the impact of the imbalances caused when cuts at one agency offset the gains that are being implemented at others through ACI increases.**

6.2 National Virtual Observatory (NVO)

NVO: The NVO was the top-ranked "small" project in the Decadal Survey and was the only program in the small category to be explicitly ranked. The slow pace on the joint NASA-NSF solicitation for proposals to manage the NVO operation is reducing momentum on this innovative program. Discussions should also be undertaken with DOE HEP regarding their involvement in NVO as collaborative projects develop. **The AAAC recommends that NSF and NASA, possibly with OSTP assistance, expedite their plan to solicit**

proposals for the operation of the NVO and move forward expeditiously this year in implementing this key step for the implementation of the NVO.

6.3 Advanced Technology Solar Telescope (ATST) – Solar Dynamics Observatory (SDO) Synergy

ATST: The AAAC applauds the progress that has been made on this important program and greatly appreciates the support from the NSF Director's Office in moving ATST into the MREFC Readiness Phase. ATST is a major project with a projected construction budget of $225M that demonstrated its readiness to move forward at its recent Preliminary Design Review (PDR). The choice of Haleakala as the site for ATST has brought some site-specific challenges. It is hoped that these will not lead to delays in the project, but alternative locations should be considered if delays occur. **The AAAC recommends that NSF move ATST quickly through the MREFC process to a New Start to take advantage of the scientific synergies that will arise from overlap with the NASA Solar Dynamics Observatory (SDO), to minimize both the carrying costs for AST of a project post-PDR and the impact on other major astronomy projects that are potential MREFC funding recipients, and to realize one of the goals of the Senior Review, namely the focus of activities on new, more powerful facilities.**

6.4 Giant Segmented Mirror Telescope (GSMT) – James Webb Space Telescope (JWST) Synergy

GSMT/JWST Synergy: The AAAC emphasizes that operation of GSMT in the JWST era would provide major scientific synergies. A joint report from the GSMT and JWST Science Working Groups (SWGs) highlights the scientific value of such synergy. **The AAAC strongly encourages NSF to take advantage of opportunities that would help GSMT move forward more expeditiously so that the GSMT/JWST synergies could be realized.**

6.5 Dark Energy: The Dark Energy Task Force (DETF)

Dark Energy: The AAAC recognizes the interest in 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 and completed its report in 2006. The findings and recommendations from the DETF were transmitted through the AAAC and the High Energy Physics Advisory Panel (HEPAP) and will help to optimize a dark energy program that the science community and the agencies can implement to make progress over the next decade quickly and cost-effectively. **The AAAC recommends that the agencies coordinate their plans and activities in this area and that particular attention be given to supporting DETF near-term Stage III projects as a means of making progress quickly and providing a framework for the much more expensive Stage IV projects.**

6.6 Joint Dark Energy Mission (JDEM)

JDEM: A number of important developments occurred in 2006 for JDEM. Three JDEM concepts were selected by NASA for two-year mission concept studies, NASA requested an NRC Beyond Einstein study (Beyond Einstein Program Assessment Committee, BEPAC) that includes JDEM, and the DETF provided a refinement of the gains that should be expected from a selected JDEM mission (and LST or any other Stage IV activity). The AAAC welcomed the involvement and support of DOE HEP in making the NRC BEPAC study a joint NASA/DOE study. The AAAC awaits with interest the outcome of that study. **JDEM is a particularly interesting case for interagency cooperation, and the AAAC welcomes and appreciates**

the continuing willingness of the agencies to work towards overcoming some of the challenges that result from the different approaches to "doing business."

6.7 Dark Matter Science Assessment Group (DMSAG)

DMSAG: The AAAC welcomed the formation of a Dark Matter Scientific Assessment Group (DMSAG) jointly by the AAAC and the High Energy Physics Advisory Panel (HEPAP) to advise DOE HEP and the NSF Division of Physics (PHY) and AST concerning the U.S. dark-matter direct-detection research program. The DMSAG draft report was recently discussed by both the AAAC and HEPAP, and the DMSAG was commended for their excellent work. Noting that an external expert review had worked well for the TFCR and DETF reports, the AAAC asked the DMSAG committee to undertake a similar external review. The AAAC also requested a finer-grained prioritization of activities for the final report. The AAAC expects to receive the final DMSAG report in spring 2007 for transmittal to the agencies. The DMSAG identified a path to significant advances with a modest increase in funding that would ensure the continuation of US leadership. **The AAAC strongly endorses increased support for the dark-matter direct-detection efforts.**

6.8 ExoPlanet Task Force (ExoPTF)

ExoPTF: The detection and characterization of planets around other stars has become one of the exciting research fields of our time, with great public interest. The search for planets involves both space missions and ground-based programs. In 2006, the AAAC recommended that the agencies consider the establishment of a Task Force to develop a strategic plan for planet detection and characterization, as well as planetary formation, with consideration of the relative roles and contributions of future ground-based programs and space missions. Such a report, as well as being a guide for agency planning, will also provide very valuable input to the next Decadal Survey. NSF and NASA responded very positively, and the ExoPTF held its first meeting in February 2007 with a goal of producing its report by Fall 2007. **The AAAC greatly appreciates the agencies' rapid response to its recommendation to set up the ExoPTF.**

6.9 Cosmic Microwave Background: Task Force on CMB Research (TFCR)

CMB Task Force: The CMB Task Force (TFCR) was the first Task Force undertaken under the auspices of the AAAC. The TFCR's comprehensive and valuable study will provide a basis for moving forward in this exciting area on a broadly based program for CMB polarization research whose ultimate goal is probing the first instant of the universe (the inflation epoch). The NRC report, Elementary Particle Physics in the 21st Century *(*EPP2010), recently highlighted the importance of CMB research. The TFCR report will provide invaluable guidance for the next Decadal Survey. **The AAAC would be interested in discussing with the agencies the impact of the TFCR's recommendations.**

6.10 Implementation of Task Force Recommendations

Task Force Recommendations: The AAAC transmitted final reports to the agencies from the Task Force on CMB Research (TFCR) in October 2005 and from the Dark Energy Task Force (DETF) in June 2006. The transmission of the Dark Matter Scientific Assessment Group (DMSAG) report will occur by the middle of 2007. The ExoPlanet Task Force (ExoPTF) is underway and will report late in 2007. These reports will also provide valuable input for the next Decadal Survey. A key question surrounds the implementation of the recommendations in these reports. **In the coming year the AAAC is interested in further discussion with**

the agencies about how these recommendations will be folded into agency planning and roadmapping activities, Research and Analysis (R&A) funding, and instrument and facility planning.

6.11 South Pole Station Communications

South Pole: There is now a very substantial investment at the NSF South Pole Station (over $300M) in science programs like the IceCube neutrino observatory, the South Pole Telescope (SPT) and a variety of other smaller facilities. Reliable high-bandwidth data communications are key to their effective operation. The normal geostationary satellites used for data communications are not visible from the South Pole, and so the only high-speed option is the Tracking and Data Relay Satellite System (TDRSS). The AAAC discussed the concerns about the reliability and availability of TDRSS with the NSF Office of Polar Programs (OPP). Bandwidth is available in the short term, but there is considerable concern about the long term. **The AAAC encourages joint discussions between NSF and NASA and planning to develop a long-term alternative to the aging TDRSS for South Pole data communications.**

6.12 Gamma-ray Large Area Space Telescope (GLAST)

GLAST: The AAAC is very encouraged that the Gamma-ray Large Area Space Telescope (GLAST) is moving forward towards a launch in late 2007. A successful GLAST mission will bring great scientific progress, as well as provide a useful working model for future NASA-DOE partnerships.

6.13 Lessons-Learned Interagency Study

Lessons-Learned: Following discussions with the agencies and OSTP early last year, and a letter from the AAAC regarding the value of a “Lessons-Learned” study, the AAAC was pleased to hear that the agencies and OSTP were undertaking such an activity regarding collaborative interagency projects under OSTP guidance. **The AAAC hopes that this activity comes to fruition this year and that OSTP can make the resulting report available to the Committee.**

6.14 Funding for Committee Meetings

Committee Travel: The burden for travel for the AAAC has fallen fully on NSF AST and is a serious impact on their limited Salaries and Expenses (S&E) budget. **The AAAC believes that it would be appropriate for the three agencies it advises to share in the travel burden and recommends that they find mechanisms that would allow sharing of the travel costs.**

Synopsis: The NRC Decadal Survey and the NRC report CQC set out an exciting program for astronomical research that we fully 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 by astronomy over the last several decades. 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 and astrophysics.

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ACKNOWLEDGEMENTS

Over the last year we have met with many key people involved in the nation's astronomy and astrophysics enterprise. We deeply appreciate their willingness to take the time to interact with us, to listen to us, and to provide us with insights and understanding of broader issues. Our appreciation goes to the President's Science Adviser and OSTP Director John Marburger, NASA Administrator Mike Griffin, NSF Deputy Director Kathie Olsen and NSF MPS Assistant Director Tony Chan for their interest in the Committee's activities. The discussions with OMB Examiners Amy Kaminski, David Trinkle and Joel Parriott are always fascinating for their insights, and we greatly appreciate their interest in a strong science enterprise. We greatly appreciate the interactions and support of OSTP scientists Rob Dimeo and Jon Morse. They have provided a key interface and support for science in the Administration. The interest in the AAAC's activities by members of the Congressional staff were greatly appreciated, with particular thanks to Chuck Atkins, Elizabeth Grossman, Dick Obermann, Jim Wilson and Ed Feddeman.

There are many others from the agencies who have attended our meetings and provided us with excellent insight and advice, and we truly appreciate their wisdom. Our deliberations have involved presentations and discussions with many members of the community, as well, and have left us always impressed with their dedication and commitment to doing the best science possible within the budgetary constraints that necessarily frame the nation's scientific research enterprise.

We owe very special thanks to our Task Force chairs and team members. The TFCR, chaired by Rainer Weiss, and the DETF, chaired by Edward (Rocky) Kolb, produced remarkably thoughtful and valuable reports. Two other task forces will produce reports this year. The DMSAG, chaired by Henry Sobel, has produced an excellent draft report, and the ExoPTF, chaired by Jonathan Lunine has begun its deliberations.

We particularly appreciate the support and involvement with the committee of those from the agencies who have worked with the AAAC to keep it informed and who have responded to our many questions. These include Robin Staffin and Kathy Turner from DOE HEP, Colleen Hartman, Paul Hertz, Rick Howard, Michael Salamon, and Eric Smith from NASA SMD, and Wayne Van Citters and Eileen Friel from NSF AST. We truly appreciate their commitment to the science community and to the advisory process that they have supported so diligently. The AAAC's Executive Secretary from NSF AST, Dana Lehr, has worked incredibly hard on our behalf, and we are very grateful for her efforts, support and very pragmatic advice. Her responsiveness, hard work and guidance on our behalf have played a key role in making the AAAC a voice for science.

ANNUAL REPORT

ASTRONOMY AND ASTROPHYSICS ADVISORY COMMITTEE

MARCH 16, 2006 - MARCH 15, 2007

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ANNUAL REPORT

ASTRONOMY AND ASTROPHYSICS ADVISORY COMMITTEE

MARCH 16, 2006 - MARCH 15, 2007

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. Through its use of innovative technologies and cutting edge research programs, the Federal investment in astronomical research has demonstrated U.S. scientific and technological vitality and resulted in profound insights about the universe.

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 address the increasingly important interfaces among the agencies involved in supporting astronomy and astrophysics: the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), and the U.S. Department of Energy (DOE). Support for this by the Executive Branch and Congress led to the establishment of the Astronomy and Astrophysics Advisory Committee (AAAC) under the NSF Authorization Act of 2002, modified in 2004 to include DOE (as of March 2005), with the joint goals to:
1) assess, and make recommendations regarding, the coordination of astronomy and astrophysics programs of NSF, NASA, and DOE and
2) assess, and make recommendations regarding, the status of the activities of NSF, NASA and DOE as they relate to the recommendations contained in the National Research Council's 2000 Decadal report, and the recommendations contained in subsequent National Research Council reports of a similar nature. (See Appendix A for the full language.)

The formal inclusion of the DOE reflected the increasing activities of the Office of High Energy Physics (HEP) in astronomy and astrophysics and was a very welcome addition.

1.2 Context and Activities

The National Academy of Sciences (NAS) Astronomy and Astrophysics 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 2000 NRC Decadal Survey *Astronomy and Astrophysics in the New Millennium*[1] (hereafter called the Decadal Survey), followed by the NRC report *Connecting Quarks with the Cosmos*[2] (CQC), set out an exciting, viable program for

[1] http://www.nap.edu/books/0309070317/html/
[2] http://www.nap.edu/books/0309074061/html/

astronomical research that the AAAC heartily endorses. The recent NRC report from the Committee to Assess Progress Toward the Decadal Vision in Astronomy and Astrophysics[3] reaffirmed the vitality and relevance of the program outlined in the Decadal Survey. The AAAC fully concurs with the NRC committee's assessment 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 broad suite of missions and projects developed by the astronomical community working with NASA and NSF, and increasingly by DOE, is key to the scientific success and public visibility achieved in astrophysics over the last several decades. Increasingly NASA, NSF and DOE are involved in cooperative, collaborative, and joint ventures. While challenges arise from the different approaches to supporting research, joint programs (such as the Gamma-Ray Large Area Space Telescope, GLAST) or synergistic activities (such as the concurrent operations of the Hubble Space Telescope, HST, with 8-meter-class ground telescopes) enable more efficient use of national resources for scientific endeavors. A healthy scientific research budget is essential for each agency – NSF, NASA and DOE – if we are to continue to build on these joint and synergistic activities.

The attention given to the importance of basic physical research in the American Competitiveness Initiative (ACI) is most encouraging. The increases in the FY07 President's budget requests for NSF and DOE provide opportunities to enhance the Nation's research, training and technological base. The Congressional support for NSF research and DOE science in the FY07 budget that passed the House and Senate in January and February 2007 was reflected in significant increases for these agencies. Given that the FY07 Congressional budget largely held spending constant at FY06 levels for most agencies, the acknowledgement of the importance of science at NSF and DOE was received very positively. As was the case last year, the good news here is offset by concerns regarding the impact of the changes for NASA science. The decreases (after inflation) in NASA's Science Mission Directorate (SMD) budget over the next five years are of great concern for the astronomical, space and earth sciences.

Responding to CQC, the report of the NSF-NASA-DOE National Science and Technology Council (NSTC) working group was released early in 2004. This report, *A 21st Century Frontier of Discovery: The Physics of the Universe*[4] (POU), is an excellent example of interagency cooperation for dealing with initiatives that are of mutual interest to more than one agency. The AAAC has formulated several Task Forces, several in conjunction with the NSF-DOE High Energy Physics Advisory Panel (HEPAP), to address tactical issues relating to specific important research areas in astronomy and astrophysics and in particle physics. These Task Forces will play a major role in guiding the agencies during planning for future budgets and will provide input for the next Decadal Survey. These Task Forces include: the Task Force on CMB Research (TFCR), whose report was accepted in mid-2005; the Dark Energy Task Force (DETF), whose report was accepted in mid-2006; the Dark Matter Scientific Assessment Group (DMSAG), whose report will be finalized in the first half of this year; and the ExoPlanet Task Force (ExoPTF), which has just been formed to assess the opportunities for extra-solar planet detection and characterization on the ground and in space, and which is expected to report by late 2007.

This report summarizes the findings and recommendations of the AAAC for the one-year period between 16 March 2006 and 15 March 2007. The AAAC held five meetings between 16 March 2006 and 15 March 2007. Face-to-face meetings were held at the NSF on 11-12 May 2006 and 12-13 October 2006 and hosted by NASA on 7-8 February 2007. Telephone conferences were held to review and transmit the DETF report on 19 December 2006 and to review a draft of this report on 9 March 2007. The AAAC meeting agendas and minutes, as well as reports, can be found at http://www.nsf.gov/mps/ast/aaac.jsp

[3] http://www.nap.edu/catalog.php?record_id=11230
[4] http://www.ostp.gov/html/physicsoftheuniverse2.pdf

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 of reports such as CQC.

2.0 National Science Foundation

A). The AAAC was very encouraged by the NSF budget increase in the FY07 budget request and its continuation in the FY08 budget request as steps towards the long-awaited budget "doubling" for research through the ACI. The Congressional FY07 Joint Funding Resolution support for an increased NSF research budget ensured that the momentum was not lost. Such increases are key to a future cutting-edge science and technology research program in the nation, and greatly encourages the commitment of young researchers to a science career. ***The AAAC strongly supports the effort to further strengthen R&D through ACI increases at NSF. Significant innovation and competitiveness gains will accrue.***

B). The MREFC program continues to be of great interest to the AAAC, since major facility projects play such a central role in astronomy and astrophysics. The release of NSB-05-77 provides more structure to the MREFC process, as does the release of the first Facility Plan. However, the value of the Facility Plan for current and potential MREFC projects would benefit from the inclusion of likely timelines, phasing and key milestones for each project. ***The MRFEC process is of great interest to the astronomy community since major facility projects are essential for progress in astronomy and astrophysics. The AAAC fully supports efforts to improve the MREFC process and to refine the Facility Plan.***

C). The AAAC also recommends that consideration be given to a phased management approach and "lifecycle" costing approach that recognizes the very different funding and management requirements of the different phases of large, high technology projects. A crucial phase that is not well supported by the current Divisional and MRFEC approaches is the pre-construction phase, in which key technologies and processes are demonstrated and the detailed construction plans developed. We also note that the immediate post-construction commissioning phase is a particularly critical period requiring adequate funding. By managing and funding these phases as an agency-level activity, the NSF should be able to reduce the risk of cost growth during construction and should ensure that high science returns are achieved more rapidly after construction ends. ***The multi-stage process for major, high technology projects recommended by the AAAC will make the MREFC program more robust, lessen cost growth and risk during construction and enhance science return during operations.***

D). The AAAC commends AST for carrying out the Senior Review as a broad-ranging NSF astronomy "portfolio" review, and the Senior Review committee members for their effort on behalf of the community. The effort to obtain community input via solicitations and "Townhall" meetings was particularly appreciated. The Senior Review was a key step in moving forward on several very powerful new astronomy facilities, since the MREFC investments in major facilities like the Atacama Large Millimeter Array (ALMA), the Advanced Technology Solar Telescope (ATST), the Giant Segmented Mirror Telescope (GSMT), and the Large Synoptic Survey Telescope (LSST), will require significant operations funds to realize their full potential. ***The AAAC commends AST for initiating and supporting the Senior Review and for fully involving the astronomy community through its solicitations of input and its "Townhall" meetings.***

E). A growing concern for major projects is the support of operations, maintenance, and upgrades (new instrumentation). For example, a single $0.5B project with a typical 10% annual budget for operations, maintenance and upgrades would alone consume a major fraction of the AST facility operations budget. In addition to the savings realized from closing or reducing operations of current facility operations in AST, as recommended by the Senior Review, the need for additional operations funding for next-generation facilities should be considered as future budgets are developed for MPS and AST. ***The AAAC recommends consideration of the operations funding needs of major projects as an integral part of a thorough "lifecycle" cost assessment, and planning for the likely required additional funding.***

F). A number of remarkably powerful astronomy facilities from the Decadal Survey are under development or construction. The continued support by NSF for ALMA during the re-assessment of its construction budget is greatly appreciated, as was the transition of ATST to Readiness in MREFC. The AAAC hopes that the site issues will not delay ATST's transition to a New Start – or if delays become significant that consideration is given to other locations. The Expanded Very Large Array (EVLA) Phase 1 will be completed by 2010. The submission of an LSST proposal to the NSF as a proposed joint NSF/DOE program was welcomed. The development of GSMT, the top-ranked, large ground-based program in the Decadal Survey, continues, but largely by utilizing private funds at this time. Discussions regarding the Federal role are underway. Science community input is needed on any potential change in the ranking of GSMT and LSST. The AAAC suggests that the next Decadal Survey provides a suitable mechanism for doing this as part of its broad re-assessment of unfinished projects, without impacting progress on either facility in the near-term. ***The AAAC appreciated the NSF support for the revised ALMA budget, and hopes that ATST can be moved forward as a New Start. The AAAC welcomes the continuing development of LSST and GSMT, and recommends that the next Decadal Survey be used to assess the ranking of these facilities for Federal support, without impacting their near-term efforts.***

G). A 2003 NSB report (02-190) highlighted the need for mid-scale instrumentation funding. Such funding (~$5M to ~$20M) is at levels above the $2M MRI cost cap, but is too small for MREFC. The AAAC concurs with the NSB report recommendation and further recommends that the NSF and MPS give added consideration and visibility to mid-scale instrumentation funding, as it is becoming an increasing critical aspect of the research framework for astronomy and astrophysics. ***The AAAC recommends that NSF, MPS and AST respond to the need for mid-scale instrumentation funding.***

H). GSMT is the top-ranked large ground-based program in the 2000 Decadal Survey. Two projects, the Giant Magellan Telescope (GMT) and the Thirty Meter Telescope (TMT), which would be largely funded privately (with private funding that could exceed $500M in total), are under development. The timescale for private funding is potentially much shorter than Federal funding and so the Federal role and mechanism for funding remains unclear. This is discussed in some detail in §5.4. ***The AAAC recommends that NSF, AST and MPS, along with the projects, explore mutually-beneficial (and likely innovative approaches) for funding the Federal component of GSMT, with OSTP help if need be.***

I). The Senior Review identified a number of programs for which closure or reduced cost operations are required. The AAAC will hear more this coming year about the impacts of those recommendations on other agencies. Other recommendations concerned operational efficiency improvements at national centers and also improvements in the balance between science return from current facilities vs. future projects. Particular attention was given to the National Optical Astronomical Observatory (NOAO) in this context, though the operational costs at Gemini were identified as a concern. The role of NOAO in LSST, and as the GSMT "program manager" for the NSF, makes operational efficiencies of particular interest to the AAAC. ***The AAAC recommends that NSF, AST and MPS, along with the projects, explore mutually-beneficial (and likely innovative approaches) for funding the Federal component of GSMT, with OSTP help if need be.***

NSF AND ACI: The NSF plays a central role in the Nation's science enterprise. The agency 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.

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 effort to "double the budget" of the NSF in the 2002 Authorization Act. The nation's research endeavor is one of its great strengths. The lack of any progress on the doubling for several years was disappointing, but we were encouraged last year when the American Competitiveness Initiative (ACI) was announced with its emphasis on the importance of the physical sciences. Growth in NSF's budget due to ACI will have a significant effect on the vitality of the research efforts across the nation, particularly for researchers and their students who are funded by the NSF in academic institutions.

Putting the NSF budget back on a track for significant growth is a key step in meeting the goals of ACI. The first step in that doubling, the 7.9% increase requested for NSF for FY07, was extremely welcome news for the scientific research community. The initial concerns about the loss of momentum due to the implementation of a Continuing Resolution for the FY07 Congressional budget were removed when the FY07 Joint Funding Resolution contained essentially the whole ACI increase for the research component of the NSF's budget (the majority of the budget). The 7% increase in FY07 from Congress was a major step forward towards realizing a doubling of the NSF research budget. The AAAC was very encouraged by the subsequent ACI increase of 6.8% (7.7% for Research) for NSF in the FY08 budget request. We hope that Congressional action of the FY08 budget reflects that increase and leads the NSF further along the path to a substantially larger research budget.

MAJOR PROJECTS/MREFC: Astronomical explorations using ground-based telescopes have yielded some of the most exciting discoveries in astronomy and physics 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. We expect that collaborative efforts between NSF and DOE will also grow, and play an important role, as have the physics programs within the NSF Directorate for Mathematical and Physical Sciences (MPS) and the DOE Office of Science. However, NSF will remain at the heart of a broad ground-based program in astronomy and astrophysics.

One aspect of NSF's activities that is becoming increasingly important is the support of major projects that are initiated from within the Divisions. Astronomy is one area where this has been traditionally the case. An example is the extremely powerful Atacama Large Millimeter Array (ALMA). This is a central element of the current program of the Division of Astronomical Sciences (AST). The AAAC appreciates the efforts within MPS and in AST that have kept this important project on track through a year of challenges. As expressed in a letter[5] to the NSF Director and Deputy Director last year, the AAAC greatly appreciated the decision of the NSF Director's Office to support the revised plan and budget for ALMA. The continuing discussion regarding ways to strengthen the Major Research Equipment and Facilities Construction

[5] http://www.nsf.gov/attachments/106804/public/alma_aaac.pdf

(MREFC) process to minimize unexpected cost growth in major projects is very welcome. A key challenge is to manage costs while ensuring that projects move expeditiously through the MREFC process and into construction. The time it takes to move through the MREFC process has become a concern for the AAAC. The AAAC is very supportive of the agency's efforts to improve the MREFC process and has some suggestions for further enhancement in the following section (§2.1).

A growing concern for major projects is the support of operations, maintenance, and upgrades (e.g., new instrumentation). For example, a $1B project with a typical 10% annual budget for operations, maintenance and upgrades would alone consume ~50% of the AST budget. The need for additional operations funding for these next-generation facilities, in addition to the savings realized from closing or reducing operations of current facility operations in AST, should be considered as future budgets are developed for MPS and AST.

The AAAC was also very encouraged by the NSF's decision to move the Advanced Technology Solar Telescope (ATST) into the Readiness Phase over a year ago. This is a key step in the MREFC process. ATST passed a major milestone with its Preliminary Design Review in November 2006, and is now looking forward to its transition to a New Start. The AAAC very much hopes that this step is reflected in the FY09 budget.

AST SENIOR REVIEW: The NSF Division of Astronomical Sciences (AST) faces significant challenges in moving forward on the many high-priority projects advocated by the 2000 Decadal Survey and the Connecting Quarks with the Cosmos (CQC) report. The AAAC is very encouraged by the steps underway within AST to respond to both evolving circumstances and the need for structural changes. While the 8.3% requested increase in the AST budget in FY08 is very positive, the demands on AST resources over the next 5-7 years exceed likely increases. The Senior Review that was undertaken by AST is key to utilizing the major new and extremely powerful facilities like the Atacama Large Millimeter Array (ALMA) that have been recommended through the Decadal Survey process, as is the need to provide funding opportunities in response to the Decadal Survey and to the programs outlined in the CQC and its companion report *Physics of the Universe*.

The Decadal Survey specifically recommended that NSF AST conduct a "competitive review of NSF astronomy facilities and organizations…about every 5 years." The Senior Review is such an evaluation, and the AAAC commends AST for its successful implementation of this important Decadal Survey recommendation. The AAAC has expressed its strong support for the Senior Review[6] and was very impressed with the care and thought that went into the recommendations regarding the difficult issues of facility re-alignment and closure. The AAAC expects that the Senior Review and its implementation by NSF-AST will position AST for optimizing the program of new and current facilities over the next decade.

The Senior Review was a key step in moving forward on several very powerful new astronomy facilities. The MREFC investments in major facilities like ALMA, the Advanced Technology Solar Telescope (ATST), the Giant Segmented Mirror Telescope (GSMT), the Expanded Very Large Array (EVLA), and the Large Synoptic Survey Telescope (LSST) will need substantial operations funds to realize their full potential. The Senior Review recommendations will provide some resources for operations, but, as noted above, they will not be enough – additional operations funding will be required for these next-generation facilities.

Below we address several key issues for NSF. In §2.1 we identify recommended changes to the agency's planning and management of large-scale projects funded by the MREFC account. In §2.2 we discuss the increasing involvement of NSF PHY with astrophysics. In §2.3 we consider major Decadal Survey projects that are under construction or under consideration for construction during this decade, including ALMA,

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[6] http://www.nsf.gov/attachments/103158/public/ast_senior_review-aaac.pdf

ATST, GSMT, EVLA, and a Large Survey Telescope (LST). In this section we also discuss AST's stewardship of astronomy as well as the Division's initiation and implementation of a Senior Review process to evaluate the balance of its facilities portfolio and to identify funds both for new major initiatives and for its highest-priority existing facilities.

2.1 MREFC and Long-Range Planning at NSF

The Major Research Equipment and Facilities Construction (MREFC) process is of great importance for astrophysics and is becoming of increasing importance to NSF. The major observatories and facilities constructed through MREFC provide dramatic advances in scientific exploration in astrophysics. Because of the long history of major astronomy projects, and because our future is so interwoven with MREFC, it is an aspect of the NSF's funding to which we pay particular attention. Based on our long experience with major facility construction and operation, we can also bring valuable insights to discussions of the MREFC process. The MREFC process has become more open and transparent. The key to an effective MREFC process is that it be appropriate for the NSF's oversight responsibility, yet maintain sufficient flexibility to respond to the particular needs of different disciplines.

A Facility Plan is an essential component of program such as MREFC. Such a plan provides guidance for the agency and all stakeholders. Concerns about the rigidity of such plans can be alleviated by periodic reassessment so that the plan is responsive to changing circumstances. Together, the process and Facility Plan should ensure that all stakeholders understand the status, timescale and progress of large projects. The process should also provide opportunities for negotiation with potential international, multi-agency or private partners. Such complexities have become the norm for major astronomy projects, and recognition is needed that procedures and timelines should allow private and/or international partnerships to be folded into the planning and approval processes. The AAAC supports the broad direction outlined in NSB 05-77, though several questions and possible concerns remain. The AAAC was encouraged to see that a Facility Plan was developed, though it remains incomplete in that it does not show likely timelines, phasing and key milestones for each project, as is done for plans at other agencies where large projects are undertaken. The value of the Facility Plan to current and potential MREFC projects would benefit from the inclusion of these elements, and the AAAC hopes that the next version of the Facility Plan is more complete in these areas.

One cautionary note might be applied to the current process. As the process has increased in complexity, we are concerned that MREFC may become unable to respond effectively to opportunities for interagency, public-private and international projects aligned with Decadal Survey priorities. It would be very useful to do a timeline and step-by-step walk-through of the current MREFC process with a project that involves international cooperation and private donors, all of whom have different timescales, management constraints and funding processes. We suspect it would challenge the present approach. With a more nimble and responsive process, scientific opportunities can be optimized for the greatest benefit from the investment of Federal and private resources. This is of particular importance for large 20- to 30-m telescope projects, where the potential exists for very substantial private contributions, as we discuss below and in §5.4.

An important aspect for astronomical projects is that they inevitably utilize forefront technologies. This imposes significant challenges for a major construction project and leads to substantial upfront costs for technology development so that major areas of risk are retired before the construction phase. The implications of this are addressed in the next section.

Implementation Phases and Lifecycle Costing of MREFC Projects: An important aspect of the MREFC process will be the need to understand and identify the "lifecycle" aspects of major projects and their associated costs. The AAAC discussed these issues in some detail in its 2006 report, and the Senior Review committee stressed these same issues in Finding (3) of their report, where they noted that “realistic life cycle costing for the observatories that are under construction or consideration is an essential part of planning.” The term “lifecycle” is used to encompass the multiple, well-defined components in the realization of major projects: the conceptual design and preliminary development phase (Phase 1); a development and demonstration phase (Phase 2); the construction phase (Phase 3); a commissioning phase (Phase 4); and the operations and science return phase (Phase 5). In addition, there is a final end-of-life stage, which is de-commissioning the facility. The recent Senior Review discussions have highlighted the possibly very significant costs associated with this last stage.

The “lifecycle” analysis and cost-profiling approach has become the norm at NASA and DOE and other agencies from their long experience with major projects, and it may be useful for NSF to look at the experiences of other agencies to determine what aspects might be appropriate for the NSF environment. The mapping of Phases 1-5 onto DOE’s CD-0 through CD-4 and NASA’s pre-Phase A through Phase E is not one-to-one, but has many parallels.

Most major programs will have their pre-construction development phases and post-construction operations funding identified from within the appropriate Division. There are, however, serious limitations to such an approach when the projects reach a certain scale. For these large MREFC projects, even with substantial commitment of resources from the Division, the pre-construction developments may not allow the risk retirement that is the primary goal of such pre-construction efforts. If the project goes ahead, the agency as a whole assumes a larger risk of schedule slippage and cost growth than if adequate resources had been expended before entering the construction phase. The identification of two phases of pre-construction development, as noted above in the “lifecycle” costing approach, is a well-understood approach to risk retirement. The first phase demonstrates conceptual reality and usually endeavors to assess the main technological hurdles while also evaluating the likely facility performance and the resulting scientific capabilities. This is a crucial step, but one which takes time and only modest levels of funding, with review as appropriate. The next pre-construction step is when the key technologies and processes are demonstrated to be in place and when much more detailed and realistic costing can be done. This step is intrinsically more expensive, is run under much tighter management constraints and is the subject of key reviews to ensure that the risks are understood and retired before going into construction.

The first phase (Phase 1) is an activity that can be funded by the Divisions using current approaches. On major projects the second phase (Phase 2) is unlikely to be done well with the resources available to the Divisions. Experience has shown (depending on the project) that about 20% of the total construction cost needs to be spent in the second stage for effective risk retirement, though it could well be more for a very technically-challenging project. The NASA James Webb Space Telescope (JWST) is likely to spend ~40% of its total budget before going into construction (Phase C/D). Because risk retirement is in the best interest of the agency as a whole (particularly because the whole agency bears the downside of major problems during the construction phase), the agency should work to develop a process in which the Phase 2 activity is either funded under the MREFC account or budgeted at the agency level rather than at the Division level.

To summarize, the AAAC recommends that the NSF consider an approach which differs from the current one in that the pre-construction activities are clearly separated into:

1) a long but modest level of effort funded by the Divisions, wherein the conceptual design, required technologies, expected performance and scientific capabilities are developed (Phase 1);
2) a shorter, more focused and more tightly managed phase (that is inherently more costly) in which key technologies are demonstrated and reviewed, system-level issues are evaluated and the detailed costs are established (Phase 2). This should be done under an agency-level activity that is closely linked to the MREFC process.

To further develop this approach, the AAAC recommends the involvement of experienced project managers and program officers in the formulation of procedures and processes for MREFC-scale projects.

A similar two-phase structure exists on the back-end of projects, following construction. As construction is completed, the project transitions to the commissioning phase. This phase, which involves different mixes of personnel skills and experience, is intrinsically different from operations and again requires a different level of support. This is an important aspect of taking a “lifecycle” planning approach to major projects. It is obviously undesirable to make a major investment in a program and then have that project not reach its design level of scientific return because the funding was too low for effective and timely commissioning of the project. Since commissioning can be funded from MREFC we consider that it would be good practice to budget this where appropriate. Thus, to follow item 2) above we have:

3) the construction phase (Phase 3), as per current MREFC practice;
4) the commissioning phase (Phase 4), with its overlap with the engineering resources from construction and with the technical expertise that will handle operations. The commissioning phase needs higher overall resources than the operations phase, and again should be viewed as an agency-level activity that is closely tied to the MREFC process;
5) the operations phase (Phase 5), during which the science is carried out. This is at a lower funding level than commissioning.

Finally there is:

6) a de-commissioning activity whose funding is very project dependent, but could be quite significant.

The impact and timescales of these steps are, in summary:
Phase 1) conceptual development: low annual cost, moderate to lengthy duration;
Phase 2) system-level assessment and detailed costing: moderate-high annual cost, short duration;
Phase 3) construction: high annual cost, moderate duration;
Phase 4) commissioning: moderate-significant annual cost, short duration;
Phase 5) operations: moderate cost, long duration;
and 6) de-commissioning: variable but a sometimes significant cost activity

The importance of developing a “lifecycle” approach to project conceptual development through construction to operations becomes particularly important as the scale of projects increases. In particular, the importance of careful evaluation of the funding level of operations and science return during the operations period cannot be understated. Both science operations and upgrades (e.g., new instruments) are key factors during this period. It is this last phase wherein all the cost is “recovered” through science output. Inefficiencies at this time are not cost-effective. The challenges associated with operations have been noted above, namely that a $1B project with a typical 10% annual budget for operations, maintenance and upgrades would alone consume ~50% of the AST budget. The need for added operations funding for these next-generation facilities is clear.

Lifecycle budgeting was addressed in the 2003 NSB report, *Science and Engineering Infrastructure for the 21st Century*[7], (NSB 02-190) from the Committee on Programs and Plans Task Force on Science and Engineering Infrastructure. Under their Recommendation (4): “Strengthen the infrastructure planning and budgeting process through the following actions,” they note in item (3): “Develop and implement budgets for infrastructure projects that include the total costs to be incurred over the entire life-cycle of the project, including research, planning, design, construction, commissioning, maintenance, operations, and, to the extent possible, research funding.”

[7] http://www.nsf.gov/nsb/documents/2002/nsb02190/nsb02190.pdf

In summary, a funding base for large initiatives that includes both Division- and agency-level contributions during critical project lifecycle phases would: expedite the later phases of the design and development process; lower the risk of cost growth; achieve science goals more reliably and quickly; and reduce serious impacts on ongoing research infrastructure within the discipline, including human resources. The AAAC urges the consideration of new approaches for funding the design and development phase of major initiatives. Both the design and development phase and the commissioning phase should be supported with funding from within the Divisions and from more agency-wide approaches, possibly linked to MREFC.

2.2 NSF Division of Physics

An important development in recent years has been the involvement of the NSF Division of Physics (PHY) in areas of interest to the astronomy and astrophysics community. This involvement stems from the realization that fundamental physics can be studied by analyzing astronomical data or potentially by direct measurement of particles with cosmic origins. Through their involvement with the NSF-DOE High Energy Physics Advisory Panel (HEPAP), PHY has been involved with the AAAC in several Task Forces considering how to move forward in the areas of the cosmic microwave background, dark energy, and dark matter.

An important example of PHY's contribution in this area is support for experiments searching for dark matter. NSF PHY is jointly supporting these efforts with DOE-HEP. AAAC is pleased to note that this cooperation has worked well to date and that the two agencies are working together to ensure a timely response to the recommendations of the Dark Matter Scientific Assessment Group (DMSAG), a joint subcommittee of the AAAC and HEPAP. The DMSAG will provide guidance on how optimally to use increased funding for dark-matter direct-detection experiments.

2.3 NSF Division of Astronomical Sciences

The primary driver for the AAAC's interest in MREFC is due to the essential role that MREFC plays for NSF AST projects recommended by the astronomy and astrophysics Decadal Survey.

A) Status of AST MREFC Projects: A major consideration for the AAAC concerns the timing of the major Decadal Survey projects that are under construction or under consideration for construction during this decade: the Atacama Large Millimeter Array (ALMA – a top priority of the 1990 decadal survey) is currently under construction, while the Advanced Technology Solar Telescope (ATST) is in the Readiness Phase. A number of other projects remain under development, including the Giant Segmented Mirror Telescope (GSMT), a major upgrade to the Very Large Array (EVLA), and a Large Survey Telescope (LST). GSMT is the top-ranked ground-based project in the Decadal Survey; EVLA 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). The first phase of the EVLA upgrade is in progress with completion expected in 2010.

Progress on these projects is driven not only by Decadal Survey priorities but also by technical readiness and, in several cases, alternate funding scenarios that involve interagency activities, international partnerships or non-Federal private funding sources. The lifecycle cost issues, including the particular challenges of operations funding, also become especially significant with some of these large projects. Because NSF PHY and AST are gaining significant experience in dealing with large facility projects, it would be useful to discuss that experience and link it to some of the issues and questions raised with regard to the MREFC processes discussed above. The status of the individual projects, and of the processes associated with MREFC, are a key interest for the AAAC, and further discussion during this coming year would be valuable.

ALMA, currently under construction, is a very high-priority program for the astrophysics community. The cost growth in ALMA is a serious concern but reflected circumstances largely beyond the control of both the project and the Division. We appreciated that the NSF Director, the MPS Assistant Director and the AST Division Director found a solution that enabled the U.S. side to move forward when the European partner encountered delays in the antenna procurement in 2005. The subsequent cost study that led to a revised budget and spending profile also required a very proactive stance on the part of NSF to resolve. We appreciate that the agency supported the increased budget, and its associated the FY07 changes, and that the new cost profile is now reflected in the FY08 budget request. As discussions develop on the lifecycle costing approach it will be useful to see what lessons can be learnt from the ALMA experience.

The AAAC was very encouraged to see **ATST** move into the MREFC Readiness Phase. The AAAC has noted in its last three annual reports the importance of the overlap between this project and the NASA Solar Dynamics Observatory (SDO) mission. As the first astronomy project likely to go forward under the new MREFC process, ATST is a key pathfinder for the new process. The AAAC views positively the effort to include a significant component of international participation and notes the very wide-ranging collaborative efforts that have developed as ATST has matured. Given the SDO timeline (late 2008 launch), the AAAC is concerned that ATST move through the MREFC process as quickly as possible. Significant synergies accrue from overlapping operations. With a lifecycle cost of over $800M, SDO reflects a substantial investment by the nation. ATST overlap with SDO would provide significant cost-effective, interagency science return.

The very successful ATST Preliminary Design Review (PDR) last November indicated that the ATST project was ready to move ahead, and so the AAAC hopes that the NSF supports a new start for ATST in the FY09 budget. With a construction budget of $225M, ATST is a major project, and the carrying costs are large for AST while awaiting MREFC funding for a new start. The Haleakala site in Hawaii appears to be an excellent location, and we hope that the activities needed to obtain approval for construction are moved forward expeditiously. However, the choice of Haleakala has brought some site-specific challenges, and it is hoped that these will not lead to delays in the project. In addition to the carrying costs noted above, the impact on other major astronomy projects that are being considered for MREFC funds could be substantial if they are delayed. It would be prudent to explore alternative locations if significant delays occur with the current choice.

The AAAC was encouraged by the allocation of significant funding of $14M over a four-year period for technology development for the Large Synoptic Survey Telescope (**LSST**), one of the contenders for the Large Survey Telescope project recommended by the Decadal Survey (which used LSST as a more general moniker for this capability). The LSST project has recently submitted a construction proposal for MREFC funding. This is a major project and is under discussion as a joint effort with the DOE Office of High Energy Physics (HEP), with some private funding (where the proposed funding split is 63%, 24% and 13%, respectively). The total cost of LSST in actual-year dollars is projected to be $467M, with operations projected to be ~$50M per year in actual-year dollars.

One interesting issue concerns the ordering of projects in the MREFC queue. The MREFC timescale is now so long that projects entering the MREFC process may take many years before a New Start, and in so doing, limit the access for other projects. (For ATST the lag from Readiness to New Start will be at least 5 years.) The usual approach at NSF has been to accept proposals on a first-come, first-served basis. Such an approach, especially given these long time-scales, can distort the Decadal Survey priorities. This issue was a particular concern for the optical/infrared ground-based astronomy long-range planning group (the OIR Long Range Planning Committee, OIR-LRPC) that was formed to provide input to the Senior Review. The issues surrounding the sequencing of proposals were discussed in the OIR-LRPC report, *Strategies for Evolution of U.S. Optical/Infrared Facilities*[8]. The group noted that, as one of its findings and associated recommendations, "any LST construction proposal should trigger an evaluation of its impact on the first-ranked project, GSMT. This should be assessed with community input. Public access to scientifically useful data products should be an important criterion." The Senior Review committee also recognized this issue and noted: "The sequencing of GSMT and LST is also a critical issue for AST, as recognized by the [OIR-LRPC]."

The AAAC believes it would be appropriate to consider the recent submission of the LSST proposal in this context. This is no reflection on the scientific merit of LSST; rather, it is a statement on responsiveness to Decadal-Survey priorities and the need for a re-assessment by the community. Normally, consideration of a possible change in priority from Decadal Survey recommendations would have been undertaken by the NRC Committee on Astronomy and Astrophysics (CAA). Given the proximity of the next Decadal Survey, the AAAC recommends that consideration of the appropriate phasing should be carried out by the Decadal Survey. During those deliberations, neither GSMT nor LSST will be close to MREFC approval as a New Start. LSST needs to undertake and pass several significant steps before it reaches the MREFC Readiness Phase, especially given the interagency aspects of the LSST project. Since much work needs to be done on GSMT planning and on consideration of the LSST proposal before a major decision point is reached deliberations on their relative phasing should not impact the anticipated project timelines. The Decadal Survey and project-specific planning and reviews can be carried out as parallel activities.

In the Decadal Survey the highest ranked ground-based large project (and the second-highest behind JWST when considering both ground and space) was **GSMT**. Two concepts for GSMT, the Giant Magellan Telescope (GMT) and the Thirty Meter Telescope (TMT), are maturing rapidly. Substantial private investments have been made in developing both the GMT and TMT concepts, with the potential for hundreds of millions of dollars of additional private investment. The Federal role in GSMT remains very unclear, however. The mechanisms to link Federal processes (i.e., MREFC, operations planning and funding) to major private investments are not well developed. The opportunity is here for a top-ranked, scientific project to be funded largely privately (with an international component) at levels of $0.5-1B, but there is no obvious way to move towards the involvement of the Federal government as a significant partner (fraction TBD, but in the range of ~25-50%).

The concern is often raised that having a modest level of private funding might be a way for a project to bypass procedures and/or to get priority over other programs. Neither is the case here. This is the top-ranked program in the Decadal Survey, and the amount of private funding being discussed would likely overshadow the Federal contribution. Instead, the Federal government would likely be a major, but not dominant fiscal partner, and so the opportunity exists for considerable leveraging of Federal funds. National telescope access would be assured at a fraction of the full cost of the project. The AAAC has discussed the challenges of finding suitable mechanisms for private-public partnerships in each of its last two reports (2005 and 2006), but moving forward on this has proved to be a challenge. We emphasize again in §5.4 the great value that such an activity would have.

A significant challenge for both the astronomy community and NSF – particularly for MPS and AST – is timely implementation of highly ranked, major Decadal Survey projects like GSMT. Modest Federal funding for GSMT technology development was invested in 2005 ($1M) and 2006 (~$2M), with a more significant increment ($5M) projected in the FY07 budget. The FY08 request level is also $5M. This ramp-up is valuable, but is a small fraction of the private resources that have been invested to date. We hope that the NSF R&D funding grows to match the originally requested $39M total for GMT and TMT. In addition, a major concern for moving ahead more substantially with GSMT is the slow pace of projects through the

[8] http://www.noao.edu/dir/lrplan/lrp-committee.html

MREFC process. This adds significant cost, not only in dollars, but also in lost scientific opportunity and loss of synergy with space-based missions of limited lifetimes. The Committee has noted previously (in its 2004 and 2005 reports) that the synergy of JWST in space and GSMT on the ground is of particular scientific value, as has been the case for HST and ground-based, 8-m-class telescopes. The 2004 study[9] commissioned by the AAAC gave added clarity and emphasis to this recommendation (see §6.4). The recent significant change for the Federal involvement in GSMT developed from the Senior Review recommendations regarding the role of the National Optical Astronomy Observatory (NOAO) and from further development of the two approaches, GMT and TMT. This is discussed in more detail in §5.4. As envisaged by AST, NOAO's role is to represent the interests of the National community as the potential GSMT projects mature and to identify a viable approach from a Federal perspective for the community's usage access to GSMT (be it GMT, TMT or some combination). The combination of these many changes and of the uncertainty about the implementation of the recommended GSMT capabilities needs to be worked by both the community and AST (see §5.4).

B) Mid-Scale Instrumentation: The astronomical community depends upon NSF for funding to build the next generation of instruments for its telescopes. The current programs within AST are not well structured to meet the needs of 8-meter-class telescope instrumentation nor the needs of proposed larger telescopes (e.g., GSMT) where instruments may cost tens of millions of dollars. Funds to support construction of instruments that reap the full benefit of large telescopes sometimes come from private donors, but the NSF role is becoming increasingly important as the instrument cost increases. An attractive funding instrument is the Major Research Instrumentation (MRI) Program, but this program is currently capped at $2M, well below the total cost of the types of spectrographs and cameras needed to pursue frontline work in areas such as large-scale structure and star formation, which benefit from large fields of view and high sensitivity. The recent DETF report highlighted the need for projects and instruments for Stage III work to investigate dark energy. Many of the projects under consideration for these dark energy Stage III activities will exceed this limit, too. A program that fills the niche between the current MRI program and the much larger MREFC program is required – a need which cannot be met by AST's Division-level instrumentation program, in which one 8-meter class telescope instrument would use more than the entire funding line.

The concern expressed here is not new, nor unique to astronomy and astrophysics. The February 2003 NSB report (NSB 02-190), *Science and Engineering Infrastructure for the 21st Century*[10], discusses mid-scale instrumentation. Their recommendation 2 is: "Give special emphasis to the following four categories of infrastructure needs: Increase research to advance instrument technology and build next-generation observational, communications, data analysis and interpretation, and other computational tools; Address the increased need for midsize infrastructure; Increase support for large facility projects; Develop and deploy an advanced cyber-infrastructure to enable new S&E in the 21st century." The AAAC concurs with this recommendation and further recommends that AST and MPS give added consideration and visibility to mid-scale instrumentation funding, as it is becoming an increasing critical aspect of the research framework for astronomy and astrophysics.

C) AST Senior Review: A critical activity for AST and the astronomical community was undertaken over the last two years. The Division realized that, if the astronomical community was going to achieve its goals of developing and operating major new facilities in the next decade, AST must find a way to free up funding for both initial technology development and for operations. For example, operations funding for ALMA, which has already begun its ramp-up, will clearly stress the AST budget. It is clear that funds for the next-generation projects will have to come, at least in some part, from existing facilities with their base of users. The Division recognized the critical steps that will be needed if the astronomical community and the Nation

[9] http://www.nsf.gov/attachments/103158/public/gsmt_jwst_synergy_report_final.pdf
[10] http://www.nsf.gov/nsb/documents/2002/nsb02190/nsb02190.pdf

are to benefit fully from the investment of the government's resources in major new projects that provide next-generation capabilities.

By beginning the process to identify funds for operations at an early stage, by being willing to take extensive input from the stakeholders, and by supporting the need for a thorough community-based review (the Senior Review), the AST leadership has rendered a remarkable service to the community. The Senior Review was designed to evaluate the distribution of funding within the Divisional portfolio and to identify strategies a) to begin to provide for the U.S. share of operations funding for ALMA, b) to free up 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 the GSMT and LST, and c) to identify potential reinvestment in the highest priority existing programs in AST. With every aspect of the current AST program on the table, with the exception of agency-mandated programs and grants to individual researchers, the Senior Review process was initiated with clarity and simplicity.

The AAAC strongly supported the Senior Review and commends the Division for its proactive stance towards long-range planning. The AAAC was very impressed with both extensive effort undertaken by the Senior Review committee and the thought that went into the very difficult recommendations regarding facility and telescope restructuring and closures. The very broad nature of the Senior Review, essentially dealing with the full portfolio of AST programs and facilities, distinguished it from the more mission-focused Senior Reviews that are undertaken at NASA. As such, it was a very different activity, more akin to a "portfolio" review, and therefore impacted a very broad segment of the astronomical community. The effort that AST put into holding many "town hall" discussions with the community early in the Senior Review process was greatly appreciated and was a key element in making the Senior Review a successful and widely accepted process. The subsequent town hall meetings, following the completion of the Review and currently ongoing, are also a key step in gaining broad acceptance of the changes that will come from the Senior Review recommendations. Clearly a central goal of this effort is to position AST to optimize the overall program of new and current facilities over the next decade. The Senior Review contributed significantly to that optimization process.

A particularly challenging area for the Senior Review was the National Optical Astronomy Observatory (NOAO). The increasing focus at NOAO on future facilities like GSMT and LSST was questioned by the Senior Review. Two recommendations pertained to the optical-infrared ground-based research enterprise; both have significant implications. The first is for the Optical-Infrared Astronomy Base Program: "The Optical-Infrared Astronomy Base program should be led by the National Optical Astronomy Observatory. It should deliver community access to an optimized suite of high performance telescopes of all apertures through Gemini time allocation, management of the Telescope System Instrumentation Program and operation of existing or possibly new telescopes at Cerro Tololo Inter-American Observatory in the south and Kitt Peak National Observatory or elsewhere in the north. The balance of investment within the Base Program should be determined by the comparative quality and promise of the proposed science. In addition, there should be ongoing support of technology development at independent observatories through the Adaptive Optics Development and the Advanced Technologies and Instrumentation Programs."

The second relates to the Optical-Infrared Astronomy Transition Program: "Gemini operations will continue through 2012. Decisions on new Gemini instrumentation and negotiations for operation beyond 2012 should be guided by a comparison with the cost, performance, and plans of other large optical telescopes. The National Optical Astronomy Observatory should plan to reduce its major instrumentation, data products, administrative and science research staff over the next five years and concentrate on executing its base program more efficiently. Growth in support of a Giant Segmented Mirror Telescope and a Large Survey Telescope should be paced by Federal project choices and the schedule for Major Research Equipment and Facilities Construction account funding as well as progress by the partners in these projects."

The recommended refocusing of NOAO's efforts on current facilities was advocated as a rebalancing of the observatory's activities. There is significant rationale to a balanced approach that allows for scientific return from current telescopes, while also responding to the need for national involvement in the future major projects arising from the Decadal Survey. Finding the right balance will be a challenge within a constrained budget, however. The Senior Review was also concerned about the high cost and efficiency of the Gemini operation. One anomaly, which has a historical basis, is the separation that occurred between the Gemini Observatory and the NOAO. While the rationale for this may have been necessary in the past, it would be useful to consider the efficiencies that could be gained from developing a much closer linkage between Gemini and NOAO's smaller optical facilities, as well as linkages with the facilities now being planned. Coherent planning across these facilities, perhaps within the context of a national observatory, would minimize overhead and optimize limited resources. The goal would be to enhance scientific productivity for the suite of current telescopes while providing added funding opportunities for future facilities. It is clear that any change in the structure would have to be developed carefully under the leadership of NSF-AST and with the understanding and agreement of our international partners, but it would be useful to consider this as a longer-term goal, cognizant of the 2012 Gemini timeframe, for optimizing the scientific return on AST's investment.

The interagency implications of some of the Senior Review recommendations are now under discussion with the AAAC. The AAAC heard about some of the issues connected with the potential shutdown of the Very Long Baseline Array (VLBA) (e.g. the impact on science from the Gamma Ray Large Area Space Telescope), the Global Oscillation Network Group (GONG) (e.g. the loss of concurrent operation with the NASA Solar Dynamics Observatory) and the Planetary Radar at Arecibo Observatory (e.g. its utility for studies of Near-Earth Objects). The interagency discussions on these facilities and the impacts of closure have only just begun, and so the discussions with the AAAC are at an early stage – too early for any recommendations to be made.

The recent budget increases at NSF have not lessened the importance of the Senior Review. These budget increases are extremely valuable at a time when extraordinary new capabilities and technologies are under development. Both the Division and the astronomical research community hope that AST benefits, as it should, from further growth in the NSF's budget as part of the ACI initiative. However, the scale of the future needs for the major projects that have been recommended from the Decadal Survey and CQC is such that, even with significant increases, a reevaluation of the facilities program is essential. As ALMA, ATST and other major programs like GSMT and LSST come online, AST's focus must of necessity change to reflect the needs of these new, powerful and very expensive facilities.

As part of the input to the Senior Review, two long-range planning groups developed framework documents with roadmaps in radio astronomy (*Report of the Radio, Millimeter and Submillimeter Planning Group*[11]) and in optical/infrared ground-based astronomy (*Strategies for Evolution of U.S. Optical/Infrared Facilities*[12]). Both committees had participation from a broad representation of the astronomical community. They developed guiding principles regarding the development of major new facilities recommended through the Decadal Survey, with some preliminary discussion of longer-term initiatives. These efforts also provided a broad, systemic view of how existing and upcoming facilities will support AST research activities. The roadmaps were input for the Senior Review and should provide added guidance for the upcoming Decadal Survey.

The Senior Review also voiced in its Finding (4) considerations that resonate with the AAAC and its role in optimizing the national astronomy and astrophysics enterprise: "Towards a Coherent National Astronomy Enterprise: In order to meet the challenge of (multi-)billion dollar, ground-based optical-infrared and radio

[11] http://astrosun2.astro.cornell.edu/~haynes/rmspg/docs/rmspgreport.pdf
[12] http://www.noao.edu/dir/lrplan/strategies-final.pdf

observatories, there will have to be strong collaboration between the Federal and independent components of the US astronomical enterprise and firm leadership by AST. A high-level commission addressing optical-infrared facilities provides one way to start to bring together the diverse components of the national program to realize the full potential of the US system."

The Senior Review was a major step that was needed to allow AST to move forward to the very powerful new facilities that are now being constructed or planned for construction. The support needed for the new facilities will be helped by the Senior Review recommendations, but the MREFC investments in major facilities like ALMA, ATST, GSMT and LSST will need substantial operations funds to realize their full potential. The need for added funding for facility operations in AST, as noted above, should be considered as future budgets are developed for MPS and AST.

D) Stewardship by AST: The AAAC would like to commend AST for its recognition of the importance of NSF's role as a steward of astronomy. The Division has striven to maintain an appropriate balance among major initiatives, centers and support for individual investigators. The health of the discipline depends on maintaining a balance across telescope aperture size and wavelength, across facilities and individual investigators, and across existing programs and new initiatives. The Division is working well to respond to Decadal Survey priorities and to identify resources for major Decadal initiatives. The AAAC appreciates the Division's and the Foundation's continued support of ALMA and ATST, their attention to the complexities associated with international nature of the ALMA project, and their efforts to identify and ramp up operations funding for ALMA. Bringing the Senior Review to completion last year was a major and highly important activity for AST.

A number of projects or programs involving NSF are discussed in §5 and §6. Issues relevant to NSF occur in: §5.4 with regard to GSMT; §5.5 with regard to LSST; §5.11 for the next Decadal Survey; §6.1 for R&A and Workforce Development; §6.2 for NVO; §6.3 for ATST/SDO synergy; §6.4 for GSMT/JWST synergy; §6.5 and §6.10 for the DETF; §6.7 and §6.10 for the DMSAG; §6.8 for ExoPTF; §6.9 and §6.10 for the CMB Task Force (TFCR); §6.11 for South Pole Communications; §6.13 for the "Lessons-Learned" activity; and §6.14 for AAAC travel support.

3.0 National Aeronautics and Space Administration

A). The AAAC remains deeply concerned about the impact on the NASA space science program of removing more than $3B from the Science Mission Directorate (SMD) budget in the next 4-5 years. Science has been the most visible and productive element of NASA. NASA's extraordinary successes over the last decade have resulted in large part from its challenging, ambitious science missions, combined with continuing, broadly-based research support that produces stunning science return from a diverse portfolio of programs. The challenges of transitioning within the current NASA budget to a new generation of space capabilities in the framework of the Exploration Vision, with no new funding, have become obvious. The balance among the needs of Space Shuttle (STS) operations and ramp-down, International Space Station (ISS) completion and operation, Exploration Systems development and a robust Space and Earth Science program has come under great strain as the real costs of the transition to a new human spaceflight structure have been recognized. Yet no additional funds have been identified. ***The lack of growth in the NASA budget to respond to the Exploration Vision is stressing all the agency's activities. The AAAC is deeply concerned about the growing impact on the space and earth science program.***

B). The added stress on the agency of the FY07 Joint Funding Resolution was largely alleviated for science by the explicit funding level and only a small (~1.5%) decrease for SMD. While this was welcome, a very *serious near-term concern for the AAAC is whether the FY07 Joint Resolution budget for NASA will become the new baseline on top of which a modest increase might be applied, or whether the FY08 Congressional budget for NASA will be at least the FY08 request level. If the FY07 funding level becomes the new baseline against for future budgets, further substantial cuts to science could well occur.* ***The AAAC is concerned that the appropriation for FY08 and beyond may lead to a further cut by using the FY07 appropriation as the base for future budgets, and recommends that the FY08 request be the base to preclude added impacts on science at NASA.***

C). The American Competitiveness Initiative (ACI) recognized the challenges faced by the nation in staying at the forefront of scientific and technological development. Research is essential to innovative activities and underpins a technologically-competitive society, as highlighted in the NRC report Rising Above the Gathering Storm. The exclusion of NASA science from the ACI, in contrast to the inclusion of DOE science, is inconsistent. There is no question that NASA is at the cutting-edge of science and technology research. This exciting and highly visible research contributes to the vitality of the national skill set and has encouraged young people to move into science and engineering. The Congressional interest in Innovation and Competitiveness enables a fresh opportunity for enhancing NASA science. ***The AAAC strongly encourages Congress to consider enhancing the support for science at NASA explicitly to improve innovation and competitiveness, as has been done for NSF and DOE science.***

D). The last three Astronomy and Astrophysics Decadal Surveys have all emphasized the need for a balanced program of small, medium and large missions – and have given particular emphasis to the Explorer program and to a healthy program of research support (Data Analysis – DA, and Research and Analysis – R&A). However, the program is currently dominated by large missions. The cuts in the research and analysis budget have an immediate and significant impact and seem inconsistent with the broad goals of the ACI. The very infrequent Explorer opportunities (six years between mission proposals instead of the more typical three years) are indicative of a program on life-support. The DA/R&A funds and smaller-scale missions each serve a critical role in supporting the broad fabric of research needed for realizing the science from future missions and in enabling the development of the necessary personnel and skills. The Astrophysics program should be rebalanced as a part of any increase for science, or at the least when funds become available as the major astrophysics missions pass their spending peaks. ***The balance between small, medium and large programs in the NASA Astrophysics Division has been undermined. The AAAC recommends that the funding "wedge" in FY09/10 be used to add some funding for R&A and small missions, to rebalance the program.***

E). The AAAC welcomed the Administrator's announcement regarding the HST SM4 servicing mission. The new camera and spectrograph will again renew HST. The recent JWST Technology Non-Advocate Review (T-NAR) was very successful, and combined with the larger levels of contingency allocated to the program gives confidence that JWST is on a much more stable track to launch. The progress towards launch for GLAST, Kepler, WISE, Herschel and Planck is very encouraging, and will provide a considerable resource of new data. The potential for a first Beyond Einstein mission to be initiated in 2010 is also encouraging. SOFIA has been re-instated, and while it faces considerable challenges, we look forward to a successful flight and science demonstration. The Navigator program is under stress, but we expect the recently formed ExoPlanet Task Force to provide broad guidance on how to move forward on the ground and in space in this exciting area. A major concern develops when we view the science missions launch rate in 2009 and beyond for space science. It decreases significantly compared to recent times. ***The AAAC welcomes the support and progress on many missions as they move towards launch and operations over the next few years, but notes that a significant drop in the number of science mission launches occurs after 2009, and views this dearth of new science opportunities as a major concern for the long-term productivity of the science program.***

F). Most missions now have lifecycle costs that are $2B or more. The exceptions are the cost-capped programs like Discovery and Explorer, and the future Probes like JDEM. It is crucial that programs under consideration for implementation by the Decadal Survey process reach a level of maturity that is characterized by a well-defined architecture with formally vetted costs. The AAAC emphasized last year that consistent support, roughly at the $10M level, would make a significant difference in the robustness of the mission selections in the next Decadal Survey. The improvements in early phase development funds in the FY08 budget for the major missions in Beyond Einstein (Con-X, LISA) and in Navigator (TPF) should be continued if possible until the Decadal Survey re-evaluates the mission suite in the Astrophysics arena. ***The AAAC welcomes the support for conceptual and technological development for Con-X, LISA, and TPF in the FY08 budget and recommends that such support be continued through the next Decadal Survey.***

G). The AAAC greatly appreciated NASA's support for two interagency activities. (1) ExoPlanets: With the substantial advances on the ground and the recognition of the challenges and cost of major space missions for planet search projects like SIM and TPF, the AAAC recommended last year that NSF and NASA constitute a Task Force to develop a strategic framework for how to move forward on the detection and characterization of planets around other stars. The AAAC greatly appreciates that the agencies responded positively and quickly; the ExoPlanet Task Force (ExoPTF) has been formed and has begun its deliberations. Its report is expected later in 2007. (2) Beyond Einstein: The AAAC has been concerned for some time about the slow progress on the Beyond Einstein program. We welcomed the decision by SMD last year to ask the NRC to carry out a study to determine which Beyond Einstein mission should go forward if funding became available in a possible FY09/10 funding "wedge" as HST SM4 is completed and JWST passes the peak of its spending curve. The selection of three JDEM mission concept studies for conceptual development by NASA Astrophysics, and the joint support of the NRC Beyond Einstein Program Assessment Committee (BEPAC) study by DOE were also highly welcomed by the AAAC. ***The AAAC welcomed NASA's support with NSF of the ExoPlanet Task Force (ExoPTF), and the developments in Beyond Einstein leading to a jointly funded NRC study with DOE HEP, the Beyond Einstein Program Assessment Committee (BEPAC). The selection of JDEM concept studies by NASA was also welcomed.***

H). The AAAC expressed great concern last year in our report about the lack of an advisory process at NASA. We were very encouraged when the new NASA advisory committees were established. The new structure does differ from that used previously, providing a clearer path for advice to the Administrator. The new structure has, however, lost a valuable role that was once provided by the Space Science Advisory Committee (SScAC). That structure encouraged dialogue on wide-ranging issues that cut across the SMD divisions, between SMD and a broadly-representative group from the science community. An improved interface with SMD is in the best interests of both NASA and the science community to restore this important two-way communication link that has contributed to the success of NASA science in the past. ***The AAAC welcomed the re-establishment of the advisory structure at NASA last year, but notes that dialogue between SMD and a broadly-representative group from the science community is missing in the new structure.***

BUDGET ISSUES AND THE IMPACT ON NASA: The challenges continue for the science program at NASA following the major changes in the FY07 budget request where more than $3B was removed from science for FY07-11. The FY08 request did not lead to any significant recovery. The budgets for science have been very dramatically cut, leading to substantial long-term impact. The AAAC appreciates that the damage of the impacts appears to have been understood in Congress, since the FY07 Joint Resolution budget for NASA explicitly designated and made statutory only a small cut (~1.5%) to science compared to the FY07 budget request level.

The challenges of transitioning within the current NASA budget to a new generation of space capabilities in the framework of the Exploration Vision, with no new funding, have become obvious. NASA's overall budget has remained essentially unchanged through the last three budget requests (FY06, FY07, FY08) for FY08 ($17,309M), FY09 ($17,614M) and FY10 ($18,026M). The balance among the needs of Space Shuttle (STS) operations and ramp-down, International Space Station (ISS) completion and operation, Exploration Systems development and a robust Space and Earth Science program has come under great strain as the real costs of the transition to a new human spaceflight structure have been recognized. Yet no additional funds were identified. This became visible to all stakeholders last year. The result has been a large change in the budget plans for science at NASA in the years beyond 2007, when science funding actually drops in inflation-adjusted dollars. The impact on science is large, both in the near-term and in the long-term. The entirety of the science community's planning was impacted by this sudden change in the budget slope. These budget changes were exacerbated by the realization that costs had been underestimated for a number of major programs. The resulting major restructuring of the long-term science program is a great concern to the science community and also have the potential to significantly change NASA's perceived value to the nation.

NASA's extraordinary successes over the last decade have resulted in large part from its challenging, ambitious science missions, combined with continuing, broadly based research support that optimizes the science return from a diverse portfolio of programs. NASA has demonstrated remarkable scientific leadership by implementing missions that have dramatically changed our understanding of the universe – its origin, evolution and structure, 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 (HST), the Mars Rovers, the very successful Explorer missions like the Wilkinson Microwave Anisotropy Probe (WMAP), the remarkable outer planet images in our Solar System from Cassini and Galileo, and from numerous other remarkable missions and projects has been seen as a demonstration of US technological leadership. NASA has shown time and time again that technology, driven by great science goals, can dramatically expand our horizons and bring exploration of the cosmos beyond our Earth within the reach of all. The value of these science missions is widely recognized for generating enthusiasm for science and engineering and for stimulating the interest of the nation's youth.

The leadership in the scientific and technological arena that NASA has shown – with the visibility that it brings to U.S. technological and scientific achievements – is clearly at risk in the coming years. The breadth and balance within NASA's science program is a major factor in this visibility. The substantial budget changes that are being implemented are resulting in a realignment between science and human spaceflight. We do not wish to condemn the agency to remaining with outdated facilities and goals. We are supportive of moving ahead with changes to the human spaceflight and launch vehicle capability that will bring NASA into the 21st century. We recognize the stress that the agency is under. On several occasions before he became NASA Administrator, Dr. Griffin noted presciently before Congress that NASA needed a $20B budget if the agency were to transition out of its historic programs to undertake exploration while retaining a vibrant, diverse science program.

We are now seeing the problems of a "go-as-you-pay" approach within the current NASA budget that is well under $20B. The science program is now being cut with major consequences for the nation's preeminence in Earth and Space science. It is our hope that Congress and the Executive Branch find a viable solution that does not undercut one of the nation's most visible and productive scientific research enterprises – the NASA Space and Earth science program. If the Exploration Vision is to be taken seriously and implemented effectively, "go-as-you-pay" may not be viable without doing serious damage to science, realizing the fears of many policy makers.

The AAAC appreciated that the Science Mission Directorate (SMD) budget in 2012 increased in line with the overall agency yearly increase of 2.4%, as the Administrator had announced last year. But substantial damage will have been done by that time. A very serious immediate concern for the AAAC is whether the FY07 Joint Resolution budget for NASA will become the new baseline on top of which a modest increase might be applied, or whether the FY08 Congressional budget for NASA will be at least the FY08 request level. If the FY07 funding level becomes the new baseline against which future budgets will be drawn, further substantial cuts to science could well occur.

The new Administrator has brought a great depth of experience to the position, along with a clearer vision of what it takes to implement a major redirection of the agency. The Administrator also brought clarity of thought and an openness and candor that is not only refreshing, but also most likely essential given the technical and fiscal challenges that lie ahead. The AAAC appreciated meeting with the Administrator Mike Griffin again at its February 2007 meeting. The dialogue with the Administrator was encouraging for his broad support for science, but he again acquainted us with the challenges that the agency faces in restructuring its human spaceflight capabilities within the available budget while carrying out a broad science program. The AAAC welcomed the goal that the Administrator has set to transition the agency from being driven by the vestiges of its past program – one that was devised in the 1970s – into a new, forward-looking set of objectives. The challenges that face the Administrator became even clearer with the FY07 appropriation and the FY08 budget.

ACI AND NASA: A major guiding force for the nation's research effort came into being as part of the FY07 budget request. The American Competitiveness Initiative (ACI) was widely applauded for its recognition of the challenges faced by the nation in staying at the forefront of scientific and technological development. The 2005 NRC report, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*[13], consolidated widespread concern about our future competitiveness and catalyzed efforts to improve the situation. Research is a precursor to innovative activities and underpins a technologically competitive society.

In the FY07 budget and continuing into the FY08 budget, ACI justified new investments in DOE science, at the National Institute of Standards and Technology (NIST), and at NSF that will result in clear benefits in national leadership in science and technology. Cuts to the NASA science budget, on the other hand, also have broad impact and are inconsistent with the broad goals of the ACI. There is no question that NASA is a major source of science and technology funding, and the agency indisputably supports much basic research. This research contributes to the vitality of the national skill set, has encouraged young people to move into science and engineering and has been shown to yield important, marketable spin-offs. We believe that the continued omission of NASA from ACI is inconsistent, and even shortsighted, given the visibility that the NASA science program has engendered for science and engineering across the nation. The Congressional interest in Innovation and Competitiveness enables a fresh look at the role of NASA science, and the AAAC strongly encourages Congress to consider enhancing the support for science at NASA explicitly to improve innovation and competitiveness.

ADVISORY PROCESS: The AAAC was greatly concerned in last year's report about the lack of an advisory process at NASA. The AAAC recognizes that a number of committees offer advice and/or feedback to the agencies on a variety of issues, and it is most useful and effective for all concerned if the enunciated messages are similar and synergistic. We were very encouraged when the new NASA advisory committees were established last year. From a broad agency perspective, the path for formal advice to the agency is simplified and clearer, with the only path through the NAC to the Administrator. The new structure does differ from that used previously, particularly regarding the interface with the Science Mission Directorate (SMD). The tension regarding the advisory structure led to the departure of several prominent and experienced scientists from the NAC. The new structure has lost a valuable role that was once provided by the Space Science Advisory Committee (SScAC), which encouraged dialogue between SMD and the science community on broad-ranging issues that cut across the SMD divisions (see §3.1A below). The Administrator has noted that he is willing to consider changes to the advisory structure. One area for

[13] http://www7.nationalacademies.org/cosepup/

consideration would be an improved interface with SMD. It would be in the best interests of both NASA and the science community to restore this important two-way communication link that has contributed to the success of NASA science in the past.

PROGRAM CHANGES: A number of significant changes occurred during 2006 as the impact of the FY07 budget request was considered, or as some of the revisions to mission budgets or timelines were contested. The FY07 request and FY06 operating plan changes led to cuts in Research and Analysis (R&A) and to Explorer cancellations (Nuclear Spectroscopic Telescope Array) and deferments (Wide-field Infrared Survey Explorer). The Navigator program saw major changes when Terrestrial Planet Finder (TPF) funding was set to zero and the Space Interferometry Mission (SIM) launch was deferred to no earlier than (NET) 2015/16. Moreover, funding for the Stratospheric Observatory for Infrared Astronomy (SOFIA) was set to zero; the cost of Hubble Space Telescope (HST) servicing missions was fully identified; the Beyond Einstein program was cut significantly leading to the indefinite deferral of the Laser Interferometer Space Antenna (LISA) and Constellation-X (Con-X) missions; and the James Webb Space Telesscope (JWST) budget was increased to reflect a new cost profile and level of contingency, as was the budget for the Discovery mission Kepler. This was clearly a time of dynamic and very dramatic changes for NASA Astrophysics.

SOFIA was then reinstated following international pressure and a subsequent review. With the reinstatement of SOFIA, and the selection of a 2008 launch date for HST Service Mission 4 (SM4), additional changes were needed. SIM was changed into a development program with substantially reduced funding from FY08. Since several elements of the Navigator program had been cut significantly (including the Keck Interferometer when problems arose in site approval for the associated small telescopes on Mauna Kea), the AAAC discussed the need for an assessment to balance more broadly the planet search and characterization activities.

STRATEGIC PLANNING: Given the major advances that were happening in the study of extra-solar planets, in last year's report the AAAC had suggested that it would be an appropriate time to form an ExoPlanet Task Force (ExoPTF) to consider how to move forward on the ground and in space. This became timelier given the challenges that were becoming apparent in moving forward with the TPF missions and SIM. This was discussed further during the May 2006 AAAC meeting, and a letter[14] was sent to NSF and NASA recommending that they constitute a Task Force to assess how best to move forward on exoplanet studies, including detection and characterization. The AAAC greatly appreciates that the agencies responded positively and quickly; the ExoPTF has been formed and has begun its deliberations. Its report is expected later in 2007.

During the past year there was also considerable discussion of the future of the Joint Dark Energy Mission (JDEM), a joint undertaking between DOE HEP and NASA. NASA Astrophysics announced three selected projects among a competition for funding for JDEM mission concept studies. Noting the potential opening of a funding wedge in FY09-10 as HST SM4 is completed and JWST passes the peak of its spending curve, NASA asked the NRC to undertake a study to determine which Beyond Einstein mission should go forward if funding became available. The considerations are scientific, cost and technological readiness. This study[15] is being carried out under the NRC's Board on Physics and Astronomy (BPA) and the Space Studies Board (SSB) by the *Committee on NASA's Beyond Einstein Program: An Architecture for Implementation* and includes the various Einstein Probe missions (JDEM; CMBPOL/Inflation Probe; Black Hole Finder), Con-X and LISA. The AAAC was very encouraged that DOE HEP is contributing as an equal partner in this effort because of its particular interest in the outcome for the JDEM mission. The Beyond Einstein Program

[14] http://www.nsf.gov/attachments/106804/public/ExoPlanetTF-AAAC.pdf
[15] http://www7.nationalacademies.org/ssb/BeyondEinsteinPublic.html

Assessment Committee (BEPAC) is expected to report in September 2007 to allow consideration of the outcome by the agencies for their FY09 budgets.

There is further discussion below of the issues surrounding R&A and Explorer funding and the rationale for strengthening the funding in these areas, particularly leading to more frequent Explorer opportunities and for recovering some or all of the hits to the R&A program. While the AAAC would very much like to see an increase in the R&A budget to recover some or all of the funding that was cut, the committee recognizes that it will be difficult to do so within the current, very constrained funding. If it does prove impractical to do this in the next year, the AAAC recommends that NASA consider using some of the funding wedge that opens up in FY09-10 for R&A recovery and Explorers. Clearly this is the same funding wedge that is being considered for a Beyond Einstein mission and so the pressure on the budget will remain high.

The AAAC views the overall dramatic impact of the cuts on the scientific base to be a serious issue and would like to see the funding level considered very carefully by NASA, Congress and the Administration with the goal of finding increased funding for the NASA Earth and Space Science enterprise. Our key recommendation is that Congress provide at least the FY08 budget request to NASA and stop the dangerous slide in space science funding that is threatening our leadership in this area. We strongly urge Congress to support an increase in the NASA science budget as an investment in national innovation and competitiveness, and that the Administration follows this investment with a concomitant FY09 budget proposal for the agency.

3.1 Impacts and Issues – Detailed Considerations

The AAAC has been assigned a role of stewardship for the Decadal Survey process through the requirement that the AAAC "assess, and make recommendations regarding, the status of the activities" of the agencies "as they relate to the recommendations contained in the National Research Council's 2000 report entitled *Astronomy and Astrophysics in the New Millennium*, and the recommendations contained in subsequent National Research Council reports of a similar nature." A number of issues relating to this are addressed below, as are those relating to interagency programs.

The 2005 NASA Authorization Act explicitly requested that NASA ask the NRC to undertake a series of studies to assess the progress towards meeting the recommendations of the Decadal Survey in each of the Divisions of the Science Mission Directorate (SMD). The first of the Divisions to be assessed was Astrophysics. The study, *A Performance Assessment of NASA's Astrophysics Program*[16], was carried out by the NASA Astrophysics Performance Assessment Committee (NAPA) under the NRC Committee on Astronomy and Astrophysics (CAA). The study highlighted several issues which resonated with the AAAC and which are mentioned below.

A) The Importance of Consultation and an Effective Advisory Process: The AAAC also has a responsibility to coordinate "with other Federal advisory committees that advise Federal agencies that engage in related research activities." The AAAC recognizes that the advisory committees within each agency provide more detailed insight that complements the broader perspective and role of AAAC. Many of the AAAC members were chosen because of their involvement and experience in advisory committees, agency roadmapping committees or Science Assessment Groups. Such background brings insight into the activities of the agencies that has proven to be very useful for AAAC members. It also brings a great appreciation for the work of such committees. We were very encouraged that a formal science advisory structure was brought into place at NASA after a hiatus of a year.

[16] http://www7.nationalacademies.org/bpa/caa.html

Last year the lack of any advisory process within NASA led us to discuss in considerable detail the role and importance of the internal advisory committees, with some detail about the way the previous SMD FACA committee, the Space Science Advisory Committee (SScAC), operated. This aspect and others were discussed in more detail in the AAAC's 2006 report in §3.1A. With the formation of the revised NASA Advisory Council (NAC) and its subcommittees, the advisory structure was reconstituted, though with significant changes in the way the interface was implemented for SMD. The AAAC was very encouraged that advisory committees are now in place. From a broad agency perspective, the path for formal advice to the agency is simplified and clearer, with the only path through the NAC to the Administrator. However, the new structure has lost aspects of the previous structure that were widely viewed, both within and outside SMD, as valuable to SMD and the science community. This change led to considerable tension last year within the NAC, leading ultimately to the departure of several prominent and experienced scientists.

One aspect, in particular, has been lost. Although the formal advice path is through the NAC, the SMD science divisions each interface with an associated NAC science subcommittee and can use the subcommittee as a "sounding board" for ideas and questions and as a mechanism for understanding the potential impact of decisions or choices,. However, there exists no "integrating" body with a broadly representative membership across the sciences that can interface with SMD in the same way. Such a group, like SScAC previously, can act both to provide feedback to SMD on ideas that might be under discussion (in the sense of "what impact will this have?" or "how is the community likely to react to…?") as well as provide a means of disseminating issues of concern to SMD that require an informed group to discuss with the community. This dialogue proved to be valuable to the Divisions like Astrophysics also, since it provided a much larger experience base than is represented on the more narrowly focused activities within the Division-specific subcommittees.

The recent report of the congressionally requested NAPA study noted in its Recommendation 2 that "NASA should consider changes in its advisory structure to shorten the path between advisory groups and relevant managers so as to maximize the relevance, utility, and timeliness of advice as well as the quality of the dialogue with advice givers. Clear communication between stakeholders and the agency is critical to a strong partnership for successfully implementing national priorities and realizing community science aspirations." The concern that we outlined above finds parallel arguments in this recommendation.

Last year the Administrator noted that he was willing to consider changes to the advisory structure if needed. The importance of an "integrating body" for NASA science, as discussed above, underscores the continued need for such changes.

B) American Competitiveness Initiative and Innovation and Competitiveness: Cuts to the NASA science budget have broad impact and continue to seem very inconsistent with the broad goals of the American Competitiveness Initiative (ACI). ACI was announced in the President's FY07 budget request and continues into the FY08 budget request. ACI focuses on new investments in DOE science, NIST and NSF and will result in clear benefits in national leadership in science and technology. Congressional support for increases for research at DOE and NSF in the FY07 Joint Resolution demonstrated the deep and widespread interest in bolstering the nation's research capability. Research is a precursor to innovative activities and underpins a technologically competitive society.

There is no question that NASA is a major source of science and technology funding. The agency obviously supports much basic research that matches the broad goals of ACI. Astronomical research, in particular, has paid large dividends towards these goals, breaking new ground in innovation, exploration, and ingenuity as it achieves fundamental discoveries about our physical universe. These efforts have challenged our engineering, technological as well as scientific acumen and, as such, have sharpened our competitive edge in such applied fields as low-light-level sensing, optical design, image processing, and target acquisition and tracking. The high visibility of astronomical research spurs student interest in scientific discovery, engenders a sense of public pride in our creative capabilities, and solicits international admiration that attracts the best minds to our shores.

As noted above we believe that the continued omission of NASA from the ACI plan is unwise, given the visibility that the NASA science program has engendered for science and engineering across the nation. The Congressional interest in Innovation and Competitiveness enables a fresh look at the role of NASA science, and the AAAC strongly encourages Congress to consider enhancing the support for science at NASA explicitly to improve innovation and competitiveness.

C) The Need for a Balanced Portfolio of Missions: Under the title "Ensuring the Diversity of NASA Missions" on page 7, the 2000 Decadal Survey stated: "NASA should continue to encourage the development of a diverse range of mission sizes, including small, moderate, and major, to ensure the most effective returns from the U.S. space program."

In its role as a steward of the Decadal Survey, the AAAC appreciates the NASA Administrator's continued use of the Decadal Survey recommendations to guide decisions. Such recommendations include support for smaller missions as well as the largest "flagship" missions. There is no doubt that the flagship missions have provided remarkable scientific returns. The current situation where three Great Observatories – HST, Chandra and Spitzer – are all returning excellent science data makes this a unique time for astronomy and astrophysics. These have been the highest-ranked large programs over a number of decades. We welcome NASA's support for the next generation mission JWST. This mission was the highest-ranked Major Initiative in the 2000 Decadal survey and promises to be both a remarkably powerful observatory and a very worthy successor to HST.

However, we have deep concerns about how narrowly focused the overall program has become in the Astrophysics Division as a result of the budget cuts and the cost growth in the major programs. We expressed these concerns last year in our 2006 report and would like to emphasize them again this year. We also note the very thoughtful and comprehensive report from a subcommittee of the NRC Space Studies Board (SSB) on *An Assessment of Balance in NASA's Science Programs*[17]. The SSB committee's Finding 2 emphasizes the problem: "The program proposed for space and Earth sciences is not robust; it is not properly balanced to support a healthy mix of small, moderate-size, and large missions and an underlying foundation of scientific research and advanced technology projects; and it is neither sustainable nor capable of making adequate progress toward the goals that were recommended in the National Research Council's decadal surveys."

While the science return is large from the major missions, as it would be from JWST, every Decadal Survey has emphasized the scientific returns from NASA's smaller, quicker missions. The researchers involved in such programs are the ones who ultimately provide the science rationale and often the leadership for future missions. They, and their students and postdocs, need programs on which to develop the skills that make the larger scientific missions possible. Every Decadal Survey for the last 30 years has emphasized the value of Explorer-class missions. Every Survey has also emphasized the importance of research support both for missions directly through Mission Operations and Data Analysis (MO&DA) and also for general Research and Analysis (R&A). R&A funds are not directed at specific missions but are used for a broad range of important research activities, including theory, multi-mission or archival data analysis, technology development and laboratory astrophysics programs that contribute to the interpretation of mission data. These funds support the broad fabric of research on which the mission-specific support can build. The mission-orientated research is identified under MO&DA, providing the support for the science return directly from the mission.

[17] http://www.nap.edu/catalog/11644.html

Again we find ourselves in agreement with the NAPA report. They state: “Recommendation 1: NASA should optimize the projected science return from its Astrophysics program by (a) ensuring a diversified portfolio of large and small missions that reflect the science priorities articulated in the 2000 decadal survey Astronomy and Astrophysics in the New Millennium and (b) by investing in the work required to bring science missions to their full potential: e.g., technology development, data analysis, data archiving, and theory.” This is aligned with our concern about a balanced program and the need for broadly-based funding for R&A and R&D activities. The NAPA committee also discussed the challenge of protecting small missions and programs against encroachment from large programs that run over budget by noting: “The division should also identify structural mechanisms (e.g., firewalls, cost caps, constraints on the concentration of resources in single programs) to protect small programs and mission-enabling activities such as technology development that will lay the groundwork for future missions and research support which are critical for optimizing the science return. The smaller missions and programs are particularly vulnerable to perturbations such as cost growth in large missions, changes in accounting systems, or project budget instability.”

We recognize the budget challenges that face the agency. Nonetheless, we argue that there are three areas affected by the recent budget cuts (R&A, Explorers and R&D on future major missions) that will have major near-term as well as long-term impacts on the science community and on the strength and productivity of the science program at NASA. The emphasis on large missions has contributed to the disproportionate impacts on these key areas. Resources need to be found to achieve scientific balance as well (through the Beyond Einstein program and through future efforts on extrasolar planet studies). The importance of these areas, and their relative inconspicuousness in the greater program, leads us to argue that special attention be given to them both during Congressional action on the FY08 budget and in development of the succeeding budget requests. These areas are addressed individually in the following sections.

D) R&A as a Critical Investment for Future Science: The R&A program represents research funding that is not explicitly associated with an operating mission. While the focus at NASA is on missions and mission-related data analysis, *there is a crucial need for a broader-based program that is in NASA's best interest to fund.* Even at a mission-focused agency there are essential research and development needs that must be supported if NASA is to have cutting-edge future missions. The R&A line is at the heart of this need, enabling creative extension of archived data, theoretical studies that cross traditional disciplinary boundaries, laboratory studies that develop chemistry and physics with which astronomical data can be interpreted, and new instrumentation and sensor technologies that pave the way for new science missions. This budget line develops the fabric out of which new areas of astronomical research and new mission concepts evolve, and with its strong academic participation is a key factor in workforce training. The R&A budget was cut in FY07, and the FY08 5-year run-out budget shows little opportunity for recovery. The FY06 R&A program was about $65M. The R&A cuts that are causing such concern in the community are about $15M in the Astrophysics Division. The R&A line for FY08 and beyond drops to less than $50M and changes little in actual-year dollars out through 2012. By FY10, this represents a cut of about 35% relative to FY06 in inflation-adjusted dollars.

We recognize that these cuts have occurred across all the science Divisions, and are sympathetic with the concerns also being expressed within those communities. Such cuts strike at the foundations of a strong research enterprise and seem quite inconsistent with the broad goals of the ACI. Such cuts also have a dramatic and disproportionate impact on the future of the field – on the imaginative, hard-working young scientists. These young people, along with their guides, mentors and teachers among the more senior, experienced members of the community, constitute the nation’s scientific human capital. Together they are the future of the field.

The AAAC strongly recommends 1) that Congress consider the impact of this cut during their deliberations on Innovation and Competitiveness during the FY08 budget process, and 2) that NASA increase the R&A funds in FY09 and beyond to reflect a baseline value at the inflation-adjusted 2006 level.

E) Involving the Community – Explorers: Explorers are a key component of the scientific community's "hands-on" involvement with space science missions. The Explorers have been remarkably productive scientific missions; the Cosmic Background Explorer (COBE) and Wilkinson Microwave Anisotropy Probe (WMAP) missions are excellent examples. As noted above, Explorers have been strongly supported in the last three decadal surveys. The 2000 Decadal Survey noted, "NASA's Great Observatories have revolutionized understanding of the cosmos, while the extremely successful Explorer program provides targeted small-mission opportunities for advances in many areas of astronomy and astrophysics. The committee endorses the continuation of a *vigorous* Explorer program (our emphasis). There are now fewer opportunities for missions of moderate size, however, despite the enormous role such missions have played in the past."

The decision two years ago to remove a large component of funding from Explorers ran counter to the very strong recommendations of the Decadal Survey. This program needs to be recovered and made healthy as soon as practical. We greatly appreciated the efforts with the Astrophysics Division to restore funding to the Wide-field Infrared Survey Explorer (WISE) during FY06. But the need is great for a new Announcement of Opportunity (AO). The last Explorer AO was in 2002, and the next will not occur until at least 2008, about half the rate prior to 2002. This indicates a program that is in serious jeopardy and is not what the community considers to be "vigorous."

F) Cost Credibility for Mission Prioritization: The astronomy and astrophysics community plans to convene, with the support of the agencies, a broadly based Decadal Survey study in the near future that reconsiders and prioritizes our goals for the next decade. Almost none of the high-priority initiatives from the last Decadal Survey will be completed. Given this, there is a widespread view that the next Decadal Survey will have to re-assess and re-prioritize both unfinished programs and new programs if it is to develop a viable program for the next decade. It is crucial that we go into that next Decadal Survey with adequate technology and conceptual development in hand for the many missions or programs that will be considered in the 2010 Decadal Survey. Otherwise, the Survey discussions will be devoid of solid technical underpinning and will be saddled with unreliable cost estimates. As has been noted by many across the community, the underestimates in the mission budgets in the 2000 Survey have caused significant problems, and the AAAC would very much like to see the cost estimates improved. A clear strategy for improving cost credibility is early investment in mission concept and technology development.

These concerns regarding mission conceptual development were expressed in our 2006 report with particular reference to major programs like Constellation-X (Con-X), those designated for initial technology development like the Terrestrial Planet Finder (TPF) and the moderate initiatives like the Laser Interferometer Space Antenna (LISA). A modest level of funding in these programs over the next ~2-3 years would make a big difference to the future robustness of the missions chosen for the next decade through the Decadal Survey process – and for the robustness of the process leading to the recommended pool of missions. The level of funding that has been discussed as desirable for major missions is about $10M. There have been changes in FY07 and the FY08 budget request that help towards the goal of adequate mission maturity at the time of the Decadal Survey. The total funding in the Beyond Einstein program is projected to increase from ~$22M per year in FY07 to $32M in FY08. TPF would increase from its very low level of funding in FY07 ($0) to $6M in FY08. The Single Aperture Far-Infrared Observatory (SAFIR) was recommended in the Decadal Survey for technology investment but has been essentially unfunded this decade. Also in this last year, the revision in the status of the Space Interferometry Mission (SIM) also puts it into the category of needing a continuing level of funding to ensure that it is positioned both for serious evaluation in the next Decadal Survey and for flight as funding becomes available. Given its maturity, it is funded at a higher level in FY08.

The funding for concept studies for the one of the Einstein Probes, JDEM, was a welcome development. This is the first funding for missions at the scale of the Probes, which are ~$600M missions. The AAAC was also pleased to see that last year the Space Studies Board and the NAC Astrophysics subcommittee also supported funding for conceptual and technical development.

G) Need for Consistent Costing: Last year in our report we emphasized the need for a consistent approach to mission cost and advocated that the baseline be "lifecycle" costs. This was our response to the growing concern that the community did not understand what our missions really cost over the 10-15 years that it took for Decadal Survey recommendations to be implemented. The changing cost estimates of major science missions like JWST, SIM, SOFIA and the servicing mission costs of HST surprised many. The changes also led to concerns about what other potential mission "undercostings" (to use the NASA Administrator's very appropriate word) awaited us as other missions developed towards Phase B and even into Phase C/D. Unfortunately, the costs in the 2000 Decadal Survey were not consistently estimated, nor was independent cross-checking carried out. Fortunately, both NASA and the astronomy community have recognized the problem that this undercosting has caused. Ways to improve the mission and project budgets are under discussion for the next Decadal Survey.

Two additional factors have led to significant difficulty in assessing and comparing costs among current, past and future missions. First, it has often been unclear whether the cost estimates refer to construction costs (Phase C/D) or to the lifecycle costs (pre-Phase A through E) that include technology development through operations over the mission lifetime. Second, NASA's recent transition to full-cost accounting has added significantly to the budgeted cost of a mission (since civil service labor was not previously included for those NASA centers that have a civil servant workforce – e.g., GSFC and MSFC do, JPL does not).

To put the current program into context with the historical program, we note here the estimated "lifecycle" costs of a number of ongoing and future major programs. These estimates have significant uncertainty, given both the very different situations under which they were developed, but as we noted last year, "it is better to be roughly right than have no idea at all." With the caveat that changes will occur, we note the lifecycle costs in current dollars in a full-cost accounting environment (including design and technology, construction, launch and operations) for a range of past, present and future missions:

- HST: ~$9B (assuming SM4 will occur in Fall 2008 plus 5 years of added operations)
- Chandra: ~$3.5B (with 15 years of operations)
- Spitzer: ~$1.3B (with operations through 2011)
- Cassini: ~$3B (including ESA and DOE contributions);
- JWST: ~$4.5B (assuming 2013 launch and 10 yrs of operations)
- SIM: ~$2.5B (uncertain, given the changes - depends on launch date - with 12 yrs of operations)
- SOFIA: $2.5B (with 20 yrs of operations).

We note that Chandra/AXAF was costed at $500M in the 1980 survey; Spitzer/SIRTF was $1.3B in 1990; SOFIA was $230M in 1990; SIM/AIM was $250M in 1990; and JWST/NGST was $1B in 2000. These cost discrepancies clearly indicate the need, noted above, for better cost estimates by both NASA and the Decadal Survey.

These lifecycle cost estimates also suggest why the astronomy community so values the Explorer and Discovery missions. At ~$300M for Explorers and ~$420M for Discovery missions, they can occur more frequently. It also suggests why the concept of $600M-scale missions like Einstein Probes, New Horizons and Origins Probes has been extensively discussed (and implemented as in the case of New Horizons) to provide a cost scale that is intermediate between the small missions and the rare flagships.

H) Current Major Activities: The release of the FY07 budget request in early February 2006 heralded some major and very unwelcome changes for the program. R&A was cut by $11M, SOFIA was reduced to $0, TPF was reduced to $0, SIM's launch date was deferred from 2010-11 to no earlier than (NET) 2015/16, Beyond Einstein was cut, Explorers were cut, etc. The subsequent changes during FY06 and FY07, e.g., the reinstatement of SOFIA and the return of SIM to development, were no less dramatic. In the FY06 budget request the small increases in the Astrophysics budget through FY08 were replaced by small cuts, just as the HST and JWST budgets were increasing due to re-inclusion of the HST SM4 servicing mission and the ramp-up for construction of JWST. The effect was large and dramatic. The FY08 budget request largely continues the FY07 funding profile, and the Astrophysics program remains highly constrained. As noted above (and below in "Other Missions"), a significant number of missions come to fruition in the next 2-3 years, but the pipeline dries out rapidly after 2009.

HST: Congress has directed the agency to update and repair HST if it can safely be done. The very clear recommendations of the NRC report, *Assessment of Options for Extending the Life of the Hubble Space Telescope*[18], have guided the AAAC's thinking about HST. The clarity that the Administrator has brought to the HST servicing discussion was greatly appreciated, as was the announcement in fall 2006 that SM4 would be scheduled for mid-2008. The recent failure of the Advanced Camera for Surveys (ACS) gives added weight to this servicing mission. With the planned SM4 additions of the Wide Field Camera 3 (WFC3) and the Cosmic Origins Spectrograph (COS), HST would again be a very powerful facility. We recognize that the servicing mission is a costly endeavor for SMD/Astrophysics, on the order of $12M per month, so the AAAC hopes that further delay of the mission beyond September 2008 does not occur.

JWST: The James Webb Space Telescope (JWST) is the highest-ranked Major Initiative in the 2000 Decadal Survey. It is a successor to HST yet is substantially more powerful, reflecting the technological advances that have occurred over the more than two decades since HST was designed. JWST has become significantly more costly than expected, though the underestimates by NASA in the last decade that came to be reflected in the Decadal Survey did not help. The current plan is for JWST to enter Phase C/D or construction early in 2008 and to launch in 2013. The AAAC recognizes that the JWST project has made substantial progress over the last year. A major milestone was reached recently with a review of the technological readiness of JWST, the Technology Non-Advocate Review (T-NAR). This review focused on the remaining key technologies that needed to demonstrate their readiness for flight and found that 9 of the 10 did so, with the remaining one expected to reach flight readiness (i.e., Technology Readiness Level 6, TRL-6) soon.

The JWST budget appears to have stabilized also. An independent review of the JWST project early in 2006 had identified the level of near-term contingency as a potential problem for the JWST project. Astrophysics added contingency in FY07 and FY08 to address this concern. The budget profile chart presented to the AAAC in February 2007 showed significant levels of contingency through key phases of the JWST program, adding confidence that the program's budget is likely to remain stable. This chart also demonstrated the commitment to retiring technology risk in advance of construction. A very substantial fraction of the budget is being spent before Preliminary Design Review (PDR in FY08) and Critical Design Review (CDR in FY09). JWST is an interesting test case of a "lesson learned" from previous missions, whereby all key technologies are developed and demonstrated before going into construction (Phase C/D).

There is little doubt that JWST will be a truly remarkably powerful scientific facility with huge gains in capability over our current missions. JWST will address some of the most important questions in

[18] http://www.nap.edu/catalog.php?record_id=11169

astrophysics (the state of universe in its earliest years, the buildup of galaxies, the birth of stars and planetary systems) and, like HST, will have remarkable capabilities for exploration and discovery. The goal is to ensure that JWST moves through its development without further cost growth, to recover the balance between small, medium and large missions, and to enable development for the future major missions that will follow JWST.

Other Missions: The next few years reap the investments of the first part of this decade. The progress on GLAST towards launch is very encouraging; GLAST will be launched later this year (2007). Herschel and Plank – European Space Agency (ESA) missions with significant US involvement – will be launched in mid-2008. Kepler and the Solar Dynamics Observatory (SDO) are slated for launch in 2008, with the Wide-field Infrared Survey Explorer (WISE) slated for the following year. New missions drop dramatically though after that. The first science flight of the Stratospheric Observatory for Infrared Astronomy (SOFIA) is expected in 2010, but SOFIA full science operations are not expected until 2013. Future Explorers may come about from an upcoming announcement, but any mission would not be launched until beyond 2013, and similarly for any Discovery mission. Potential exoplanet missions in the Navigator program await the ExoPlanet Task Force (ExoPTF) recommendations and the upcoming Decadal Survey, but any mission would likely not launch until the middle of the next decade. The ongoing NRC Beyond Einstein Program Assessment Committee (BEPAC) study will identify the first possible Beyond Einstein mission for a funding wedge that may open up in FY10, but that mission would not be launched until well into the next decade. The ExoPTF should provide a framework for moving forward in the exciting field of planet detection and characterization, but it will be well into the next decade before any mission could launch.

The dramatic decrease in the rate of launches after 2010 reinforces the need for a new Explorer opportunity and for further consideration of missions of the scale of New Frontiers (i.e., the Probes, like the Einstein Probes) that could be developed more quickly than major missions at the billions-of-dollars scale.

J) SMD and the Astrophysics Division support for science: The AAAC would like to commend the Astrophysics Division, particularly its Acting Director Rick Howard, for their efforts on behalf of the astronomical community over the last year. It has been an extraordinarily challenging period, with many changes driven by the new budget cuts and projections, by major changes in the science advisory structure, and by changes in the mission mix. The Division scientists and staff have been the recipients of a great deal of concern and frustration from the science community, yet have continued to be willing to listen and interact while dealing with a lot of pressure and constraints. The AAAC greatly appreciates the Division's efforts on behalf of a strong astronomy and astrophysics enterprise. The AAAC also commends the scientists and staff of the SMD office for their efforts. They have dealt with the same problems and issues, only more broadly across all Divisions. We also greatly appreciate their efforts on behalf of a strong space and earth science enterprise.

A number of projects or programs involving NASA are discussed in §5 and §6. Issues relevant to NASA occur in: §5.1 and §6.1 with regard to R&A; §5.2 for HST; §5.3 for JWST; §5.6 for the Explorer program; §5.7 for Beyond Einstein; §5.8 for Einstein/Origins Probes; §5.9 for Major Mission Technology and Conceptual Development; §5.10 for SOFIA; §5.11 for the next Decadal Survey; §6.2 for NVO; §6.3 for ATST/SDO synergy; §6.4 for GSMT/JWST synergy; §6.5 and §6.10 for the DETF; §6.6 for JDEM; §6.8 for the ExoPTF; §6.9 and §6.10 for CMB Task Force TFCR; §6.11 for South Pole data communications; §6.12 for GLAST; §6.13 for the "Lessons-Learned" activity; and §6.14 for travel support for the AAAC.

4.0 Department of Energy (DOE)

A). The DOE Office of Science, primarily through the Office of High Energy Physics (HEP), is playing an increasing role in the nation's astronomy and astrophysics enterprise. DOE HEP is contributing in significant ways to projects that will address a number of fundamental scientific questions that explore the physics of the Universe. The NRC report, Elementary Particle Physics in the 21st Century (EPP2010), recommended action by DOE HEP in several areas of astrophysics: dark matter, CMB research and dark energy. These fields lie at the boundary of astrophysics and particle physics and promise great insights. The AAAC is encouraged by the progress towards the late-2007 launch of the joint DOE/NASA project Gamma-Ray Large Area Space Telescope (GLAST). The AAAC appreciates the support of HEP (and the NSF Physics Division) for the Task Force on CMB Research (TFCR), the Dark Energy Task Force (DETF) and the Dark Matter Scientific Assessment Group (DMSAG) and looks forward to the agencies' response to these activities. The recent increases for the DOE Office of Science from the ACI program and from Congressional action on the FY07 Joint Funding Resolution provide opportunities to significantly enhance the science program at DOE, though the AAAC was concerned that the increase in the FY08 budget request for HEP was small (<1%). ***The AAAC appreciates the growing interest in astrophysics within DOE HEP and recommends that HEP continue to enhance their support of programs at the interface of astronomy and particle physics in response to the recommendations in EPP2010. The AAAC hopes that DOE-HEP shares in the ACI-led increase for DOE-science and that the FY08 request increase of <1% does not represent a trend for HEP funding.***

B). The AAAC welcomes the HEP solicitation for dark energy R&D, in addition to continuing DOE support for the Supernova Acceleration Probe (SNAP) R&D. The AAAC expects that the DETF report will provide guidance for the optimization of near- and intermediate-term activities, as well as for JDEM and LST, and we hope that DOE, NASA and NSF will work together to utilize the DETF recommendations in their planning and review processes. The AAAC considers support of the Stage III activities to be particularly valuable at this time, and the AAAC recommends that HEP give particular attention to supporting Stage III projects as a means of making progress quickly and providing a framework for the much more expensive Stage IV projects. The AAAC notes that the Dark Energy Survey DES (Stage III) was recommended by HEPAP for the start of fabrication. Similarly, the DMSAG report is expected to provide very valuable guidance on how to optimally focus resources on the direct detection of dark matter. This field is poised to make significant advances with a modest increase in funding that would ensure the continuation of US leadership. The AAAC strongly endorses increased support for the dark-matter direct-detection efforts. ***The AAAC recommends that the HEP further develop their support for R&D and programs in the areas of dark energy and dark matter, giving particular attention to supporting DETF Stage III projects that provide a framework for the much more expensive Stage IV projects (JDEM and LST). The AAAC strongly endorses increased support for the dark matter direct detection efforts.***

The U.S. Department of Energy (DOE) Office of High Energy Physics (HEP) in the Office of Science is becoming increasingly involved in research efforts related to astronomy and astrophysics. The AAAC has discussed developments and issues with HEP routinely over the last year and greatly appreciates the involvement of DOE in the Nation's astronomy and astrophysics enterprise. DOE is contributing in significant ways 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 the *Connecting Quarks with the Cosmos* (CQC) and *Physics of the Universe* (POU) reports. The AAAC welcomed the increases for the DOE Office of Science from the American Competitiveness Initiative (ACI) that were initially in the FY07 budget request ($4.1B, or +14% over the FY06 $3.6B), and then also in the FY08 budget request ($4.4B, or +7.2% over the FY07 request). Concerns that momentum on the ACI increases would be lost were greatly alleviated by the Congressional support for DOE science in the FY07 Joint Resolution, where DOE's Office of Science was one of the few agencies to receive a significant increase (to $3.8B or +5.6%). The AAAC hopes that the Congressional support in FY07 is reflected in support for the FY08 increase as well. (The overall increase in the FY 08 request would take DOE's Office of Science budget up by 16% from the FY07 appropriation.)

While the DOE Office of Science overall has done very well, there was concern that the FY08 increases that have been designated for HEP are smaller. The 8% increase in the FY07 request (vs. 14% for the Office of Science) has dropped to <1% in the FY08 request (vs. 7% in the FY08 request for the Office of Science). The astrophysics support by DOE-HEP, which is the area with which the AAAC is most familiar, is becoming increasingly crucial for advances in some of the areas of greatest interest, namely dark matter, dark energy and the birth of the universe. The AAAC hopes that the HEP budgets will reflect the increases being given elsewhere in the Office of Science.

The report of the National Academy committee EPP2010: Elementary Particle Physics in the 21st Century, *Revealing the Hidden Nature of Space and Time Charting the Course for Elementary Particle Physics*[19], identified three areas of astrophysics that were of particular interest to the particle physics community. The focus of this report was on the Large Hadron Collider (LHC) and the International Linear Collider (ILC) – recommendations regarding these major programs occupied the first three places – but astrophysics was the fourth highest recommendation. Within the Astrophysics recommendation, three areas were singled out. These were dark matter, CMB research and dark energy. Interestingly the AAAC has worked with HEP (and NSF Physics) in all three of these areas, and several projects are underway or under consideration (see below).

The AAAC played a key role in initiating and guiding three activities of interest to the DOE Office of High Energy Physics, namely the Task Force on Cosmic Microwave Background (CMB) Research (TFCR), the Dark Energy Task Force (DETF), and the Dark Matter Scientific Assessment Group (DMSAG). The DETF and the DMSAG grew out of recommendations made by the AAAC. These Task Forces reported jointly to both the AAAC and the High Energy Physics Advisory Panel (HEPAP). The DETF report was accepted and transmitted to the agencies in mid-2006. The AAAC thanked the committee for its excellent report and the very careful and thorough way in which it laid out guidance for moving ahead, both in the near-term and in the long-term. This was a superb demonstration of the value that arises from a well-chosen, dedicated scientific group who take on the responsibility to provide a path for moving forward in a cost-constrained environment. Making progress on Stage III activities (i.e., near-term as classified by the DETF) is the key next step (see §6.5).

The DMSAG has produced a draft report but is undertaking an external review of the report at the AAAC's request (as was done for the TFCR and the DETF). That DMSAG report is expected to be finalized and transmitted to the agencies by this summer. The DMSAG report appears to have made an excellent case for additional resources for direct detection of dark matter, identifying what could be done for an additional ~$7-8m beyond current expenditures (for a total around $10M). While the AAAC heartily endorses such an increase, it also recognizes the possibility that the agencies (DOE HEP and NSF Physics) may not be able to fully fund these experiments, so we asked the DMSAG to give a finer-grained structure to its recommended priorities in case the agencies could only find an intermediate amount between the current $2-3M and the hoped-for ~$10M. Such prioritization makes best use of the intellectual resources, project experience and community input that the DMSAG has brought to bear during its discussions and development of its report.

[19] http://books.nap.edu/catalog.php?record_id=11641

The AAAC greatly appreciates the effort that the DMSAG put into its report. Again it demonstrates the excellent results that accrue from a dedicated focused effort by the community in trying to find an optimal path forward. The US has exercised leadership in this area and the additional support would help continue this leading role.

Examples of the projects that DOE HEP has been considering or has begun to undertake with other agencies fall in several areas. In 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). With NSF as the lead, DOE labs are involved in R&D (particularly for the wide-field camera) for pre-conceptual design for the Large Synoptic Survey Telescope (LSST). DOE is a partner with NASA on the primary instrument for the Gamma-ray Large Area Space Telescope (GLAST). This program is moving forward towards launch in late 2007, with many of the issues that most concerned the AAAC in its 2005 report having been resolved. DOE HEP is also jointly sharing in the support of the NRC Beyond Einstein study by the Beyond Einstein Program Assessment Committee (BEPAC) that was requested by NASA to identify which among the Laser Interferometer Space Antenna (LISA), Constellation-X (Con-X), JDEM, Inflation Probe (CMBPOL) and Black Hole Finder should be started in the 2009-10 timeframe if funding becomes available. The consideration of JDEM, the DOE-NASA Joint Dark Energy Mission, was of particular interest to DOE. The NRC has been asked by the agencies to provide the BEPAC report by September 2007 to give time for consideration of the outcome in the FY09 budget process.

The continuing support of HEP for dark energy programs is very welcome. The increase in the FY07 budget for DOE Office of Science HEP includes a significant increase in SNAP R&D funds from the FY06 level of $2.6M. The FY07 request was $7.5M while the current FY07 actual plan provides $3.2M, and the FY08 request is $3.5M. Another significant contribution is the $3M in dark energy R&D funds that will be competitively awarded. Ground- and space-based concepts will be able to apply for these funds. We were very encouraged to see that an additional $5.8M is identified for continuation of this R&D effort in the FY08 budget request. We applaud HEP for carrying out these two solicitations for dark energy R&D. Coordinating with NSF and NASA would benefit the community and optimize the use of the agencies resources. The AAAC also is very pleased that DOE HEP appreciates the need for support for other concepts and is addressing ways of reducing disparities while also supporting the SNAP program. We welcome the discussions to acquaint HEPAP at its February 2007 meeting with each of the three NASA-selected JDEM concept studies (ADEPT, DESTINY and SNAP). The DETF report provides guidance for the optimization of near- and intermediate-term activities, as well as for JDEM and a ground-based Large Survey Telescope (LST), and we hope that DOE, NASA and NSF will work together to utilize the DETF recommendations in their planning and review processes, particularly in the near-term for Stage III projects.

In particular, we are aware that HEPAP, which reports to both DOE-HEP and NSF-EPP (Elementary Particle Physics), approved its Particle Physics Project Prioritization Panel (P5) subcommittee report[20] in 2006. That report recommended support for the start of fabrication for the Dark Energy Survey (DES, a project that fits in the DETF Stage III) as well as R&D funding for the DETF Stage IV projects SNAP and LSST to get them to CD-2 or PDR (as appropriate for DOE or NSF). LSST is at a very preliminary stage at DOE, as noted above. For DES, the FY08 request includes DES as a new major item of equipment (MIE). The project is planned as a partnership between DOE and the NSF, which operates the Cerro Tololo Inter-American Observatory (CTIO) 4-m telescope that DES plans to use (following selection through a call for proposals). Funding for fabrication in FY08 is contingent on successful scientific and technical readiness reviews by the funding agencies. The AAAC welcomes this as a component of the Stage III activities discussed by the DETF.

[20] http://www.science.doe.gov/hep/p5/P5Report_Final.pdf

Many of the programs that have DOE HEP involvement are some of the first examples of major interagency collaborations (e.g., GLAST, VERITAS, JDEM, etc), and so 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. Last year we recommended to the agencies that a "lessons-learned" activity might be a very useful step to take to provide guidance for the future (see §6.13). The agencies and OSTP discussed this and agreed to do so. They have been holding discussions on this topic over the last year and have given the AAAC several updates on how the discussion is progressing. The AAAC applauds this interagency activity, with its OSTP leadership, and hopes that DOE, NSF and NASA can use this effort to strengthen their collaborations. The AAAC remains very interested in the outcome of these discussions and hopes that a detailed synopsis of the "lessons-learned" report is made available, even if the full report cannot be made public.

The AAAC would like to particularly thank the HEP Associate Director Robin Staffin and Program Manager Kathy Turner for the time and interest they have shown in the AAAC's activities and for their contributions to discussions on many issues. Their efforts in working with us to help build a robust astrophysics program in the areas of interest to HEP are much appreciated.

A number of projects or programs involving DOE are discussed in §5 and §6. Issues relevant to DOE occur in: §5.5, §5.7, §5.8, §6.5, §6.6 and §6.10 with regard to JDEM and Dark Energy; in §6.9 and §6.10 for the CMB Task Force (TFCR); in §6.5 and §6.10 for the DETF; in §6.7 and §6.10 for the DMSAG; §6.2 for NVO; in §6.13 for the "Lessons-Learned" activity; and §6.14 regarding AAAC travel support.

5.0 Decadal Survey and NRC Reports Status

The following sections deal with specific projects that raised issues and/or concerns for the AAAC during its deliberations over the last year. These programs have all grown out of Decadal Survey recommendations, and so we address these under the broad heading of the status of the missions in the Decadal Survey and like NRC Reports (e.g., CQC). We have also taken particular note of issues and concerns raised during the year by NAS committees such as the Board on Physics and Astronomy (BPA) and the Committee on Astronomy and Astrophysics (CAA), since they have a particular role to play as the custodians and champions of the Decadal Survey and other similar NAS surveys. We also offer some thoughts regarding the next Decadal Survey.

5.1 Research and Analysis (R&A) and Mission Operations and Data Analysis (MO&DA) at NASA

R&A/MO&DA: The mission-specific science data analysis (the DA in MO&DA) funds are an important NASA innovation that has resulted in great science return from missions, benefiting both NASA and the science community. R&A is a complementary program that also benefits both NASA and the community. Funds from R&A complement mission-specific data analysis support, train the next generation of researchers, develop and demonstrate new technologies, and provide broad scientific underpinning for the space and earth science enterprise. The impact of the R&A budget cuts has been substantial. Even modest cuts have a dramatic impact since they result in a major reduction in near-term opportunities in a multi-year program. Recovery from such cuts is difficult since the options are few for substitute funding in an academic environment. ***The AAAC strongly recommends a restoration of R&A funding at NASA,***

particularly if new funding is added in the FY08 appropriation, or utilizing part of the FY09/10 funding "wedge" in Astrophysics.

NASA supports scientific research directly through funding for mission operations and data analysis (MO&DA) and research and analysis (R&A) programs. One aspect of this funding is directed for support of the operating missions. This component is very important for the community and for NASA since it directly funds the science from the operating missions; that is, it enables the direct return on the capital investment. Current science data analysis funding totals ~$60M for the flagship missions like HST, Chandra and Spitzer. This funding is crucial for returning the science results from operation missions that represent a huge investment for Federal dollars. The science community greatly appreciates that NASA explicitly and directly recognizes the value of science data analysis funding for its missions and ensures that such funding receives priority along with mission operations support.

A second component of community support is R&A. This broader funding trains scientists to effectively and efficiently derive exquisite scientific results from the NASA missions. This budget line encourages creative extension of archived data, theoretical studies that can cross traditional disciplinary boundaries, laboratory studies that develop chemistry and physics with which astronomical data can be interpreted, and new instrumentation and sensor technologies that pave the way for new science initiatives. This budget line develops the fabric out of which new lines of astronomical research and new mission concepts evolve, and with its strong academic emphasis, is a key factor in scientific development for the community, particularly for its younger members. The R&A program represents research funding that is not explicitly associated with an operating mission. However, this does not mean that R&A isn't targeted at areas of particular value for NASA. It typically has been. Thus, R&A has significant direct value to NASA and its future flight opportunities, as well as to the science return from current missions. The AAAC, like so many in the science community, is very deeply concerned about the long-term impact of the R&A cuts on future mission opportunities and the science return from the current missions.

The impacts of reduced R&A funding cover a wide range of activities, most of which have long timescales. A break in funding can impact our readiness for scientific mission opportunities, or technology developments, or theoretical modeling, or analysis and archiving techniques. For example, if we fail to develop a particular technology to flight readiness (TRL-6), it may preclude a whole class of missions. Coronagraphic planet detection techniques, with their exquisite and extraordinarily challenging optical requirements, are an example where progress is painstakingly slow. Detectors are a perennial problem, and it is rare for a program not to find their baseline detectors on the critical path. Stopping efforts in areas like these can have a major impact when funding does again become available – the mission suites will be limited if a long-term development program has been interrupted.

R&A can make a substantial difference in many areas, for example, by: (1) targeting low-flight-readiness technology, at a point where high risk, high payoff activities are low in cost (e.g., sensor development); (2) encouraging investment in specialized test and characterization equipment and implementation expertise in a low-cost lab environment; (3) encouraging applied physics research that can lead to novel hardware solutions, as well as to new software systems; (4) developing new and innovative data analysis approaches that leverage a huge investment in major facilities; (5) carrying out low-cost, suborbital proof-of-concept (technology and science) demonstrations for flight hardware; (6) enabling end-to-end student projects in academia that develop skills in experiment planning, design, and execution; (7) exploring theoretical models with the goal of understanding the results from multiple-missions datasets; (8) developing sophisticated numerical modeling techniques, implementing them on computer arrays and interpreting the results over the many years it takes to put these systems into place; and (9) enabling measurement through laboratory astrophysics of parameters that are essential for deriving scientific results from missions.

We were interested to note that our own views about R&A were similar to those who developed the Universe (now Astrophysics) Division roadmap in 2005, namely: “The theory, laboratory astrophysics, ground-based observation, archival research, and technology development components, together with the suborbital program described above, constitute the seed corn from which major NASA missions grow. It is the R&A program that supports creative, high-risk, novel ideas and the initial development of new detectors and instrument concepts. Support of new ideas at an early stage is the lifeblood of progress across the radiation spectrum from radio to gamma rays, cosmic rays, neutrinos, and gravitational waves. A stable, long-term program of basic research in detector development and supporting research and technology is essential for the future development of large space missions. The opportunities for hands-on training with cutting edge technologies and relatively modest R&A projects is equally critical for supporting and nourishing the scientists, technicians, engineers, and managers who will be responsible for the scientific priorities and flagship missions of the future. While the R&A program supports future developments needed to sustain the Roadmap, it also provides scientists the opportunity to do cutting-edge science: The recent Hubble observations of the oldest known planet, a Jupiter-sized body orbiting around a sun-like star in a globular cluster 5600 light years from Earth, was supported by R&A. Likewise, the Spitzer observation of the youngest planet observed outside the Solar System, the BOOMERANG balloon-borne studies of the cosmic microwave background, and the observations of prompt optical flashes from gamma ray bursts were supported by R&A.”

The R&A budget was about $65M in the Astrophysics Division in 2006 but has been cut significantly to ~$50M, and the 5-year run-out budget shows further decreases, especially when corrected for inflation. Such cuts have an immediate and direct impact. The impact was much greater than this cut might suggest, since it dramatically reduced new and renewal opportunities as the available funds focused on meeting prior commitments in the multi-year grants typical under the R&A program. They also have a longer-term impact. The investment in the suite of missions from the smallest to the largest like Spitzer, Chandra and HST exceeds $10B for development, construction and launch. The funds for the development of most missions, and especially the large ones, go primarily to the engineering and management base at the industrial contractors and NASA Centers and thus provide little direct support for the science community. However, the ultimate metric of success will be from the science returned – and that requires active, knowledgeable, trained and involved scientists. R&A develops the scientific base that provides the scientific return on the mission investment.

We recognize the challenges for the SMD and Astrophysics Division budget with the effective budget decreases after inflation over the next few years and the demands of a number of projects that are at critical points on their construction cost profile. Cuts now in such projects almost invariably lead to increased overall cost. This was discussed further in the NASA section (§3.1), but the timing for a significant recovery in the R&A funding may well be when the wedge opens up in FY09/FY10 after the peak of the JWST funding profile and after HST SM4 is completed. Certainly if Congressional action led to an improved budget for NASA, especially for science through its Innovation and Competitiveness focus, the AAAC would strongly recommend that priority be given to recovering some or all of the cuts in Astrophysics R&A.

5.2 Hubble Space Telescope (HST)

HST: The AAAC recognizes the scientific value of HST and the gains in capability that will be achieved through Servicing Mission 4 (SM4); thus, we support a carefully-managed program to maintain and upgrade HST, and we welcomed the NASA Administrator’s announcement last fall that HST SM4 would be carried out in 2008. The new Wide-Field Camera 3 (WFC3) and Cosmic Origins Spectrograph (COS) will provide powerful new scientific capabilities. The new camera in particular will continue the extraordinary images from Hubble that have captured the public's imagination. ***The AAAC welcomed the decision to***

carry out SM4, but recognizes the significant cost to SMD and the Astrophysics Division of preparing for the servicing mission and hopes that no further delays occur in SM4 beyond Fall 2008.

The AAAC has consistently supported a servicing mission SM4 for HST, guided by the very clear recommendations of the NRC report *Assessment of Options for Extending the Life of the Hubble Space Telescope*[21]. We applaud the NASA Administrator for resolving the question of what to do with the HST servicing program. Congress had directed the agency to update and repair HST if it can safely be done. In a very clear statement early in 2006, the Administrator decided that the only viable approach was through a Shuttle servicing mission. With the successful completion of several shuttle flights, the Administrator announced in fall 2006 that SM4 would be scheduled for mid-2008. We welcome this announcement.

The recent failure of the Advanced Camera for Surveys (ACS) gives added weight to this servicing mission. With the planned SM4 additions of the Wide Field Camera 3 (WFC3) and the Cosmic Origins Spectrograph (COS), HST would again be a very powerful facility. The new camera in particular will continue the extraordinary images from Hubble that have captured the public's imagination. Each of these instruments brings a new level of capability to HST. COS is a remarkably powerful spectrograph, some 50 times that of the Space Telescope Imaging Spectrograph (STIS) in the region where they overlap. Similarly, WFC3 brings ~20 times the capability of the Near Infrared Camera and Multi-Object Spectrometer (NICMOS) in the infrared and of ACS in the ultraviolet, and is especially powerful when it brings these gains to bear on the deep fields established by ACS in the optical. The recent discussions about the recovery approaches for ACS and STIS would add significantly to the overall level of science capability and science return for HST for the remaining years of its life.

We recognize that the servicing mission is a costly endeavor for SMD and Astrophysics, on the order of $12M per month, and so the AAAC hopes that further delay of the mission beyond September 2008 does not occur.

5.3 James Webb Space Telescope (JWST)

JWST: JWST is the highest-priority Major Initiative in the Decadal Survey. The realization of the high lifecycle cost of JWST in 2004-5, the disconnect between the current mission lifecycle costs and the budget estimates used in the previous Decadal Survey, and the budget cuts for SMD led to great concern about JWST's impact on Astrophysics/SMD. Considerable concern exists that JWST is still 6 years from launch and could develop problems that would further impact the balance of programs in the Astrophysics Division. The AAAC shares the view in the community, as reflected in the Decadal Survey, that a balanced program from R&A through moderate missions to "flagships" is essential. The recent very successful Technology Non-Advocate Review (T-NAR) and the identification of added contingency for JWST in FY08 and FY09 indicate a more stable path to launch and a more stable budget. ***The AAAC reaffirms the high scientific value of JWST that led to its Decadal Survey ranking, and more generally the value of "flagship missions" like JWST for the overall science program. The AAAC hopes that JWST progresses to launch without further cost growth.***

JWST is the highest-ranked large mission in the 2000 Decadal Survey (listed there as the Next Generation Space Telescope, NGST). It is a successor to HST, yet is substantially more powerful, reflecting the technological advances that have occurred over the more than two decades since HST was designed. JWST will address some of the most important questions in astrophysics (the state of universe in its earliest years,

[21] http://www.nap.edu/catalog.php?record_id=11169

the buildup of galaxies, the birth of stars and planetary systems) and, like HST, will have remarkable capabilities for exploration and discovery.

JWST has become significantly more costly than expected. The costs quoted in the Decadal Survey were largely construction (Phase C/D) costs, and these were underestimated by a factor of two or more (correcting to current dollars with inflation and full-cost accounting). JWST is not alone in suffering from this problem, nor is the problem peculiar to the 2000 Decadal Survey. In the 1990 Decadal Survey, SIM and SOFIA were considered to be moderate $250M-$230M missions, yet both are now much more expensive. (The NASA Administrator has used the word “undercosted” in connection with the estimates used). The AAAC understands some of the unfortunate history of the recent cost increases, particularly the impact of the delayed decision regarding the launch vehicle. However, the cuts in the science budget and the cost growth in JWST have combined to generate a significant level of concern in the community and have led to a serious imbalance in the NASA science program in astronomy and astrophysics. We have recommended above some actions to alleviate this concern and to restore more balance to the overall Astrophysics program.

The AAAC recognizes that the JWST project has made substantial progress over the last year. A major milestone was reached recently with a review of the technological readiness of JWST, the Technology Non-Advocate Review (T-NAR). This review focused on the remaining key technologies that needed to demonstrate their readiness for flight. The AAAC heard about the results of that review at its February 2007 meeting and was very encouraged that 9 of the 10 remaining key technologies had reached flight readiness (TRL 6), and that the remaining one (the MIRI Cryocooler) should do so soon.

The JWST budget appears to have stabilized also. An independent review of the JWST project early in 2006 had identified the level of near-term contingency as a potential problem for the JWST project. Astrophysics added contingency in FY08 and FY09 to address this concern and to bring the project cost estimate confidence level up to 70% (i.e., that there is a 70% probability that JWST will proceed to launch within its current cost profile). The budget profile chart from the February 2007 presentation showed encouraging levels of contingency through key phases of the JWST program, which adds confidence that the program’s budget is likely to remain stable. This chart also demonstrated the commitment to retiring technology risk in advance of construction. A very substantial fraction of the budget is being spent before Preliminary Design Review (PDR in FY08) and Critical Design Review (CDR in FY09). JWST is an interesting test case of a “lesson learned” from previous missions, whereby all key technologies are developed and demonstrated going into construction (Phase C/D).

There is little doubt that JWST will be a truly remarkably powerful scientific facility with huge gains in capability over our current missions. The goal now is to ensure that JWST moves through development and construction without further cost growth, to recover the balance between small, medium and large missions, and to enable development for the future major missions that will follow JWST.

5.4 Giant Segmented Mirror Telescope (GSMT)

GSMT: The AAAC greatly appreciates that NSF MPS and AST continue to support GSMT technology development through funding for the two community groups, the Giant Magellan Telescope (GMT) and the Thirty Meter Telescope (TMT). The next step is less clear. The options for Federal involvement in the GSMT project are unclear given both the potentially different timescales for GMT and TMT and the likely need for construction funding for either project more rapidly than can be provided through the MREFC process. TMT and GMT and their private donors are likely to be ready to commit hundreds of millions of dollars to construction well before an MREFC New Start could be reached. Federal involvement through an MREFC *proposal for a set of instruments that are matched to each telescope's optimization could be a very effective mechanism for the national "GSMT" role, along with archive and operations support. The early commitment of operations support for the Federal partnership poses a challenge. The involvement of OMB and OSTP, and of committees in Congress, could help develop this unusual model. The role of the National Optical Astronomy Observatory (NOAO) as the national interface for GSMT is a welcome development. 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.* ***The AAAC recommends that NSF, AST and MPS, along with the projects, explore options for funding other aspects of GSMT, including major upgrades through MREFC (e.g., a set of second-generation instruments and archives). Developing mutually-beneficial approaches for funding operations could encourage progress on the projects with private donors, who will likely invest at least several hundred million dollars into GMT and/or TMT for construction. The AAAC recommends OSTP involvement if broader policy issues arise and encourages Congressional interest if the current mechanisms challenge the use of private funding.***

A giant 30-meter-class telescope, identified as a Giant Segmented Mirror Telescope (GSMT), was the highest-ranked ground-based large project in the Decadal Survey. GSMT can play a major role in some of the most ambitious scientific goals of our time, namely understanding both 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-meter-class telescopes.

Significant efforts towards realizing GSMT have begun in the community. Two concepts have surfaced. One, the Giant Magellan Telescope (GMT), uses a small number of large segments for the mirror. The other, the Thirty Meter Telescope (TMT), uses a large number of small segments. These groups came together with a joint proposal to the NSF for GSMT technology development. The AAAC is highly supportive of the GSMT program and was very encouraged that some funds were made available from NSF AST for technology development (~$1M in FY05, $2M in FY06, and $5M in FY07, with a further $5M requested in FY08). Given the scale of these projects, these funds have not constituted a significant contribution towards GSMT, but the FY07 funding and the FY08 request level would be a valuable resource for the projects. We hope that the R&D funding grows to match the originally requested $39M total for GMT and TMT. A key area for GSMT is adaptive optics (AO), and support for AO system technology development and on-the-sky demonstrations that are directed towards capabilities needed by GSMT could also be a valuable contribution for both concepts.

The usual approach with major projects has been to prepare and submit a construction proposal for Major Research Equipment and Facilities Construction (MREFC) funding once the concept and early technology development phase is completed. This was the case for the Atacama Large Millimeter Array (ALMA) and the Advanced Technology Solar Telescope (ATST), and was recently done for the Large Synoptic Survey Telescope (LSST). Based on this, the expectation was for a path forward that led to a GSMT construction-funding request through the MREFC program. Since GSMT somewhat unusually involved two projects, the expectation, as noted last year in the 2006 AAAC report, was for a competitive selection that would lead to one project moving forward as an MREFC project. This approach was derived from an earlier community report, *Strategies For Evolution of U.S. Optical/Infrared Facilities Recommendations* of the *OIR Long Range Planning Committee*[22] (OIR-LRPC). The OIR-LRPC report, from July 2005, involved extensive discussions and input that was developed for consideration by the NSF Senior Review committee and other planning groups. Such an approach, while not the only way forward, is certainly a normal one for government-funded science projects. JWST, for example, supported technology development to the point where the competing projects submitted proposals for construction. In the case of GSMT a selection would

[22] http://www.noao.edu/dir/lrplan/lrp-committee.html

have been made that would allow the NSF to move forward with a single project for a major investment through the MREFC process for the national share of the construction costs. Unfortunately the current timescale for reaching a “new start” as an MREFC project is many years. (For ATST the lag from Readiness to New Start will be about 5-6 years.) This is a very long period for projects like TMT and GMT that have significant momentum for private funding. The challenge is compounded also by the different development stages for GMT and TMT.

This private funding is a quite unusual aspect of the GSMT program. The two candidate projects expect to bring at least several hundred million dollars of private funding into the project from private foundations, individuals and universities. International participation is also growing. (Canada is already a member of the TMT and Australia is member of the GMT 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. It provides great opportunities for bolstering the research funding available to the nation as a whole but also brings with it some interesting policy issues. How can the funding for such projects be developed so as combine the constraints, interests and approach of private foundations and donors with those of the Federal government and its agencies and Congressional oversight?

The differences in timescales between the MREFC approval process (5-6 years as noted above) and the private funding timescales presents a clear problem for moving ahead. Both projects are likely to want to move forward more rapidly once they identify their major private funding sources. Given this, it is very unlikely that MREFC can be used for the initial construction phases of GSMT. This is unfortunate since MREFC involves a well-defined process for Federal involvement and funding of a major project. However, there may well be other approaches to utilizing MREFC for GSMT. For example, the telescope construction may be initiated by the project(s) and the telescope facility largely funded through private sources, but other aspects could be funded separately. The instruments for a 30-meter telescope (the baseline GSMT in the Decadal Survey) are very challenging and expensive items. The typical cost is expected to be $50M or more, possibly significantly more for a very complex system like a major AO planet-detection system. Several instruments may then approach $200M. A MREFC proposal could well include a mix of instruments optimized for GSMT, i.e., to match the particular strengths of GMT and TMT if both projects go ahead. If both are built, the “system” approach will be key to their effective utilization – that is, an approach that optimizes and provides complementary capabilities, and not overlapping capabilities. In addition, an archive that meets National Virtual Observatory (NVO) standards for data access could also be part of such an MREFC proposal. Together (instruments and archive) these may well constitute a MREFC proposal that provides a significant investment at the Federal level and is timed to match better the telescope construction and operation. The construction could start with private funding for the observatory with an initial set of instruments, leaving the major instruments as an MREFC proposal.

Regardless of the outcome of proposals to use MREFC funding, there remains a separate clear path for the involvement of the Federal government in GSMT. This would involve funding operations. Private foundations have shown a preference for supporting major construction expenditures over a limited period, with significantly less ability 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. Clearly one approach to a national facility would be for the NSF to come in as a partner by funding 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 their 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. 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.

While discussions could be held among the interested parties, one mechanism might be a study that would address the development of a strategy that would be mutually satisfactory to NSF, OSTP, OMB, Congress and private foundations, to see what could be achieved in finding a way to utilize private resources at the level of $300-500M for funding very highly ranked science projects. The mechanism for this is not obvious – could OSTP coordinate such an effort?

Over the last few years the options for GSMT broadened from the initial TMT 30-meter project as the GMT 22-24-meter project was developed. The Senior Review gave considerable attention to the role of the National Optical Astronomy Observatory (NOAO) and recommended a number of significant changes for NOAO, as noted in §2.3. In particular, it came to be recognized during this process that the focus of activities at NOAO on TMT was not optimal from a national perspective. As a result, NSF-AST has asked AURA/NOAO[23] to act as NSF's "Program Manager" for GSMT development. This is a broad and important role that will facilitate progress on the national component of GSMT. With this new role NOAO will be expected to understand and champion national needs for a GSMT, establish appropriate, symmetrical interfaces with TMT and GMT, and promote development at a pace that recognizes both private and Federal timescales. These broad goals encompass a very extensive range of activities that are still being discussed between NSF-AST, GMT, TMT and AURA/NOAO. The AAAC views this development very positively since it provides a clearer structure for dealing with the two projects, and we will be very interested in the detailed plan for NOAO's role that is currently under development.

A larger version of GSMT is also under consideration by the Europeans through the European Southern Observatory (ESO). There is interest within the European Union (EU) astronomy community on moving forward on their own ELT, given the great success of their Very Large Telescope (VLT, which consists of four 8-meter telescopes that are 100% EU-funded). Whether this proves practical is an open question at this time, just as the question remains here as to whether GSMT will be a fully U.S. venture (private plus Federal). Regardless of these uncertainties, their interest in extremely large telescopes (ELTs) around 40-meter apertures 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 and 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. But, even if the telescopes are in the same hemisphere, the high cost of major instruments ($50M) indicates that significant advantages would accrue from shared access.

In summary, an interesting question that remains unresolved is "What is GSMT?" Is it TMT? Is it GMT? Is it access to some combination of GMT and TMT if private funds are found for both? Does it involve some combination of the above along with the ESO ELT? Will GMT and TMT combine into a single project? The level of private funding required is large, and so this may be the only practical way forward. This is a complicated option set. What is the NSF role in these different options? The good news is that the private funding may allow at least one, but possibly two, major U.S. facility(s) of the 30-meter class to be constructed. The bad news is that this complicates the path forward and reduces the clarity of the discussion regarding GSMT. This uncertainty surrounding the Federal role may impact the speed at which GSMT moves ahead, and the concurrent operation with the James Webb Space Telescope (JWST), as discussed in §6.4. It is not obvious at this point how to move forward rapidly. The lack of clarity will bring challenges both in the Decadal Survey and for long-range planning at the Federal level, but the ultimate outcome could well be two, large, somewhat different ELTs that are accessible to the U.S. community and that provide even larger scientific returns. A broad plan for how GSMT might develop would be particularly useful for the Decadal Survey. In the near-term the AAAC considers that the most valuable activity that could be

[23] The Association of Universities for Research in Astronomy (AURA) is the management organization for NOAO.

undertaken is to explore the possible options and timescales for NSF support for GSMT so that planning for them can begin both within the projects and at NSF-AST. The AAAC recommends that a meeting be arranged with the principal players to discuss the options.

5.5 Large Synoptic Survey Telescope (LSST)

LSST: LSST is a ground-based 8-meter telescope project, whose goal is a deep survey of the sky accessible from Northern Chile. LSST was the third-highest-ranked large ground-based project in the Decadal Survey and would be a unique resource of data for the science community. LSST has a broad range of exciting science goals, including deep galaxy surveys, measurement of dark matter and dark energy, time-resolved surveys, and detection of Near Earth Objects. A central aspect of LSST is the rapid availability of data through a publicly-accessible archive. The LSST consortium submitted a construction proposal to NSF in February 2007 with a proposed cost of $467M in actual year dollars. The proposed approach for LSST is a joint NSF and DOE-HEP program (led by the NSF), along with private funding (~13%). ***The AAAC is very supportive of LSST, but notes that consideration needs to be given to the consequent change in the Decadal prioritization if LSST precedes GSMT. The AAAC recommends that the next Decadal Survey be used to provide an assessment of the ranking of the two projects – while NSF and DOE-HEP evaluate the LSST proposal and GSMT approaches are being worked.***

As a 6.5-meter-class optical survey telescope, LSST was the fifth-ranked major project in the Decadal Survey (third amongst major ground-based projects). LSST also was discussed in *Connecting Quarks with the Cosmos* (CQC) and was considered by the Dark Energy Task Force (DETF) to be a Stage-IV project. The concept has developed substantially since the Decadal Survey and is now an 8-meter telescope that has been proposed for joint NSF/DOE funding (with NSF as the lead agency and proposed to utilize MREFC funds). The AAAC received an extensive briefing on LSST at its October 2006 meeting. The proposed construction cost, including a realistic contingency of 30%, is now $467M in actual-year dollars, proposed to be split among NSF ($293M), DOE ($115M) and private funding ($59M). The operations cost is estimated at ~$50M in actual-year dollars (2016), proposed to be split equally among NSF/DOE/private. The construction proposal was recently submitted to the NSF.

A very broad range of scientific objectives have been identified for this project, arising from its repeated surveying of the hemisphere of the sky accessible from Northern Chile where it will be sited. Repeated images in many filters will lead to the detection of time varying sources, as well as providing a vast resource of deep images that will be used to generate a publicly available database covering about 50% of the night sky. A key aspect of this program that makes it of great interest to a broad community is the rapid insertion of the data into the database and full public access to that database. The Decadal Survey noted that the National Virtual Observatory (NVO) would also be a vehicle for access to the LSST database. DOE HEP interests in dark energy (and dark matter) could lead to their involvement as a major partner in this project, in all likelihood through the wide-field camera.

The AAAC recognizes that the scientific case for LSST is very broad and very strong but notes that significant technical challenges exist for the telescope, the wide-field camera and, in particular, the data handling and rapid public access. Given these challenges, and the recent concerns that arose as a result of the cost-growth in the Atacama Large Millimeter Array (ALMA) project, a very thorough assessment will be needed of the technological readiness and cost robustness of the LSST project.

In addition, since the assessment of this project will take place while the next Decadal Survey is being undertaken, it will be important to have LSST considered amongst the ensemble of ground-based projects so its importance and ranking is re-established. As noted in §2.1, the MREFC timescale is now so long that projects that enter the MREFC process may take many years (5?) before a new start and in so doing limit the access for other projects. This issue was a particular concern for the Optical/Infrared Long Range Planning Committee (OIR-LRPC) that was formed to provide input to the Senior Review. Its report, *Strategies for Evolution of U.S. Optical/Infrared Facilities*[24], noted that "any [Large Survey Telescope (LST)] construction proposal should trigger an evaluation of its impact on the first-ranked project, GSMT. This should be assessed with community input. Public access to scientifically-useful data products should be an important criterion." This recommendation is certainly consistent with Decadal Survey recommendations, and the AAAC believes that the recent submission of the LSST proposal should be considered in this context. It reflects Decadal Survey priorities and the need to have an assessment by the community if the ranking could change. Given that we are close to the next Decadal Survey and that there are many significant steps to be undertaken and passed before a proposal of LSST's scale reaches the Readiness Phase in the MREFC queue, consideration of the appropriate phasing could be carried out by the next Decadal Survey. Neither GSMT nor LSST will be close to MREFC approval as a new start during those deliberations.

This is no reflection on the scientific merit of LSST – the scientific case is excellent and the science exciting. LSST would be one of the largest ground-based astronomy projects undertaken in the coming decade, and the Decadal priorities should be considered for such a project.

5.6 The Explorer Program

Explorers: The Explorer program has been identified as a high-priority activity in each of the last three Decadal Surveys. There remains strong community support for small-to-moderate scale programs within Astrophysics, and so the decision in 2006 to identify some funding for the Wide-Field Infrared Survey Explorer (WISE) was appreciated. The current frequency of missions is about one every 6 years, roughly half the previous rate. The AAAC recommends that the NASA Explorer program be restored to a level of support adequate to ensure its vitality and effectiveness with frequent announcements of opportunity (every few years) as funding becomes available. ***The AAAC recommends that the Explorer program, along with R&A, have high priority when additional funds become available, possibly through the funding "wedge" in FY09/10.***

The AAAC continues to be concerned by the low level of 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 with state-of-the-art technology. The focused investigations enabled by Explorers also provide early technology demonstration and scientific path-finding for future missions. The rapidity with which they are developed allows for young scientists and technologists to develop leadership skills on a mission that they are involved in from inception to conclusion. The competitive selection of Explorers, and their modest scale, provides an essential step in training the scientists and engineers who will be involved in the conceptualization and construction of the larger missions in NASA's future.

The funding shortfall for the last two years has caused a substantial delay in the announcement of the next Explorer opportunity. The next announcement will occur in 2008, six years after the previous announcement in 2002 – a rate that is roughly half that in the past. 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 have been identified as playing a key role in the

[24] http://www.noao.edu/dir/lrplan/lrp-committee.html

last three decadal surveys because they were implemented on much shorter timescales than major missions. The recent 2000 Decadal Survey noted, "NASA's Great Observatories have revolutionized understanding of the cosmos, while the extremely successful Explorer program provides targeted small-mission opportunities for advances in many areas of astronomy and astrophysics. The committee endorses the continuation of a vigorous Explorer program. There are now fewer opportunities for missions of moderate size, however, despite the enormous role such missions have played in the past."

The AAAC is deeply concerned that the Explorer program not continue to languish. As noted, it has been listed as very high priority in each of the last three Decadal Surveys, yet missions are now extremely infrequent. This again is one area where if Congressional action led to an improved budget for NASA, especially for science at NASA through its Innovation and Competitiveness focus, the AAAC would strongly recommend that priority be given to enhancing the Explorer budget along with the Research and Analysis (R&A) budget.

5.7 The Beyond Einstein Program

Beyond Einstein: The AAAC has been concerned for some time that the Beyond Einstein program, with its missions from both the Decadal survey and Connecting Quarks with the Cosmos (CQC), and the potentially very rewarding Einstein Probes, has not been able to move forward. The decision to carry out an NRC study through the Beyond Einstein Program Assessment Committee (BEPAC) to identify a mission for a potential funding opportunity ("wedge") that opens up in FY09-FY10 was viewed very favorably by the AAAC. Of particular interest to the AAAC was the decision by DOE HEP to share in the cost of that study because of their interest in the Joint Dark Energy Mission (JDEM). In addition, the AAAC was very encouraged by the selection of three JDEM concepts for study funding by NASA Astrophysics over the next two years. ***The AAAC is encouraged that these activities represent very real progress in the Beyond Einstein program.***

Over the last few years the AAAC has highlighted its 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 includes 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. Some of the forward steps in this program in 2004 and 2005 came to a halt in 2006 as a result changing funding profile for SMD, as detailed in the NASA FY07 budget request. Major programs such as Con-X and LISA were indefinitely deferred. 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 in the CQC report. The NAS Report from the *Committee to Assess Progress Toward the Decadal Vision in Astronomy and Astrophysics*[25] raised similar concerns: "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."

The AAAC noted in last year's report that part of this support should continue to be funding for concept development, since the Decadal Survey is expected to revisit the Beyond Einstein program and its missions. The AAAC was encouraged to see that Astrophysics identified some additional funding for these missions in the FY08 budget request, and notes that it would be valuable to carry this support through to the next Decadal Survey.

[25] http://www.nap.edu/catalog.php?record_id=11230

The Einstein probes are a particularly interesting element of the Beyond Einstein program, with the potential to tackle a number of exciting scientific objectives at a reasonable cost scale. This aspect of Beyond Einstein is discussed in §6.6 in the context of the study of dark energy for one of its missions, the Joint Dark Energy Mission (JDEM), which would be a DOE/NASA joint program. The Einstein Probes include several potential missions of great interest, namely the Inflation Probe (CMBPOL), the Black-Hole Finder and the Dark Energy Probe. While the Probe program is still identified as part of the Beyond Einstein initiative, the only activity thus far has been the selection of three missions for JDEM concept studies. The situation for the Einstein Probes mirrors that of the Beyond Einstein program as a whole: it has yet to receive significant fiscal traction, though the selection of three JDEM concept studies for funding for conceptual development was a very encouraging step.

The AAAC was thus encouraged by the recognition within SMD and Astrophysics last year that a funding wedge that potentially opens up in FY09-FY10 that could be used to initiate development of a Beyond Einstein mission. We noted earlier that this funding wedge might be an opportunity to re-balance the Astrophysics program, but we consider that a ramp-up of a Beyond Einstein mission is an appropriate major part of that wedge. SMD developed a plan to support an NRC study of the Beyond Einstein program mission suite (Con-X, LISA, JDEM, CMBPOL/Inflation Probe, and Black-Hole Finder) whose primary charge was to "recommend which of these five should be developed and launched first." This NRC study, *NASA's Beyond Einstein Program: An Architecture for Implementation*, is underway and has been requested to report by September 2007. The committee, the Beyond Einstein Program Assessment Committee (BEPAC), is hearing from all the potential candidate missions and is also soliciting input from the community through a series of town hall meetings. While most of the missions being assessed by this committee are specific to NASA, the JDEM mission is of particular interest to DOE HEP as well. Because of that interest, DOE HEP are jointly supporting the BEPAC study with NASA. The AAAC commends both agencies for their willingness to work together on this study and hope that it foreshadows a similar joint effort, along with the NSF, for the next Astronomy and Astrophysics Decadal Survey later this decade.

5.8 Einstein/Origins Probes

Einstein/Origins Probes: The Einstein/Origins Probes (similar to the New Frontiers program in the Planetary Science Division) would lie in cost between the ~\$300M Explorer and ~\$420M Discovery missions and the very infrequent flagship missions, and can address scientific questions that cannot be done within the cost envelope of the Explorer and Discovery missions. ***The AAAC recommends that the NASA Science Mission Directorate (SMD) and the Astrophysics Division further refine the conceptual development of the Probes (~\$600M missions) to where the "Probes" concept could be presented to the next Decadal Review as a potential option for mid-scale missions that could address specific science questions within the Astrophysics Division.***

The Einstein Probes were conceived because it became clear that there was an emerging scientific need for a class of missions that is well above the present Explorer cost cap but (unlike flagship missions) would be focused on particular science questions. The cost level identified for the Probes is around \$600M and would be the Astrophysics analogue of the New Horizons line. The Gamma-ray Large Area Space Telescope (GLAST) is another example at ~\$750M. The AAAC recommends that NASA continue to develop the Einstein and Origin Probes concept that could to provide the Decadal Survey with options that can address particular science questions. The Decadal Survey could establish guidelines for that balance that include a range of mission sizes.

5.9 Major Mission Technology and Conceptual Development

Conceptual Development for Flagship Missions: The AAAC recommended in its 2006 report that NASA provide resources for continuing a modest level of technology development for likely Major Initiatives identified in the 2000 Decadal Survey up through the next Decadal Survey. A useful level of such support was estimated to be about $10M/yr and would enable a much better understanding of the technological readiness and the likely performance, as well as improve cost estimates. The missions identified for this support were Constellation-X (Con-X), the Laser Interferometer Space Antenna (LISA) and the Terrestrial Planet Finder (TPF). ***The AAAC was encouraged to that the Astrophysics Division has been trying to increase the funding for Con-X, LISA and TPF and has identified funds in the FY08 budget request. The AAAC recommends that this be continued up through the next Decadal Survey.***

The underestimates in the mission cost estimates in the 2000 Decadal Survey (referred to as "undercosting" by the NASA Administrator) have caused problems. As discussed below in §5.11, it is crucial that we establish more realistic cost estimates for the missions and projects under consideration by the next Decadal Survey. Two key aspects of this are that the state of key technologies is understood and that a significant level of conceptual development has occurred. Otherwise, the Decadal Survey discussions will be devoid of solid technical underpinning and will be saddled with unreliable cost estimates.

A particular concern arises for the Major Initiatives at NASA since, given recent cost history, these missions are likely to all have lifecycle costs that are in the couple-to-several $B class (i.e., ~$2-4+B). This would include those missions like LISA, Con-X, and TPF that have received some funding this decade and which, we have argued, should be the recipients of a modest level of funding over the next few years. Such funding (at the level of ~$10M) would make a critical difference to the future robustness of the missions chosen for the next decade through the Decadal Survey process and add robustness to the process leading to the recommended pool of missions. The AAAC was encouraged to see that Astrophysics identified some additional funding for these missions in the FY08 budget request, and notes that it would be valuable to carry this support through the next Decadal Survey.

One of the Decadal Survey Major Initiatives recommended for technology and conceptual development this decade was the Single Aperture Far Infrared (SAFIR) mission. This 10-meter-class cryogenic observatory would complement the ground-based Atacama Large Millimeter Array (ALMA) in exploring the infrared universe by taking advantage of the extraordinarily dark sky between the peaks of the zodiacal and the cosmic microwave background (CMB) emission. SAFIR would build upon architectural elements being developed for the James Webb Space Telescope (JWST), and so it might be appropriate to begin considering an assessment of the technology issues as the Decadal Survey approaches, particularly given the technical maturity of JWST. Some SAFIR concept development would also provide valuable input for the Decadal Survey.

The proposed $600M-class of missions (the Einstein Probes, of which JDEM is one, along with the Origins Probes) would also benefit from some funding to help characterize the cost envelope. As has been seen with Discovery missions, as well as with Explorers, cost growth has become a significant issue even for missions where the cost constraints are given high weight and visibility. The Probes are likely to suffer the same cost-growth problems. The funding being provided to the three JDEM concept studies is an excellent first step in helping develop the Probe mission line.

5.10 Stratospheric Observatory for Infrared Astronomy (SOFIA)

SOFIA: The SOFIA program underwent some dramatic changes in the last year. After an initial plan that would have reduced SOFIA to $0 and terminated the program, SOFIA underwent a recovery and is now part of the Astrophysics budget. SOFIA has had a troubled and costly development history and will not reach full operations until 2013, more than 15 years after the project began. SOFIA has a distinctly different operational model, akin to ground-based telescopes, in that its instruments can be developed to take advantage of ongoing technological developments. SOFIA is a major mission, with a lifecycle cost for 15 years of operations that exceeds $2B. From FY09 on its yearly cost is estimated to be $90M, including Institutional costs, broadly comparable to HST (excluding servicing costs) and similar to that expected for JWST, though an operations review is underway to assess the operations model and to see if any savings can be found. When fully operational, SOFIA is estimated to provide ~900 hours of on-target time per year for science observations. SOFIA provides for new instruments with the latest technology, and so the science opportunities can be high. However, as outlined below the cost per hour of operation is comparable to HST and JWST. ***Given its cost and limited on-target time, the AAAC considers that it is crucial that SOFIA operates as efficiently as possible and fully involves the science community to provide high science returns.***

SOFIA was recommended as a moderate-scale mission in the 1990 Decadal Survey to replace the Kuiper Airborne Observatory (KAO). SOFIA started its development in the late 1990s. By offering access to a 2.5-meter telescope aboard a modified Boeing 747 aircraft above most of the water vapor in the Earth's atmosphere, this observatory is designed to provide visibility in broad, critical infrared wavelength regimes that are otherwise inaccessible from the ground. Access to these regions would provide key insights to star and galaxy formation and to the astrophysics and evolution of molecular gas in the cosmos. SOFIA allows such measurements to be made with instrumentation that is routinely accessible, upgradeable and repairable and that allows the science to take advantage of the steep trajectory of infrared sensor improvements that technology development efforts are providing. In this SOFIA is rather more like a ground-based telescope in that it can take advantage of technology improvements.

This mission is significantly over budget and behind schedule. The project underwent a near-death experience in the last year when its budget was reduced to zero; consideration of international obligations and a subsequent technology review led to its reinstatement. Recognition of the remaining challenges has led to the deferral of full science operations until 2013 with partial operations planned for 2010.

SOFIA is now undergoing an operations review. This is a timely activity since the operations costs of SOFIA as outlined in the FY08 budget is $77M next year and $90M per year, including the institutional support, from FY09 on. By the time of first science in 2010 over $700M will have been spent on SOFIA – and nearly $1B by the time of full science operations in 2013. SOFIA has considerable scientific potential but the project has not yet demonstrated that it can fully achieve its scientific objectives. The very substantial growth in the project lifecycle cost now places SOFIA within the category of Major Initiatives. The re-instatement of SOFIA also impacted other programs within Astrophysics, since no new funding was available.

Given the recognition of the cost of SOFIA and its status as a major mission, with a lifecycle cost for 15 years of operations that exceeds $2B, SOFIA needs to provide commensurate science returns. When fully operational, SOFIA is estimated to provide ~900 hours of on-target time per year for science observations. (For comparison, low earth-orbit programs like the HST and Chandra provide ~2400 hrs, while missions in drift-away or L2 locations like Spitzer and JWST can provide ~6000 hrs per year.) Clearly SOFIA offers observing and instrument opportunities that are unavailable for space missions, but we note that the amortized cost-per-hour of on-target science observing is comparable to that of HST and more than expected for JWST (for 10-15 years of operations given ~$2B total for SOFIA, ~$9B total for HST and ~$4.5B for JWST). It is crucial that the SOFIA program has extremely efficient operational models given the limited on-target hours, utilizes forefront instruments, and fully involves the science community to provide high scientific returns.

5.11 Considerations Regarding the Next Decadal Survey

Next Decadal Survey: The AAAC's tactical role, providing advice on the implementation of the Decadal Survey recommendations, provides it with some "front-line" experience on how well these very important NRC studies achieve their goals. Our collective experience suggests that there are several areas where the Decadal Survey process could be improved. These include (i) careful re-consideration and ranking of the unfinished projects and missions ("carry-over" projects), (ii) development of a more explicit science framework, (iii) consideration of the tradeoffs between continuing to support missions with high levels of annual operation costs vs. using those resources to initiate new small, intermediate or large missions, (iv) developing a process that might allow iteration on the Decadal Survey recommendations during the decade, and (v) establishing better cost estimates and better review of the cost estimates. ***The AAAC recommends that the NRC and the agencies consider these issues during their discussions on the next Decadal Survey.***

During the year the AAAC heard from the NRC Committee on Astronomy and Astrophysics (CAA) Co-Chair Meg Urry and NRC CAA Staff Officer Brian Dewhurst on issues that the CAA had been considering for the next Decadal Survey. The AAAC 's tactical role in implementing the last Decadal Survey has given us insights into a number of issues and led to a number of suggestions for the upcoming Survey that we recommend the agencies consider during their discussions on the next Decadal Survey. This list is by no means complete but identifies some of aspects that should be consider.

"CARRY-OVER" PROJECTS: With the support of the agencies, a broadly-based Astronomy and Astrophysics Decadal Survey NRC study will be undertaken in the next few years to consider the community's goals and priorities for the next decade. It is very obvious that almost none of the high-priority recommendations from the last Decadal Survey will be completed this decade. Traditionally, unfinished projects have been "carried over" into the next decade's plan. To do so this time would largely render a new study moot; since the previously recommended program is so incomplete, the carry-over items could essentially preclude any new programs. Thus, there is a growing sense that the next Decadal Survey will have to re-assess and re-prioritize the unfinished mission and projects if it is to develop an exciting, viable and "saleable" program for the next decade. The question of "what is to be reconsidered and what is not" is not an easy one to answer, and so it might best be left to the Decadal Survey committee to discuss all unfinished programs and decide on their ranking n the current Survey. Experience has shown that even programs well on their way to completion can develop significant problems and cost growth, and so advice from the NRC Decadal Survey committee could provide guidance on how to deal with the impact of any such changes on other programs, i.e., the priorities for any delays or cancellations.

SCIENCE FRAMEWORK: *Connecting Quarks with the Cosmos* (CQC) enjoyed considerable visibility because of its very well developed science discussion and focus on broad science questions. This resonated with policy and decision makers. Given the challenge involved in developing a realistic program in the next Decadal Survey, with current project and mission costs and likely budgets, it will be important to highlight and utilize the science framework and goals more explicitly, rather as CQC did. In addition, it may well be impractical to give every community a "piece of the pie" in the 2010 Survey, and we will ultimately need to resort to making even tougher choices than in the past – and these should be done on the basis of science priorities that have been established as part of the same overall process.

TRADEOFFS – NEW *vs.* OPERATING PROGRAMS: The next Decadal Survey may need to give consideration to the tradeoffs between continuing to support missions with high levels of annual operation costs *vs.* using those resources to initiate new small, intermediate or large missions. For example, some consideration might be given to recommending mechanisms for evaluating the science return of ongoing missions such as HST and SOFIA whose annual costs are high (roughly around $100M per year), against, for example, more frequent Explorer/Discovery/Probe missions. Senior reviews have traditionally been used where the discussion focuses on whether the mission is returning good science, but in the case of such expensive operations, the central question is whether the science being done is better than what might be done with a new mission such as an Explorer or even a future intermediate or large mission. Such questions are better handled by a broadly-based review than by one that focuses solely on a single program's science productivity. The approach that is needed is more akin to the recent NSF AST Senior Review which, with its very broadly based assessment of the field, provided a much more comprehensive "portfolio" evaluation. The Decadal Survey is ideally positioned to do this. The Decadal Survey could provide recommendations on some of the difficult tradeoffs of operating current facilities and missions *vs.* starting new projects.

RE-EVALUATION DURING THE DECADE: Related to this is developing a process that might allow iteration during the decade on the Decadal Survey recommendations in a way that carries "corporate memory" of the discussions and issues that framed the choices made in the Decadal Survey. This is not easy to do, but one possible mechanism might be to reconvene (a subset of) the Decadal Survey committee at times when it becomes clear that major changes have occurred in the overall science budget or individual mission/project timescales and costs. This would presumably be done only when the scale of changes was beyond that which could be readily dealt with by the standing NRC committees that deal with Astronomy and Astrophysics issues (the SSB, BPA, CAA) and which would be done in conjunction with those standing committees.

COST ESTIMATES: Better cost estimates are clearly needed for the upcoming Decadal Survey, along with an assessment of the likely agency budgets for astronomy. The recognition that this is a serious issue with the last Survey has led already to extensive discussion of how to improve the cost estimates. A key issue will be to balance the level of cost reliability with what can realistically be done before and during the Decadal Survey process. A Realistic goals may be to (i) establish common ground rules (e.g., any cost estimates would most usefully include both full lifecycle costs and costs within the coming decade), (ii) provide independent cost estimates (not just cost estimates from the project proponents), (iii) aim to provide costs that are less systematically underestimated, and (iv) include experts in project management and cost assessment in the deliberations.

6.0 Interagency Coordinated Programs

The following sections deal with specific projects or activities of an interagency nature that came before the AAAC in its deliberations during the 2006-2007 timeframe of this report. These activities fall into the area of interagency cooperation and future return from initiatives that will be the focus of more than one agency.

6.1 Research and Analysis (R&A) and Workforce Development

R&A: The AAAC notes that a central goal of the American Competitiveness Initiative (ACI) is to improve basic research in the physical sciences and in so doing excite and train young researchers and technologists. The AAAC noted in its 2006 report that cuts at NASA in R&A run counter to that ACI goal and that R&A funding should be restored at NASA. The cuts at NASA are leading to increased pressure on the smaller R&A (grants) program at NSF. Given its role in advising on the optimization of the astronomy and astrophysics enterprise in the nation, the AAAC is quite concerned that decreases in R&A budgets overall will lead to less-than-effective utilization of current facilities, reduced productivity, slower progress on major scientific issues of great public interest, and slower development of new facilities to address cutting-edge science questions. Many examples can be enunciated where R&A cuts damage a much larger and broader research community's productivity (e.g., detector development, laboratory astrophysics, data analysis tools, numerical modeling, etc). ***The AAAC recommends that OSTP consider the impact of the imbalances caused when cuts at one agency offset the gains that are being implemented at others through ACI increases.***

As discussed in §5.1, R&A plays a key role in the community's ability to be productive and effective users of facilities that have been developed at very considerable cost. This is true of both NASA and NSF facilities. We strongly encourage the NASA Science Mission Directorate (SMD) to restore funding for R&A. We fully recognize the challenges faced by the Astrophysics Division in its budget. Cuts in R&A have broad impact and seem very inconsistent with the broad goals of the American Competitiveness Initiative (ACI). Such cuts have a dramatic and disproportionate impact on the future of the field – particularly on the imaginative, hard-working young scientists. These young people, along with their guides, mentors and teachers among the more senior, experienced members of the community, constitute the scientific human capital. Together they are the future of the field.

Even if NASA is largely excluded from ACI, NASA indisputably supports basic research, and to cut R&A at NASA while funding increases elsewhere (NSF, DOE, NIST) could lead to no net gain or even overall cuts, given the scale of the R&A activities at NASA. The breadth of the scientific investigations that are supported through R&A is also an investment for the future for NASA. R&A support for theory, for technological development and for multi-mission analysis all add substantial breadth to the science program and provide the framework for future missions. In many respects, the R&A program seeds the ideas and training for the next generation of programs and missions.

An example of the programs that R&A supports was brought to the AAAC's attention in its May 2006 meeting during a presentation regarding a recent workshop on Laboratory Astrophysics. The results from laboratory astrophysics research underpins the interpretation of a wide range of astronomical phenomena, and so it is a small but very important component of the overall research enterprise in astronomy and astrophysics. The funding needs of researchers such as these who benefit a much wider community are met through R&A programs. Cuts in R&A programs significantly impact these broadly-beneficial research undertakings. This is but one of many examples where the immediate science returns, future capabilities and future science productivity for a broad range of science investigations can be damaged by cuts.

The Decadal Survey explicitly recognized that the R&A and grants programs at NASA and NSF are the means by which the community undertakes the professional development needed for missions and programs by "ensuring the creation of the next generation of instrumentalists… and establishing expertise in computational techniques, data-mining and algorithmic skills" through "postdoctoral training, NASA's [Long-Term Space Astrophysics (LTSA)] program, and the participation of women and minorities". These themes are reinforced in the AST Senior Review's second principle, *Optimizing the Workforce*: "The development and operation of next-generation astronomical facilities requires concomitant investment in the development of next-generation personnel and the retention of key individuals with highly specialized skills and abilities."

While NSF AST has taken a protective stance with its R&A grants program, NASA's support for R&A is decreasing. For example, the ~25% cut in the last year in theory R&A at NASA (theory funds in the Beyond Einstein Foundation Science and the Astrophysics Theory Program were $4M in FY06 and decreased to $3M in the Astrophysics Theory and Fundamental Physics program in FY07) is almost immediately reflected in extra demand on NSF because of the very limited options at NASA for theory funding. Yet theory is an integral part of the science return from an ensemble of missions. As the Senior Review noted, "NASA has decreased the support of its R&A program substantially in its 2006 and 2007 budget requests. This is already leading to increased pressure on the AST program as astronomers whose research involved space missions are turning increasingly to ground-based telescopes"

6.2 National Virtual Observatory (NVO)

NVO: The NVO was the top-ranked "small" project in the Decadal Survey and was the only program in the small category to be explicitly ranked. The slow pace on the joint NASA-NSF solicitation for proposals to manage the NVO operation is reducing momentum on this innovative program. Discussions should also be undertaken with DOE HEP regarding their involvement in NVO as collaborative projects develop. ***The AAAC recommends that NSF and NASA, possibly with OSTP assistance, expedite their plan to solicit proposals for the operation of the NVO and move forward expeditiously this year in implementing this key step for the implementation of the NVO.***

A National Virtual Observatory (NVO) effort was recommended by the Decadal Survey as a joint NASA-NSF program. NVO was the top-ranked small program. The NVO will provide a "virtual sky" based on the enormous data sets being created now and on the even larger ones proposed for the future. It 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, infrared to radio wavelengths. Such data sets are orders of magnitude larger, more complex, and more homogeneous than in the past. The NVO will maximize the scientific productivity of both existing and new facilities and programs by providing the ability to match and correlate data from such vastly different sources. It empowers astronomers to mine the data archives to maximum benefit. In essence, the NVO will enable new modes of research for professional astronomers and will provide the public an unparalleled opportunity for education and discovery. The AAAC expects that the capabilities of the NVO will encourage and stimulate more widespread archiving of data by institutions and organizations that are currently not planning to do so, and recommends that the NASA and NSF take the next step with the NVO project. The AAAC would also be interested in having discussions develop with DOE regarding their future involvement in NVO as collaborative projects occur.

NSF and NASA have been working together to create a joint program for implementing and managing the NVO by developing a memorandum of understanding (MOU) for a joint solicitation for establishing the operations and management of NVO. The expectation is that the NVO will be operated as a distributed center, and proposals for operation of the NVO will likely come from collaborations and consortia of institutions. The goal was to release a solicitation and to select the operations group by the end of 2006. Progress on the NVO by the initial team has been excellent, and cooperation between the agencies appears to be good, but the final steps towards release of the solicitation have progressed very slowly. The continuation of support for NVO activities until a solicitation is announced has minimized disruption to the program, and is appreciated, but the lack of progress also impacts the enthusiasm of the team.

The AAAC hopes that the disappointing progress in 2006 does not continue and strongly recommends that progress be accelerated so as to expedite the solicitation in 2007.

6.3 Advanced Technology Solar Telescope (ATST) – Solar Dynamics Observatory (SDO) Synergy

ATST: The AAAC applauds the progress that has been made on this important program and greatly appreciates the support from the NSF Director's Office in moving ATST into the MREFC Readiness Phase. ATST is a major project with a projected construction budget of $225M that demonstrated its readiness to move forward at its recent Preliminary Design Review (PDR). The choice of Haleakala as the site for ATST has brought some site-specific challenges. It is hoped that these will not lead to delays in the project, but alternative locations should be considered if delays occur. ***The AAAC recommends that NSF move ATST quickly through the MREFC process to a New Start to take advantage of the scientific synergies that will arise from overlap with the NASA Solar Dynamics Observatory (SDO), to minimize both the carrying costs for AST of a project post-PDR and the impact on other major astronomy projects that are potential MREFC funding recipients, and to realize one of the goals of the Senior Review, namely the focus of activities on new, more powerful facilities.***

Recent AAAC reports have noted that the Decadal Survey and the NAS study *The Sun to the Earth and Beyond*[26] gave strong emphasis to understanding the development of solar magnetic fields in space and time and to understanding how magnetic fields power flares and eruptive activity. Contemporaneous observations from the ground-based Advanced Technology Solar Telescope (ATST) and the space-based Solar Dynamics Observatory (SDO) would play a major role in meeting this scientific goal (see e.g., http://atst.nso.edu/science/). In this past year, both NASA and NSF have made steady progress toward realizing these missions. SDO continues towards launch in 2008. ATST underwent a very successful Preliminary Design Review (PDR) following its transition into the Readiness Phase in the MREFC process. Given the successful PDR, the AAAC hopes that NSF will move ATST expeditiously into a New Start in the MREFC queue in FY09. Site-specific planning for the chosen site on Haleakala on Maui in Hawaii is moving forward, though the AAAC is aware of concerns regarding approval for that site. The Haleakala site appears to be an excellent location, and the committee hopes that the NSF gives high priority to resolving these issues and moving ATST forward expeditiously. However, if the problems cannot be resolved relatively quickly, it would be prudent to think about other site options. With a construction budget of $225M ATST is a major project, and the carrying costs for AST are large before MREFC funds become available through the transition to a New Start. In addition to the carrying costs noted above, the impact on other major astronomy projects that are being considered for MREFC funds could be substantial if they are delayed as a result of delays in ATST site approval.

Discussions have occurred with potential international partners. Given the substantial cost of this facility, a strong international component would add significant value to the program, both in the near-term development and construction and in the long-term operation and scientific effectiveness of the Observatory.

6.4 Giant Segmented Mirror Telescope (GSMT) – James Webb Space Telescope (JWST) Synergy

[26] http://www.nap.edu/catalog.php?record_id=10477

GSMT/JWST Synergy: The AAAC emphasizes that operation of GSMT in the JWST era would provide major scientific synergies. A joint report from the GSMT and JWST Science Working Groups (SWGs) highlights the scientific value of such synergy. ***The AAAC strongly encourages NSF to take advantage of opportunities that would help GSMT move forward more expeditiously so that the GSMT/JWST synergies could be realized.***

As noted above, GSMT and JWST are the highest ranked large programs in the Decadal Survey on the ground and in space, respectively. We have commented above on each of these missions and on the central role that they will play in cutting-edge science in the coming decade. There is another aspect of these programs that deserves particular attention. The experience of concurrent operations of the Hubble Space Telescope (HST) and the current generation of 8-meter class ground-based telescopes has demonstrated that, working together, they synergistically provide scientific advances beyond even their enormous individual capabilities. At the request of the AAAC, the GSMT Science Working Group (SWG) worked with the JWST SWG to enunciate the science gains from overlapping operation in a two-page summary document[27] and a full report[28]. The report cover letter noted, "This report concludes that many of the most ambitious scientific goals of the next decades – for example, understanding the formation of galaxies and the chemical elements and the formation of stars and planets – can only be fully realized through construction of both GSMT and JWST and via their concurrent operation. We hope that this message evokes an enthusiastic response among Federal officials. Providing the support for such frontier facilities promises a great legacy for science and for the United States." The synergies outlined in this report remain as relevant today as they were in 2005 when the report was developed.

Another synergistic area is developing between ground and space as a result of 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 many researchers to think 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-meter-class, AO-equipped telescopes enables observations of some 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. This question is being explicitly addressed through the ExoPlanet Task Force (see §6.8) that is evaluating the approaches to planet detection and characterization on the ground and in space.

GSMT would lead to major discoveries, both as a uniquely powerful facility and in conjunction with JWST. The opportunities (and challenges) for NSF AST in moving GSMT forward are discussed more fully in §5.4.

6.5 Dark Energy: The Dark Energy Task Force (DETF)

Dark Energy: The AAAC recognizes the interest in 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 and completed its report in 2006. The findings and recommendations from the DETF were transmitted through the AAAC and the High Energy Physics Advisory Panel (HEPAP) and will help to optimize a dark energy program that the science community and the agencies can implement to make progress over the next decade quickly and cost-effectively. ***The AAAC recommends that the agencies coordinate their plans and activities in this area and***

[27] http://www.nsf.gov/attachments/103158/public/gsmt_jwst_synergy_handout_final.pdf
[28] http://www.nsf.gov/attachments/103158/public/gsmt_jwst_synergy_report_final.pdf

that particular attention be given to supporting Stage III projects as a means of making progress quickly and providing a framework for the much more expensive Stage IV projects.

The discovery of dark energy at the end of the 1990's is one of the great scientific surprises of our time. Dark energy was discovered using observations of distant supernovae from ground-based telescopes and was further constrained by higher redshift observations in space with the Hubble Space Telescope (HST). A number of complementary approaches, such as weak gravitational lensing, distant supernovae, the evolution of galaxy clusters, and the growth of structure in the matter of the Universe, are now being utilized for their potential in identifying the nature of the dark energy. The Decadal Survey and CQC (plus its implementation companion *Physics of the Universe*) recommended that two major approaches to this effort be developed in the longer-term: a ground-based program now generically called the Large Survey Telescope (LST) and a space-based mission known as the Joint Dark Energy Mission (JDEM). JDEM was developed as a joint effort by DOE and NASA and reflects the increasing interest by DOE HEP in astrophysical programs of interest to the physics community. Two ground-based projects are potential implementations of LST, the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS) and the Large Synoptic Survey Telescope (LSST). The LSST consortium is collaborating with DOE investigators who are working to design the camera.

However, many groups both within the U.S. scientific community and internationally are actively working to address dark energy on a shorter timescale using existing facilities or updates to those facilities. To assist in defining a framework for the agencies in the near-to-intermediate term, the AAAC recommended that a Task Force be formed. NASA, NSF and DOE responded very positively to this request and established the Dark Energy Task Force (DETF). The DETF activity generated a high level of interest in the community; the committee received over 50 white papers in response to its solicitation for input. In mid-2006 the DETF report[29] was completed, accepted by both the AAAC and the High Energy Physics Advisory Panel (HEPAP), and transmitted to the agencies. (See http://www.nsf.gov/mps/ast/detf.jsp for the DETF charge, membership, report and transmittal letters.)

The DETF findings and recommendations clearly show the value of an expert study, where the objective is to establish a broadly based framework within which experiments and projects can be prioritized and carried out within the limited budgets of the agencies. The DETF noted that a program that includes multiple techniques could provide an order-of-magnitude increase in their figure of merit. They found that "this would be a major advance in our understanding of dark energy." The DETF reported, "No single technique is sufficiently powerful and well established that it is guaranteed to address the order-of-magnitude increase in our figure-of-merit alone. Combinations of the principal techniques have substantially more statistical power, much more ability to discriminate among dark energy models, and more robustness to systematic errors than any single technique. Also, the case for multiple techniques is supported by the critical need for confirmation of results from any single method." This very important result already suggests that, within a cost-capped situation, a variety of approaches will be more important than a single, very accurate (but likely costly) program that utilizes only one of the four science techniques considered by the DETF (baryon oscillations, clusters, supernovae and weak lensing). Such feedback is immensely valuable to the field, to proposers of projects, and to the agencies that will fund the developments.

The DETF report provides guidance for the optimization of near- and intermediate-term activities, as well as for JDEM and LST, and we hope that DOE, NASA and NSF will work together to utilize the DETF recommendations in their planning and review processes, particularly in the near-term for DETF-classified Stage III projects. Last year HEPAP approved its Particle Physics Project Prioritization Panel (P5) subcommittee report, which recommended support for the start of fabrication for the Dark Energy Survey (DES, a project that fits in the DETF Stage III) as well as R&D funding for the DETF Stage IV projects

[29] http://www.nsf.gov/mps/ast/aaac/dark_energy_task_force/report/detf_final_report.pdf

SNAP and LSST to get them to CD-2 or PDR (as appropriate for DOE or NSF). LSST has submitted a proposal to NSF and is currently "pre-conceptual" at DOE, as noted earlier. For DOE, the FY08 request includes DES as a new major item of equipment (MIE). The project is planned as a partnership between DOE and the NSF, which operates the Cerro Tololo Inter-American Observatory (CTIO) 4-m telescope that DES plans to use (following selection through a call for proposals). Funding for fabrication in FY 2008 is contingent on successful scientific and technical readiness reviews by the funding agencies. The AAAC welcomes this as a component of the Stage III activities discussed by the DETF.

The AAAC welcomed the decision by HEP to provide $3M in dark energy R&D funds that will be competitively awarded and constitute part of a broad Stage III effort. We were very encouraged to see that an additional $5.8M is identified for continuation of this R&D effort in the FY08 budget request. We applaud HEP for carrying out these two solicitations for dark energy R&D. NSF AST and DOE HEP have indicated that they will coordinate their efforts – this certainly would benefit the community and optimize the use of the agencies resources. We urge the agencies to move forward with increased funding for Stage III research programs. The near-term results will benefit the design and implementation of the much more expensive Stage IV programs.

6.6 Joint Dark Energy Mission (JDEM)

JDEM: A number of important developments occurred in 2006 for JDEM. Three JDEM concepts were selected by NASA for two-year mission concept studies, NASA requested an NRC Beyond Einstein study (Beyond Einstein Program Assessment Committee, BEPAC) that includes JDEM, and the DETF provided a refinement of the gains that should be expected from a selected JDEM mission (and LST or any other Stage IV activity). The AAAC welcomed the involvement and support of DOE HEP in making the NRC BEPAC study a joint NASA/DOE study. The AAAC awaits with interest the outcome of that study. ***JDEM is a particularly interesting case for interagency cooperation, and the AAAC welcomes and appreciates the continuing willingness of the agencies to work towards overcoming some of the challenges that result from the different approaches to "doing business."***

One of the initial responses by the agencies to the community interest in dark energy and to the *Connecting Quarks with the Cosmos* (CQC) report was the development of an interagency agreement to carry out a DOE-NASA Joint Dark Energy Mission (JDEM). One particular implementation of JDEM, the Supernova Acceleration Probe (SNAP), has been supported at DOE for some time, and so the AAAC was encouraged by the NASA Astrophysics Division's selection of three two-year JDEM mission concept studies through competitive evaluation. The study of a number of mission concepts is likely to lead to a mission that most cost-effectively accomplishes the science goals of the JDEM program. The AAAC has recognized that the agencies' different approaches to funding conceptual development activities has led to the DOE HEP-supported program being funded at a higher level than other mission concepts. The SNAP concept began several years earlier, and so it has had more time and support to mature. The NASA effort provides an opportunity for other concepts to be considered and to develop some maturity so that a competitive selection plays out on a more level field. DOE's R&D competition may also provide funds for other concepts to mature.

Congressional interest in moving SNAP forward at DOE surfaced last year during budget discussions. The suggestion was made that DOE might consider other partners. Such options are desirable, but there are additional challenges if the outcome involves joint international-U.S. spacecraft, telescope and/or instrument projects. The AAAC hopes that the willingness of the agencies to work together on the jointly funded BEPAC study and the selection of SNAP along with two other programs for concept development by NASA Astrophysics demonstrates that the agencies are now working towards a common goal. The agreement that the BEPAC study would be completed in time to allow input into the FY2009 budget process at the agencies was also another indication of a commitment to finding a solution that worked for both agencies. The AAAC also expects that the DETF report will provide guidance for the optimization of JDEM and hopes that NASA and DOE HEP will utilize the DETF recommendations in their assessment of the approaches under consideration for JDEM.

The AAAC hopes that the "lessons-learned" activity, recommended by the AAAC last year and currently being undertaken by the agencies and OSTP, will discuss the impact of the different approaches to the funding of JDEM mission concepts and whether a better approach might have led to longer-term funding of a number of mission concepts by both agencies.

6.7 Dark Matter Scientific Assessment Group (DMSAG)

DMSAG: The AAAC welcomed the formation of a Dark Matter Scientific Assessment Group (DMSAG) jointly by the AAAC and the High Energy Physics Advisory Panel (HEPAP) to advise DOE HEP and the NSF Division of Physics (PHY) and AST concerning the U.S. dark-matter direct-detection research program. The DMSAG draft report was recently discussed by both the AAAC and HEPAP, and the DMSAG was commended for their excellent work. Noting that an external expert review had worked well for the TFCR and DETF reports, the AAAC asked the DMSAG committee to undertake a similar external review. The AAAC also requested a finer-grained prioritization of activities for the final report. The AAAC expects to receive the final DMSAG report in spring 2007 for transmittal to the agencies. The DMSAG identified a path to significant advances with a modest increase in funding that would ensure the continuation of US leadership. ***The AAAC strongly endorses increased support for the dark-matter direct-detection efforts.***

The detection and understanding of the mysterious dark matter that dominates the mass of the universe is one of the great scientific quests of our time. Understanding its nature is important to both particle physics and astronomy. The direct detection of dark matter is developing into a vibrant field, with numerous approaches that could be followed. There is significant interest in identifying the most promising experimental approaches for the direct detection of dark matter using particle detectors. While this is an area most directly of interest to the High Energy Physics Advisory Panel (HEPAP), the astrophysical community's great interest in this question and in the potential role of astrophysical constraints led the AAAC to suggest that DOE HEP and NSF Division of Physics (PHY) and AST form a joint Task Force to provide advice on priorities and strategies for the direct detection and study of dark matter. The agencies responded positively and have asked both committees to jointly establish a Dark Matter Scientific Assessment Group (DMSAG) to advise NSF and the DOE HEP concerning the U.S. dark-matter direct-detection research program. Such an activity also builds on recommendations in the interagency working group report, *The Physics of the Universe: A Strategic Plan for Federal Research at the Intersection of Physics and Astronomy*[30], that was produced under the auspices of OSTP. It was also explicitly identified as a high priority activity in the astrophysics arena in the EPP2010: Elementary Particle Physics in the 21st Century committee report of the National Academy, *Revealing the Hidden Nature of Space and Time: Charting the Course for Elementary Particle Physics*[31].

The DMSAG committee recently presented a draft version of its report to the AAAC. This nearly final version reflects extensive, thoughtful effort by the committee and is close to completion. The AAAC suggested some modifications, including an improved discussion of priorities in case the hoped-for funding increase was not available, and asked for some external reviewers to comment on the report (as has been done for our other task forces). The AAAC expects to receive the final report in spring 2007 for approval

[30] http://www.ostp.gov/html/physicsoftheuniverse2.pdf
[31] http://books.nap.edu/catalog.php?record_id=11641

and transmittal. It is clear, however, from the draft report that the DMSAG makes a strong case that substantial progress could be made with added funding in a number of areas. (They suggest an increase to about $10M per year.) This would be consistent with the EPP2010 recommendations and would likely be strongly supported by the AAAC once the report is completed and transmitted to the agencies.

The DMSAG committee charge, members and eventually (once accepted) the report can be found at: http://www.nsf.gov/mps/ast/dmsag.jsp.

6.8 ExoPlanet Task Force (ExoPTF)

ExoPTF: The detection and characterization of planets around other stars has become one of the exciting research fields of our time, with great public interest. The search for planets involves both space missions and ground-based programs. In 2006, the AAAC recommended that the agencies consider the establishment of a Task Force to develop a strategic plan for planet detection and characterization, as well as planetary formation, with consideration of the relative roles and contributions of future ground-based programs and space missions. Such a report, as well as being a guide for agency planning, will also provide very valuable input to the next Decadal Survey. NSF and NASA responded very positively, and the ExoPTF held its first meeting in February 2007 with a goal of producing its report by Fall 2007. ***The AAAC greatly appreciates the agencies' rapid response to its recommendation to set up the ExoPTF.***

Interest in planet searches, in the characterization of planets, and in the broader scientific issues encompassing planet formation is rapidly growing in the community. The technological challenges associated with planet searching and characterization are formidable. This has led to a number of extremely innovative techniques and approaches being developed and applied on the ground and under consideration for use in future facilities in space. In the near term a number of space missions, including the Hubble Space Telescope (HST), the Spitzer Space Telescope, the COnvection, ROtation and planetary Transits (COROT) experiment and the Kepler mission are or will be used to address a broad range of scientific questions about the frequency and variety of planetary systems. Several missions are under discussion for the future, including Discovery-class missions, the Space Interferometry Mission (SIM), a Terrestrial Planet Finder-Coronograph (TPF-C), a Terrestrial Planet Finder-Interferometer (TPF-I), and the Darwin space interferometer. The science case for current and future large ground-based telescopes with innovative (and very challenging) adaptive optics (AO) capabilities includes programs that are contributing to this topic or are planned to do so. Given this great interest in the field of exoplanet research – and the challenges and high cost of both ground- and space-based experiments and missions – the AAAC asked NSF and NASA to undertake a study similar to what has been done recently for studies of the cosmic microwave background (CMB) and of dark energy. The results of such a study would also be very valuable input for the next Decadal Survey.

Given the dramatic changes that have occurred at NASA in the last two years with regard to planet searching, the recommendations of such a group could also provide a more stable framework under which a planet search/characterization program could be developed. The agencies responded positively and supported the establishment of the ExoPlanet Task Force (ExoPTF). The charge was developed and an excellent committee assembled[32]. The first meeting was held in mid-February 2007. The goal of the committee is to produce a report by fall 2007. White papers have been requested from the community and will form a major part of the input to the committee. The timing of the report will allow the community to build on its findings and develop recommendations through the next Decadal Survey later this decade.

[32] http://www.nsf.gov/mps/ast/exoptf.jsp

6.9 Cosmic Microwave Background: Task Force on CMB Research (TFCR)

CMB Task Force: The CMB Task Force (TFCR) was the first Task Force undertaken under the auspices of the AAAC. The TFCR's comprehensive and valuable study will provide a basis for moving forward in this exciting area on a broadly based program for CMB polarization research whose ultimate goal is probing the first instant of the universe (the inflation epoch). The NRC report, Elementary Particle Physics in the 21st Century (EPP2010), recently highlighted the importance of CMB research. The TFCR report will provide invaluable guidance for the next Decadal Survey. ***The AAAC would be interested in discussing with the agencies the impact of the TFCR's recommendations.***

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. These measurements and results have been the result of a long program of careful detector development and testing through ground- and balloon-based telescopes supported by NSF that led to the recent spectacular success of the NASA Wilkinson Microwave Anisotropy Probe (WMAP) Explorer satellite mission. One of the key chapters in cosmology remains to be written – the ambitious goal of probing the first instants of the universe and testing inflation by definitive measurements of the polarization of the CMB. This goal was highlighted in both the *Connecting Quarks with the Cosmos* (CQC) and *Physics of the Universe* (POU) reports.

The AAAC enthusiastically supported the effort to set up a Task Force to develop a joint NSF-NASA-DOE strategic plan leading to definitive measurements of the CMB polarization. The final report[33] of that group, the Task Force on CMB Research[34] (TFCR), was accepted by the AAAC and HEPAP late in 2005. The AAAC noted that the TFCR report set a very high standard for subsequent studies and will be a resource for many years to come, particularly during the next Decadal Survey process. CMB studies were subsequently highlighted in the Astrophysics recommendation in the EPP2010: Elementary Particle Physics in the 21st Century committee report of the National Academy, *Revealing the Hidden Nature of Space and Time: Charting the Course for Elementary Particle Physics*[35]. The AAAC is now interested in how the agencies will follow up on the recommendations of this report (see §6.10 below).

6.10 Implementation of Task Force Recommendations

Task Force Recommendations: The AAAC transmitted final reports to the agencies from the Task Force on CMB Research (TFCR) in October 2005 and from the Dark Energy Task Force (DETF) in June 2006. The transmission of the Dark Matter Scientific Assessment Group (DMSAG) report will occur by the middle of 2007. The ExoPlanet Task Force (ExoPTF) is underway and will report late in 2007. These reports will also provide valuable input for the next Decadal Survey. A key question surrounds the implementation of the recommendations in these reports. ***In the coming year the AAAC is interested in further discussion with the agencies about how these recommendations will be folded into agency planning and roadmapping activities, Research and Analysis (R&A) funding, and instrument and facility planning.***

The AAAC Task Forces involve many scientists from the community in a time-consuming effort to identify a path forward in an area that has been recognized by both the community and the agencies as being of high priority. At the completion of their reports and the subsequent transmittal to the agencies by the AAAC, a

[33] http://nsf.gov/mps/ast/tfcr_final_report.pdf
[34] http://nsf.gov/mps/ast/tfcr.jsp
[35] http://books.nap.edu/catalog.php?record_id=11641

key question asked by the Task Force members and other scientists is "what happens now?" This is a very appropriate question. The AAAC recognizes that there will be differences of approach that depend (i) on the report topic, (ii) on the scale of the mission/program/project/activity that has been recommended by the Task Force, and (iii) on the agencies involved and how they support research programs and instrumentation developments. It would be valuable for the AAAC, and, through the AAAC, for the community to develop a clearer understanding of the responses and the approaches that will likely occur. An example occurred with the announcement by DOE HEP of a solicitation of research proposals relating to dark energy where $5M was designated as being available for R&D. The responses from the agencies will differ according to the scale of the activity. A $5M instrument could well be handled very differently from a $300K research proposal, for example. An initial discussion regarding the agencies' responses to Task Force reports occurred at the February 2007 AAAC meeting, but the time available was not adequate for such a complex topic. The AAAC would appreciate further discussion of this topic during the coming year so that its members can respond more appropriately to the "what happens now?" question.

6.11 South Pole Station Communications

South Pole: There is now a very substantial investment at the NSF South Pole Station (over $300M) in science programs like the IceCube neutrino observatory, the South Pole Telescope (SPT) and a variety of other smaller facilities. Reliable high-bandwidth data communications are key to their effective operation. The normal geostationary satellites used for data communications are not visible from the South Pole, and so the only high-speed option is the Tracking and Data Relay Satellite System (TDRSS). The AAAC discussed the concerns about the reliability and availability of TDRSS with the NSF Office of Polar Programs (OPP). Bandwidth is available in the short term, but there is considerable concern about the long term. ***The AAAC encourages joint discussions between NSF and NASA and planning to develop a long-term alternative to the aging TDRSS for South Pole data communications.***

The NSF Office of Polar Programs (OPP) has a very large investment in infrastructure and science facilities at South Pole Station (in excess of $400M), with a substantial yearly operating budget that runs over $50M. Reliable, fast data communications plays a crucial role in the scientific return from the Station. The science activities at the South Pole are unique facilities that complement other ground and space programs. Geosynchronous satellites are not visible from the Earth's poles; thus, the bulk of the communications and data transfer to South Pole Station relies on an old NASA Tracking and Data Reply Satellite (TDRS 1) that is on an inclined Earth orbit. The AAAC commends the recent NSF and NASA collaborative effort that resulted in an increase in the bandwidth for 2007 by nearly an order of magnitude to roughly 90 Gigabytes per day. This meets the current needs of the station, including the daily transfer of the large data sets acquired by the astrophysics projects at South Pole Station.

The AAAC is concerned, however, that the current communication link is unsustainable. TDRS 1 could fail at any moment; it has already exceeded its expected lifetime. Moving the TDRS 3 satellite into position could provide an expensive short-term solution, but it is also at risk of failure. It is clear that a long-term, robust solution for sustainable, high-bandwidth communications is needed urgently. We strongly encourage NSF and NASA work to find an acceptable long-term solution as soon as possible.

6.12 Gamma-ray Large Area Space Telescope (GLAST)

GLAST: The AAAC is very encouraged that the Gamma-ray Large Area Space Telescope (GLAST) is moving forward towards a launch in late 2007. A successful GLAST mission will bring great scientific progress, as well as provide a useful working model for future NASA-DOE partnerships.

The AAAC was pleased to learn that the Gamma-ray Large Area Space Telescope (GLAST) is on track for a launch late in 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 (with four foreign partners). 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, similar joint efforts such as the Joint Dark Energy Mission (JDEM). A successful GLAST mission will bring great scientific progress, as well as provide a useful working model for future NASA-DOE partnerships.

Being more than an order of magnitude more sensitive than the earlier Compton Gamma Ray Observatory (CGRO), GLAST will have a major impact on our understanding of the astrophysics of sources that emit high-energy radiation. Specifically, it is expected that GLAST will discover thousands of new high-energy sources, many of which will require detailed, correlated observations using instruments at longer wavelengths. We note that a relatively comprehensive multi-wavelength program will be needed to fully capitalize on the GLAST mission, and that much of this program will be carried out using ground-based facilities supported by NSF. One possible area of overlap is with the Very Long Baseline Array (VLBA), which that has been slated for reductions as recommended by the NSF AST Senior Review. The AAAC is interested in understanding the impact of that closure on the science return from GLAST.

6.13 Lessons-Learned Interagency Study

Lessons-Learned: Following discussions with the agencies and OSTP early last year, and a letter from the AAAC regarding the value of a "Lessons-Learned" study, the AAAC was pleased to hear that the agencies and OSTP were undertaking such an activity regarding collaborative interagency projects under OSTP guidance. ***The AAAC hopes that this activity comes to fruition this year and that OSTP can make the resulting report available to the Committee.***

After discussion at several meetings during 2005, the AAAC sent a letter[36] to the agencies outlining the value of a "lessons-learned" activity that would provide guidance to the agencies, OMB, OSTP and Congress on what problems arose regarding GLAST and how they were dealt with, and whether, in retrospect, different approaches could have been taken that might have minimized some of the problems. We also noted that it would also be valuable to cover other interagency projects, such as the NSF-DOE-Smithsonian Very Energetic Radiation Imaging Telescope Array System (VERITAS), so the experiences of all three agencies in the astrophysics arena could be captured. The AAAC recognized that there is no "one-size-fits-all" approach – the nature of the cooperation on joint projects depends both on the project and the agencies involved – and that it would be valuable if the report could capture how any differences in approach were handled. This is clearly a "living process" in that current and future activities will add to the experience in interagency projects, but it is of considerable value to summarize what has been learned to date.

The letter submitted to the agencies in early 2006 recommended that the agencies undertake the production of a report incorporating the thoughts and experiences regarding process, oversight, coordination, and resolution of technical and fiscal challenges for GLAST and VERITAS (and for other projects, as appropriate, e.g., JDEM, CMB experiments), including the issues involved in international collaborations. Such a report could be used within the agencies and advisory groups such as the AAAC as a guide for future

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36 http://www.nsf.gov/attachments/104203/public/lessonslearned_aaac.pdf

collaborative efforts. The agencies and OSTP reported that they had agreed to undertake such an activity at our May 2006 meeting and noted subsequently that meetings had been held with OSTP guidance. The AAAC hopes that the "lessons-learned" process is completed this year and that the report (or a comprehensive summary) is made available to the committee and other interested parties.

6.14 Funding for Committee Meetings

Committee Travel: The burden for travel for the AAAC has fallen fully on NSF AST and is a serious impact on their limited Salaries and Expenses (S&E) budget. ***The AAAC believes that it would be appropriate for the three agencies it advises to share in the travel burden and recommends that they find mechanisms that would allow sharing of the travel costs.***

For many years now the travel funding for AAAC members to attend its meetings has come solely from the NSF AST Salaries and Expenses (S&E) account. This has proved to be a major burden for the agency and the AST Division since travel under S&E is very often constrained. This year it appears that the AAAC may have to cancel one of its three face-to-face meetings (in May 2007), because of the FY07 budget limits on S&E, at a time when it is particularly important to follow up on issues raised by the AAAC Annual Report. While the NSF S&E budget is expected to improve in FY08, the burden of AAAC travel is disproportionately loaded onto NSF. The AAAC hopes that discussions with other agencies will lead to an equitable sharing of the travel costs.

APPENDIX A: ESTABLISHMENT OF THE AAAC UNDER THE NATIONAL SCIENCE FOUNDATION AUTHORIZATION ACT OF 2002 AND ITS SUBSEQUENT MODIFICATION TO INCLUDE DOE

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, and the Department of Energy 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, and the Department of Energy;

(2) assess, and make recommendations regarding, the status of the activities of the Foundation and the National Aeronautics and Space Administration, and the Department of Energy as they relate to the recommendations contained in the National Research Council's 2000 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, the Secretary of Energy 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) 4 members selected by the Director;
(2) 4 members selected by the Administrator of the National Aeronautics and Space Administration;
(3) 3 members selected by the Secretary of Energy; and
(4) 2 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 that 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

AA	Associate Administrator
AAAC	Astronomy and Astrophysics Advisory Committee
ACI	American Competitiveness Initiative
AIM	Astrometric Interferometry Mission (now known as SIM)
ALMA	Atacama Large Millimeter Array
AO	Adaptive Optics
AO	Announcement of Opportunity
AST	NSF Division of Astronomical Sciences
ATST	Advanced Technology Solar Telescope
AURA	Association of Universities for Research in Astronomy
AXAF	Advanced X-ray Astrophysics Facility (now known as Chandra)
BEPAC	Beyond Einstein Program Assessment Committee
BPA	Board on Physics and Astronomy
CAA	Committee on Astronomy and Astrophysics
CDR	Critical Design Review
CEV	Crew Exploration Vehicle
CGRO	Compton Gamma Ray Observatory
Chandra	Chandra X-ray Observatory (formerly known as AXAF)
CMB	Cosmic Microwave Background
CMBPOL	CMB Polarization Mission
COBE	Cosmic Background Explorer
COMRAA	Committee on Organization and Management of Research in Astronomy and Astrophysics
Con-X	Constellation X-Ray Observatory
COROT	COnvection, ROtation and planetary Transits
CQC	Connecting Quarks with the Cosmos (2004 NAS report)
COS	Cosmic Origins Spectrograph
CTIO	Cerro Tololo Inter-American Observatory
DETF	Dark Energy Task Force
DMSAG	Dark Matter Science Assessment Group
DOE	U.S. Department of Energy
ELT	Extremely Large Telescope
ESA	European Space Agency
ESO	European Southern Observatory
EVLA	Expanded Very Large Array
ExAO	Extreme Adaptive Optics
ExoPTF	ExoPlanet Task Force
FACA	Federal Advisory Committee Act
FY	Fiscal Year
GLAST	Gamma-ray Large Area Space Telescope
GMT	Giant Magellan Telescope
GONG	Global Oscillation Network Group
GSFC	Goddard Space Flight Center
GSMT	Giant Segmented Mirror Telescope
HEP	DOE Office of High Energy Physics
HEPAP	High Energy Physics Advisory Panel
HST	Hubble Space Telescope

ILC	International Linear Collider
ISS	International Space Station
JDEM	Joint Dark Energy Mission
JPL	Jet Propulsion Laboratory
JWST	James Webb Space Telescope (formerly known as NGST)
KAO	Kuiper Airborne Observatory
LAT	Large Area Telescope
LHC	Large Hadron Collider
LISA	Laser Interferometer Space Antenna
LST	Large Survey Telescope
LSST	Large Synoptic Survey Telescope
LTSA	Long-Term Space Astrophysics
MIE	Major Item of Equipment
MO&DA	Mission Operations and Data Analysis
MOU	Memorandum of Understanding
MPS	NSF Directorate for Mathematical and Physical Sciences
MREFC	Major Research Equipment and Facilities Construction
MSFC	Marshall Space Flight Center
NAC	NASA Advisory Council
NAS	National Academy of Sciences
NAPA	NASA Astrophysics Performance Assessment Committee
NASA	National Aeronautics and Space Administration
NEO	Near-Earth Object
NET	No Earlier Than
NICMOS	Near Infrared Camera and Multi-Object Spectrometer
NIST	National Institute of Standards and Technology
NGST	Next Generation Space Telescope (now known as JWST)
NRC	National Research Council
NSB	National Science Board
NSF	National Science Foundation
NSTC	National Science and Technology Council
NuSTAR	Nuclear Spectroscopic Telescope Array
NVO	National Virtual Observatory
OMB	Office of Management and Budget
OSTP	Office of Science and Technology Policy
Pan-STARRS	Panoramic Survey Telescope and Rapid Response System
PDR	Preliminary Design Review
PHY	NSF Division of Physics
R&A	Research and Analysis
R&D	Research and Development
RTF	Space Shuttle Return to Flight
SAFIR	Single Aperture Far-Infrared Observatory
SDO	Solar Dynamics Observatory
SIM	Space Interferometry Mission (formerly known as AIM)
SIRTF	Space Infrared Telescope Facility (now known as Spitzer)
SLAC	Stanford Linear Accelerator Center
SM4	HST Servicing Mission 4
SMD	NASA Science Mission Directorate
SNAP	Supernova Acceleration Probe

SOFIA	Stratospheric Observatory for Infrared Astronomy
Spitzer	Spitzer Space Telescope (formerly known as SIRTF)
SPT	South Pole Telescope
SScAC	Space Science Advisory Committee
STIS	Space Telescope Imaging Spectrograph
STS	Space Transporation System (a.k.a. Space Shuttle)
SWG	Science Working Group
TDRSS	Tracking and Data Relay Satellite System
TFCR	Task Force on CMB Research
TMT	Thirty Meter Telescope
TPF	Terrestrial Planet Finder
TPF-C	Terrestrial Planet Finder-Coronagraph
TPF-I	Terrestrial Planet Finder-Interferometer
T-NAR	Technology Non-Advocate Review
TRL	Technological Readiness Level
VAO	Virtual Astronomical Observatory
VERITAS	Very Energetic Radiation Imaging Telescope Array System
VLA	Very Large Array
VLBA	Very Long Baseline Array
VLT	Very Large Telescope
WFC3	Wide-Field Camerca 3
WISE	Wide-field Infrared Survey Explorer
WMAP	Wilkinson Microwave Anisotropy Probe