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ANGELA V. OLINTO, *Chair*

March 15, 2016

Dr. France A. Córdova, Director
National Science Foundation
4201 Wilson Blvd., Suite 1205
Arlington, VA 22230

Mr. Charles F. Bolden, Jr., Administrator
Office of the Administrator
NASA Headquarters
Washington, DC 20546-0001

Dr. Ernest Moniz, Secretary of Energy
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

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

The Honorable Lisa Murkowski, Chairwoman
Committee on Energy & Natural Resources
United States Senate
Washington, DC 20510

The Honorable Lamar Smith, Chairman
Committee on Science, Space and Technology
United States House of Representatives
Washington, DC 20515

Dear Dr. Córdova, Mr. Bolden, Secretary Moniz, Chairman Thune, Chairwoman Murkowski, and Chairman Smith:

I am pleased to transmit to you the annual report of the Astronomy and Astrophysics Advisory Committee for 2015–2016.

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 2010 report entitled *New Worlds, New Horizons in Astronomy and Astrophysics*, 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, the Committee on Commerce, Science and Transportation of the United States Senate, the Committee on Energy and Natural Resources of the United States Senate, and the Committee on Science, Space, and Technology of the United States House of Representatives, on the Advisory Committee's findings and recommendations under paragraphs (1) and (2).

The attached document is the thirteenth such report. The executive summary is followed by the report, with findings and 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,

Angela Olinto
Homer J. Livingston Professor
Chair, Astronomy and Astrophysics Advisory Committee

cc: Senator Bill Nelson, Ranking Member, Committee on Commerce, Science and Transportation, United States Senate
Senator Maria Cantwell, Ranking Member, Committee on Energy & Natural Resources United States Senate
Representative Eddie Bernice Johnson, Ranking Member, Committee on Science, Space, and Technology, United States House of Representatives
Senator Ted Cruz, Chairman, Subcommittee on Space, Science, and Competitiveness, Committee on Commerce, Science and Transportation, United States Senate
Senator Gary Peters, Ranking Member, Subcommittee on Space, Science, and Competitiveness, Committee on Commerce, Science and Transportation, United States Senate
Senator Richard Shelby, Chairman, Subcommittee on Commerce, Justice, Science, and Related Agencies, Committee on Appropriations, United States Senate
Senator Barbara Mikulski, Ranking Member, Subcommittee on Commerce, Justice, Science, and Related Agencies, Committee on Appropriations, United States Senate
Senator Lamar Alexander, Chairman, Subcommittee on Energy and Water Development, Committee on Appropriations, United States Senate
Senator Dianne Feinstein, Ranking Member, Subcommittee on Energy and Water Development, Committee on Appropriations, United States Senate

Representative Barbara Comstock, Chairwoman, Subcommittee on Research and Technology, Committee on Science, Space and Technology, United States House of Representatives
Representative Daniel Lipinski, Ranking Member, Subcommittee on Research and Technology, Committee on Science, Space and Technology, United States House of Representatives
Representative Mike Simpson, Chairman, Subcommittee on Energy and Water Development and Related Agencies, Committee on Appropriations, United States House of Representatives
Representative Marcy Kaptur, Ranking Member, Subcommittee on Energy and Water Development, Committee on Appropriations, United States House of Representatives
Representative John Culberson, Chairman, Subcommittee on Commerce, Justice, Science and Related Agencies, Committee on Appropriations, United States House of Representatives
Representative Mike Honda, Acting Ranking Member, Subcommittee on Commerce, Justice, Science and Related Agencies, Committee on Appropriations, United States House of Representatives
Representative Brian Babin, Chairman, Subcommittee on Space, Committee on Science, Space, and Technology, United States House of Representatives
Representative Donna Edwards, Ranking Member, Subcommittee on Space, Committee on Science, Space, and Technology, United States House of Representatives
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Dr. John Grunsfeld, Associate Administrator, Science Mission Directorate, National Aeronautics and Space Administration
Dr. Geoffrey Yoder, Deputy Associate Administrator, Science Mission Directorate, National Aeronautics and Space Administration
Dr. Paul Hertz, Director, Astrophysics Division, Science Mission Directorate, National Aeronautics and Space Administration
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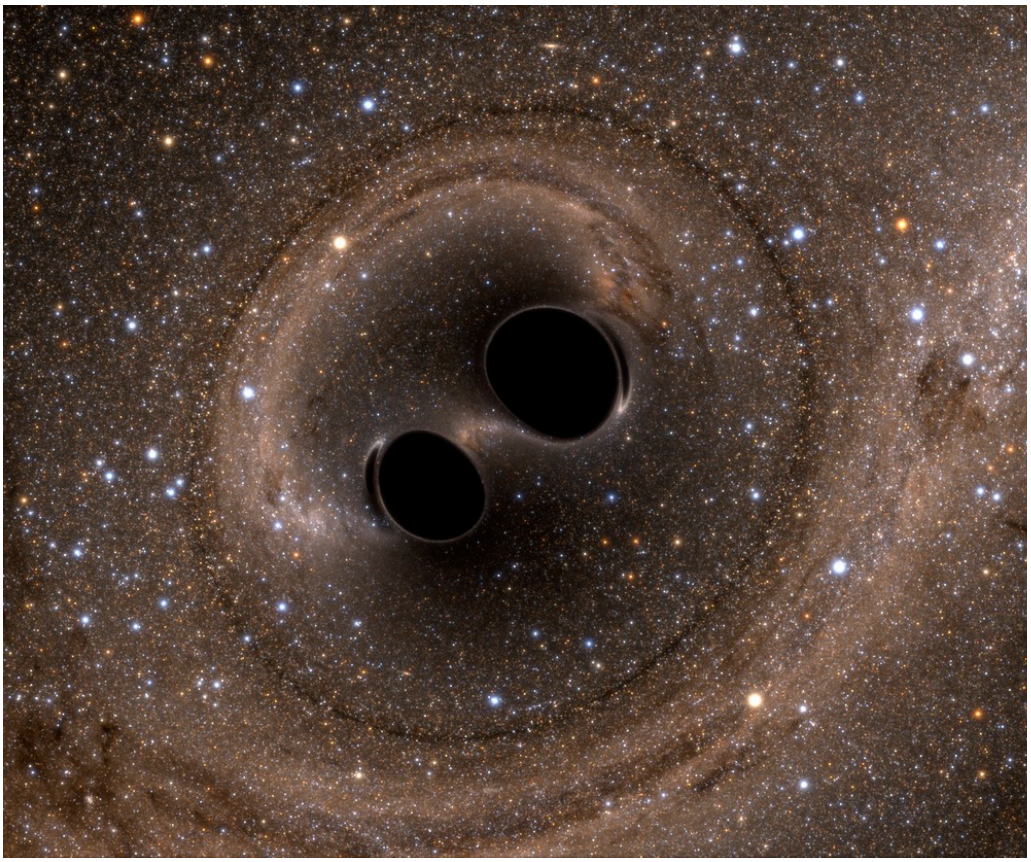
Dr. James Siegrist, Director, Office of High Energy Physics, U.S. Department of Energy
Dr. Glen Crawford, Division Director, Research and Technology Division, Office of High Energy Physics, U.S. Department of Energy
Dr. Kathleen Turner, Program Manager, Office of High Energy Physics, U.S. Department of Energy
Dr. Jo Handelsman, Associate Director for Science, Office of Science and Technology Policy, Executive Office of the President
Dr. Tamara Dickinson, Principal Asst. Director for Environment and Energy, Office of Science and Technology Policy, Executive Office of the President
Dr. J.D. Kundu, Program Examiner, NSF, Office of Management and Budget
Dr. Grace Hu, Program Examiner, NASA, Office of Management and Budget
Dr. Avital Bar-Shalom, Program Examiner, DOE, Office of Management and Budget
Dr. James Ulvestad, Director, Division of Astronomical Sciences, National Science Foundation
Dr. David Boboltz, Acting Deputy Division Director, Division of Astronomical Sciences, National Science Foundation
Dr. Christopher Davis, Program Director, Division of Astronomical Sciences, National Science Foundation

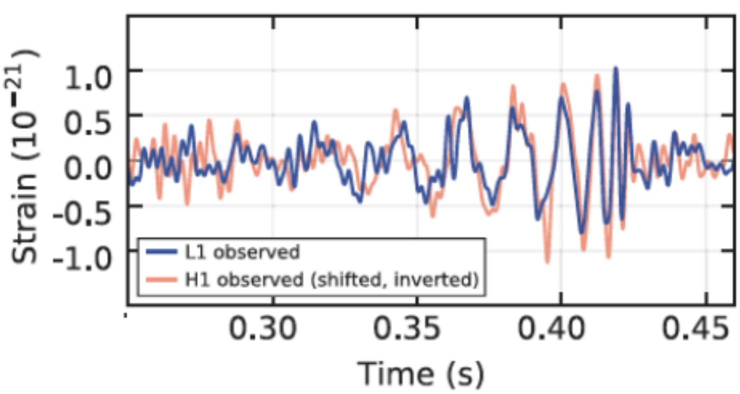
Astronomy and Astrophysics Advisory Committee Members:

Dr. James Buckley, Washington University at St. Louis
Dr. Craig Hogan, University of Chicago
Dr. David Hogg, New York University
Dr. Klaus Honscheid, The Ohio State University
Dr. Buell Jannuzi, University of Arizona, Steward Observatory
Dr. Lisa Kaltenegger, Cornell University
Dr. Rachel Mandelbaum, Carnegie-Mellon University
Dr. Angela Olinto, University of Chicago, Chair
Dr. William Smith, ScienceWorks International
Dr. Angela Speck, University of Missouri
Dr. Suzanne Staggs, Princeton University
Dr. Jean Turner, University of California, Los Angeles
Dr. Martin White, University of California, Berkeley

Report of the Astronomy and Astrophysics Advisory Committee

March 15, 2016





Contents

The cover image is a model sky near two approximately 30 solar mass black holes about to coalesce to produce the first gravitational wave ever directly detected. The image includes starlight bent by the extreme gravity near the holes, as well as multiple images of the holes themselves. (Image produced by the Simulating eXtreme Spacetimes, SXS, Project.) The actual signal appeared on September 14, in both Advanced LIGO detectors. "The source lies at a luminosity distance of 410 (+160−180) Mpc corresponding to a redshift z =0.09 (+0.03/-0.04). In the source frame, the initial black hole masses are 36 (+5−4) M_{solar} and 29 (+4−4) M_{solar}, and the final black hole mass is 62 (+4/−4) M_{solar}, with 3.0 (+0.5−0.5)$M_{solar}c^2$ radiated in gravitational waves" (LIGO collaboration, PRL 116, 061102 (2016)).

Executive Summary

US investment in astronomy and astrophysics continues to create an outstanding portfolio of preeminent research facilities that have revolutionized our understanding of the Universe, fascinating the public and inspiring new generations of scientists and engineers.

The Astronomy and Astrophysics Advisory Committee (AAAC) is chartered to assess and make recommendations regarding the coordination of NSF, NASA, and DOE astronomy programs and the status of the activities relative to the priorities of the National Research Council (NRC) decadal survey *New Worlds, New Horizons in Astronomy and Astrophysics* (*NWNH*) and its predecessors. This AAAC report summarizes the progress in astronomy and astrophysics and the support by the agencies over the last year.

The past year witnessed momentous scientific results, excellent agency coordination, and continuous progress toward the construction of the top priorities in *NWNH*. The challenging budget environment has strained the balance of the portfolio, causing a significant decline of success rates in competed grants as discussed in the attached "*Competed Grant Success Rates in US Astronomy and Astrophysics"* report.

We list our findings and recommendations below. (Acronyms are introduced in the text and listed in Appendix B.)

Collected Findings and Recommendations

Section 2

***FINDING*: Thanks to US investment in basic research at NSF, NASA, and DOE, the US program in Astronomy and Astrophysics has achieved spectacular breakthroughs over the past year.**

Section 3

***FINDING*: US agencies work well together to support the priorities of the scientific community, both in collaboration on large managed projects and in coordination of diverse research programs.**

***FINDING*: Some unique information in the high quality data that will be obtained in several future surveys— particularly LSST, Euclid, and WFIRST— will be significantly enhanced by combining their analysis at an early "pixel" stage, rather than a more highly reduced catalog stage.**

***RECOMMENDATION*: Where it can improve overall science productivity and efficiency, cooperation in database design and data sharing is encouraged among US agencies, international agencies, and scientific collaborations.**

***FINDING:** The most cost effective approach to discovering and mapping the orbits of earth-threatening solar system objects ("Near Earth Objects" or NEOs) is likely to include a significant contribution from ground-based telescope facilities. Achieving the congressionally mandated goals will likely require cooperation between NSF and NASA.*

***FINDING:** With its history of successes funded by NASA, NSF, and DOE, CMB science crosses the boundaries of agencies. Third generation ground-based efforts and suborbital payloads are now reaching the sensitivity that could enable ground-breaking discoveries of CMB B-modes.*

***FINDING:** The scientific community studying the cosmic microwave background has made significant progress on a unified strategy for a fourth generation, ground-based survey of the Universe ("CMB-S4"), orders of magnitude more capable than current experiments, with enormous potential for new scientific discovery. A larger role of DOE coordinated with NSF is important to realize the great scientific potential of CMB-S4.*

***RECOMMENDATION:** We encourage DOE, NSF, and the university community to continue working toward a plan for a future (Stage 4) ground-based CMB experiment.*

Section 4.4

***FINDING:** The NSF Division of Astronomical Sciences has done a commendable job of finding creative solutions to respond to the recommendations made by the Portfolio Review Committee (PRC) while limiting permanent shut down of a number of facilities. These actions serve to reduce the amount the NSF/AST is spending on the operating budgets of legacy facilities and thus move closer to the desired balance in the portfolio recommended by the PRC.*

***FINDING:** Divestments recommended by the Portfolio Review are proceeding, but at a slower pace than anticipated due to the complexities of decommissioning and the ongoing searches for operating partners.*

***FINDING:** The loss of open access facilities results in a cost to the US user communities, in terms of loss of open nights and access to a variety of instruments.*

***RECOMMENDATION:** Strong efforts by NSF for facility divestment should continue as fast as is practical. Efforts to explore partnerships, interagency cooperation and private resources to maintain some access to facilities for the US community that may mitigate the loss of open access should continue. Transferring the cost of operating a facility outside of the NSF/AST budget is preferable to complete loss of a capability from the suite of capabilities used by US researchers.*

Section 4.8

FINDING*:** ***The agencies are working together to ensure that the highest priorities of NWNH, WFIRST and LSST, are moving forward. WFIRST has recently successfully moved into the formulation phase under the guidance of NASA, and LSST is well into the construction phase, with the camera under construction under DOE support and facility construction in the MREFC line at NSF led by AST.

FINDING*:** ***The NSF MSIP program is funded at a level well below that envisioned in NWNH, but is becoming the only mechanism available for funding the high priority activities advocated in NWNH. NSF/AST is funding MSIP at the highest level commensurate with program balance. The program is supporting a larger number of projects with a lower budget and not able to support the higher cost projects as envisioned by NWNH.

FINDING*:** ***Budgetary constraints have not allowed progress on recommendations for a US partnership in an optical/infrared Giant Segmented Mirror Telescope (GSMT).

FINDING*:** ***Budgetary constraints have not allowed progress on a major new X-ray telescope (IXO). NASA is working towards US participation in the ESA ATHENA project providing future resources for the US astronomy and astrophysics.

FINDING*:** ***The international CTA consortium is moving forward to build the CTA observatory. US participation at a more modest level than envisioned by NWNH would still enable US access and leadership roles. US funding for CTA may be attainable through competed mid-scale funding such as the MSIP program in NSF/AST and mid-scale program of NSF/PHY.

FINDING*:** ***Gravitational wave astrophysics is now a reality. This exciting new field, at the frontier of physics and astrophysics, will benefit greatly from cooperation among agencies as it continues to develop and generate new science areas in its wake.

RECOMMENDATION*:** ***The AAAC encourages NASA to continue working toward a plan to develop a space-based gravitational wave observatory as envisioned by NWNH, through participation in the ESA L3 gravitational wave effort.

RECOMMENDATION*:** ***The agencies should continue to pursue international partnerships in order to further accomplish the goals of NWNH. The AAAC's "Principles for Access to Large Federally Funded Astrophysics Projects and Facilities" should guide the process.

Section 5

FINDING*:** ***Spending for astronomy and astrophysics research continues to lag the optimistic scenarios included in NWNH. Lack of a consistent funding stream puts some of the agency programs at risk and does not support the long term planning needed to execute the decadal survey plan.

<u>RECOMMENDATION</u>: We urge that the full programmatic funding required by the three agencies to execute their FY 2017 plans, as described in their budget requests, be provided.

Section 6

<u>FINDING</u>: Over the last decade proposal success rates in Astronomy and Astrophysics have dropped significantly. This is not principally the result of a decline in proposal merit, changing demographics, or an increase in the average funding request per proposal (beyond inflation). Rather this is a consequence of flat or declining budgets for individual investigator grants, more investigators, and a larger proportion of multiple and resubmitted proposals. In the absence of facility divestment by NSF/AST over the coming years, proposal success rate is expected to decline even further.

<u>FINDING</u>: A very low proposal success rate impacts both researchers and the agencies. Researchers spend more time resubmitting meritorious but unfunded proposals and serving on review panels. Some researchers may elect to leave the field or decide not to pursue original and potentially transformative research. Agencies must manage the increased workload, staffing problems, and increased costs associated with reviewing more proposals.

<u>RECOMMENDATION</u>: Community based groups, such as the AAS and the APS, should study the recent and projected growth of the leading US astronomy and astrophysics research community for the next decadal survey planning exercise of the end of this decade.

1) Introduction

The 2016 Astronomy and Astrophysics Advisory Committee (AAAC) annual report summarizes the impressive scientific and programmatic achievements over that last year resulting from our long-standing national investments, and makes recommendations to continue the success of US astronomy and astrophysics in the future. Astronomy and astrophysics research continues to expand our understanding of the Universe, our place in it, and the fundamental laws that govern its evolution and of the systems it contains.

This year's scientific highlight is the momentous discovery of gravitational waves by the Advanced Laser Interferometer Gravitational-Wave Observatory (LIGO) detectors. This discovery crowns a century old effort to study Gravity, the most challenging force to master, at its most extreme. The announced event reveals for the first time a new form of energy predicted by Einstein 100 years ago. It also unveils new systems of massive stellar black holes never observed before. Heralding the dawn of a new era of gravitational wave astrophysics, we note that this awe-inspiring detection was made possible by the long-standing support of basic research by the US through the National Science Foundation (NSF).

The past year also witnessed the discovery of 17 new Milky Way satellites, likely astrophysical sites for dark matter detection, by the Dark Energy Survey (DES), a project jointly supported by NSF and Department of Energy (DOE). DES also produced weak lensing mass maps, aimed at studying the evolution of dark energy and dark matter in the past few billion years. The Planck Surveyor mapped the sky across more than a decade of wavelengths. During this past year, the Atacama Large Millimeter/submillimeter Array (ALMA) observed the early stages of planet formation and the number of exoplanet candidates detected with the National Aeronautics and Space Administration (NASA) Kepler and K2 missions surpassed four thousand, vastly expanding our understanding of planets and nurturing the public's spirit of adventure and discovery.

The AAAC assesses and makes recommendations regarding the coordination of the NSF, NASA, and the DOE astronomy and astrophysics programs and the status of the activities relative to the priorities of the National Research Council (NRC) decadal survey *New Worlds, New Horizons in Astronomy and Astrophysics* (*NWNH*)[i] and its predecessors. The AAAC reports the committee's assessments and recommendations annually to the Secretary of Energy, the NASA Administrator, the NSF Director, and to relevant committees in the House and Senate. This communication represents the annual report of the 2015-2016 committee.

The highest priorities of *NWNH* are moving forward well. On the ground, the Large Synoptic Survey Telescope (LSST) is being built with a strong NSF and DOE partnership for construction and operations. In space, the Wide-Field Infrared Survey Telescope (WFIRST) is progressing well having moved into formulation phase (Phase A) in February 2016 under strong NASA stewardship of science and project teams.

Second priorities of *NWNH* and the portfolio balance of the core program have been difficult to achieve given challenging budgetary constraints for both ground and space efforts. In particular, the strong decline in competed grants success rates is the subject of a dedicated study by the AAAC attached to this report, named *Competed Grant Success Rates in US Astronomy and Astrophysics*. The base program of competed grants is under stress throughout the system. Particularly serious is the trend in the NSF Division of Astronomical Sciences (AST) where success rates are below historic minima and will be further aggravated by upcoming operations of new facilities. A vigorous implementation of the Portfolio Review recommendations complemented with an increase in the AST base budget is recommended before success rates decline even further. A balanced portfolio is crucial to better realize the scientific potential of the leading facilities and missions and to maintain the success of US astronomy and astrophysics in the future.

Since March 15, 2015, the AAAC has had two face-to-face meetings and two teleconferences. Representatives of the three agencies have given briefings and provided input on the status of their programs. At the time of the writing of this report, the FY16 agency spending plans have not yet been approved by Congress, and the FY17 President's budget request has recently been released. We urge that the full programmatic funding required by the three agencies to execute their FY 2017 plans, as described in their budget requests, be provided.

2) Science Highlights

There have been many important astrophysics breakthroughs during the past year. In this section, we list a small subset of these results, with more information provided in Appendix A.

A1: The NSF-funded Advanced Laser Interferometer Gravitational-Wave Observatory (LIGO) collaboration reported the first ever detection of gravitational waves, a prediction of General Relativity that had never been directly observed before now. This incredibly difficult measurement represents the culmination of decades of work, and opens up a new field of gravitational wave astronomy.

A2: Seventeen new Milky Way satellites, dwarf galaxies that are gravitationally bound to our Galaxy, have been identified in data from the Dark Energy Survey (DES), which uses the Dark Energy Camera (DECam) to image the southern sky funded by DOE and NSF. New dwarf galaxies were also discovered in a nearby galaxy cluster. These discoveries shed new light on the smallest, most dark matter-dominated galaxies in the Universe, which has implications for our cosmological model.

A3: The Dark Energy Survey, having completed its third of five observing seasons, released its first science results. These include widely-publicized weak lensing mass maps, which reveal the influence of dark energy on the growth of structure in the distribution of dark matter in the past few billion years.

A4: The Planck collaboration released science results for cosmic microwave background (CMB) observations spanning their full four-year mission, and the NASA CMB balloon mission Spider successfully carried out its observations in 2015.

A5: More than four thousand exoplanet candidates have been detected with NASA's Kepler and the K2 missions. Among those about a dozen are small enough to be rocky and orbit within the Habitable zone of their host star, where they receive similar stellar insolation to that received by the Earth from the Sun. Among these exoplanets are ones that orbit and transit close-by stars, which scientists can study in more detail with ground and space based telescopes.

A6: The Atacama Large Millimeter/submillimeter Array (ALMA) observed the early stage of planet formation around single and binary stars.

FINDING**:** ***Thanks to US investment in basic research at NSF, NASA, and DOE, the US program in Astronomy and Astrophysics has achieved spectacular breakthroughs over the past year.***

3) Interagency Coordination and Cooperation

There are many successful examples of the three agencies working cooperatively. One successful paradigm is the program of cosmic surveys: the Sloan Digital Sky Survey (SDSS, begun in 1990), DES (currently collecting data), Dark Energy Spectroscopic Instrument (DESI, in development), and the first priority in *NWNH* for ground-based projects, the LSST (now under construction, and to conclude its main operations around 2032). Often in these projects, which have transformed not only astronomy but also much other science, NSF provides the telescope, DOE contributes the instrument, and both bring computational and scientific analysis expertise.

NASA also partners with both of the other agencies; for example, the Fermi Gamma-ray Space Telescope had principal instruments built by DOE, and ground-based follow-up observations enabled by NSF. The NASA funded Extreme Precision Doppler Spectrometer (EPDS) instrument at the Wisconsin-Indiana-Yale-NOAO (WIYN) telescope at Kitt Peak National Observatory (KPNO) part of the National Optical Astronomy Observatory (NOAO) funded by NSF/AST will address the NWNH priority of high-precision radial velocity surveys of nearby stars in order to validate and characterize exoplanet candidates and amplify the science impact of the Transiting Exoplanet Survey Satellite (TESS) mission. The Hubble Space Telescope routinely makes observations that benefit from complementary observations from the ground: for example, by larger aperture telescopes, or radio wave observations.

***FINDING*: US agencies work well together to support the priorities of the scientific community, both in collaboration on large managed projects and in coordination of diverse research programs.**

Much of the success of digital-age surveys, starting with the Sloan Digital Sky Survey, has come from unanticipated impacts enabled by broad access and thoughtfully conceived databases and tools. The proliferation of new high quality survey data from many different sources introduces a new integration challenge, and new opportunities for agencies to maximize their impact by working to maximize the access and connectivity of the databases.

***FINDING*: Some unique information in the high quality data that will be obtained in several future surveys— particularly LSST, Euclid, and WFIRST — will be significantly enhanced by combining their analysis at an early "pixel" stage, rather than a more highly reduced catalog stage.**

***RECOMMENDATION*: Where it can improve overall science productivity and efficiency, cooperation in database design and data sharing is encouraged among US agencies, international agencies, and scientific collaborations.**

The considerable national investment in the Large Synoptic Survey Telescope provides a capability uniquely well suited to the task of finding faint moving objects over large areas of the sky. The telescope and camera are much larger than can be practically flown in space, so for some kinds of objects it is the best tool we will have for the foreseeable future. However, achieving the congressionally mandated goals may require compromises in other science programs and some funding for development and operation of additional capabilities not in the current funded project. NASA has commissioned a "Study of LSST NEO Capabilities" that should provide technical data needed for careful planning. It would be appropriate for the AAAC to comment on the results of that study when they are available.

***FINDING*: The most cost effective approach to discovering and mapping the orbits of earth-threatening solar system objects ("Near Earth Objects" or NEOs) is likely to include a significant contribution from ground-based telescope facilities. Achieving the congressionally mandated goals will likely require cooperation between NSF and NASA.**

Cosmic microwave background (CMB) third generation experiments are reaching the sensitivity to probe the earliest moments of the Universe. Building on the experience of deploying current third generation experiments, CMB scientists are planning for a future (Stage-4) ground-based CMB effort, known as CMB-S4, to improve the sensitivity to CMB B-modes by orders of magnitude. The ground-based effort will be complementary to NASA experiments from space or balloons. The basic technology is well proven, but some R&D will be needed to scale up from projects currently under development by more than an order of magnitude in the number of active detectors. CMB-S4 is well aligned with the High Energy Physics Advisory Panel (HEPAP) Particle Physics Project Prioritization Panel (P5) vision and has the support of several DOE labs, which have proven capabilities of building large-scale detector systems, which are critical to the success of CMB-S4.

***FINDING*: With its history of successes funded by NASA, NSF, and DOE, CMB science crosses the boundaries of agencies. Third generation ground-based efforts and suborbital payloads are now reaching the sensitivity for ground-breaking discoveries of CMB B-modes.**

***FINDING*: The scientific community studying the cosmic microwave background has made significant progress on a unified strategy for a fourth generation, ground-based survey of the Universe ("CMB-S4"), orders of magnitude more capable than current experiments, with enormous potential for new scientific discovery. A larger role of DOE coordinated with NSF is important to realize the great scientific potential of CMB-S4.**

***RECOMMENDATION*: We encourage DOE, NSF, and the university community to continue working toward a plan for a future (Stage 4) ground-based CMB experiment.**

4) Status and Implementation of Decadal Surveys

4.1 Overview

The AAAC charter directs the committee to assess and advise on the status of the activities of the three funding agencies (NSF, NASA and DOE) in relation to the recommendations made by the Decadal Surveys from the NRC. The Decadal Surveys provide critical guidance for NASA/APD and NSF/AST, and also impact NSF Physics Division (NSF/PHY) and the Office of High Energy Physics (HEP) of the Department of Energy (DOE). The most recent such survey report, from 2010, is titled *New Worlds, New Horizons in Astronomy and Astrophysics* (*NWNH*). It was the first to include the DOE.

The *NWNH* report will be supplemented by a report from the Mid-Decadal Review committee convened by the NRC as requested by the agencies. The report is planned for release in May 2016. Implementation of *NWNH* is closely related to other planning exercises, including the Cosmic Frontier recommendations in the Particle Physics Project Prioritization Panel (P5) process (which impacts DOE/HEP and NSF/PHY), the NSF Portfolio Review, and NASA senior reviews (see Section 5).

Here we assess the ongoing efforts of the three agencies to implement the recommendations of *NWNH* in the context of budgetary constraints and the complementary capabilities and goals of the international community. After summarizing key aspects of *NWNH* in Section 4.2, we provide the context in section 4.3. In Section 4.4, we summarize results from the NSF Portfolio Review Committee (PRC). In 4.5 we discuss the implementation of the *NWNH* recommendations and the ongoing Mid-Decadal review in 4.6.
In Section 4.7 we briefly describe projects related to P5 recommendation. Finally, the summary assessment is presented with findings and recommendations in Section 4.8.

4.2 NWNH priorities and recommendations

The *NWNH* report proposed a plan for the decade 2012-2021, organized around three key science themes: "searching for the first stars, galaxies, and black holes; seeking nearby habitable planets; and advancing understanding of the fundamental physics of the universe" (*NWNH,* p. 2). The *NWNH* Committee aimed to address these three themes with a comprehensive plan that also sought to lay some groundwork for the subsequent decade. *NWNH* recommended a program of activities on the ground and in space, classified according to scale. The 11 unranked recommendations for small-scale activities, which included several targeting technology and instrumentation development for the future, were divided nearly equally between space- and ground-based activities. Each of the three recommended medium-scale activities tied closely to one of the three science themes, with two of the three targeting preparation for possible large centerpiece activities for the post-2021 decade. Below we summarize the eight large projects identified by *NWNH* as having the highest priority for the decade.

4.2.1 Space-based Projects

(1) The Wide-Field Infrared Survey Telescope (WFIRST) — an observatory with a very large field of view designed to tackle aspects of all three *NWNH* science themes, by answering questions about dark energy, exoplanets, and galaxy evolution.

(2) Augmentation to the Explorers Program— expansion of the existing NASA program to provide opportunities for rapidly realizing new scientific opportunities.

(3) The Laser Interferometer Space Antenna (LISA)—a low-frequency gravitational wave observatory to complement higher-frequency Earth-based observatories like LIGO and provide access to new means for studying black holes and making precision tests of general relativity.

(4) The International X-ray Observatory (IXO)—a major new X-ray telescope for studies of the high-energy Universe.

4.2.2 Ground-based Projects

(1) The Large Synoptic Survey Telescope (LSST)—a multipurpose wide-field optical telescope targeting aspects of all three *NWNH* science themes, with particular emphasis on probing the fundamental natures of dark energy and dark matter, and surveying the transient sky.

(2) The Midscale Innovations Program (MSIP) — introduction of a competed grants program at the NSF to augment support for mid-scale projects, designed to allow significant advances in scientific discovery for astronomy and astrophysics beyond the scope of the Astronomy and Astrophysics Grants (AAG) program.

(3) The Giant Segmented Mirror Telescope (GSMT)—a large optical and near-infrared telescope that will provide a spectroscopic infrared and optical complement to the James Webb Space Telescope (JWST), the Atacama Large Millimeter Array (ALMA), and LSST. Two international consortia led by US institutions are planning GSMT construction: The Giant Magellan Telescope (GMT) in Chile and the Thirty Meter Telescope (TMT) in Hawaii.

(4) Atmospheric Čerenkov Telescope Array (ACTA)—an international instrument for high-energy gamma-ray astrophysics, aimed at answering questions about high-energy astrophysics and the fundamental nature of dark matter. The international Cherenkov Telescope Array (CTA) consortium is currently moving toward construction.

4.2.3 Other Recommendations

NWNH made a series of additional recommendations directed toward the astronomy and astrophysics community as a whole. These addressed the need for international collaboration and strategic planning, the importance of scientists committing to serve in governmental policy positions, the benefits from training younger people broadly, and the pressing need to diversify the community.

NWNH highlighted the different strengths that the agencies bring to research in Astronomy and Astrophysics as they pursue their mission to promote scientific discovery. They have a strong history of collaborating to maximize the use of resources for astrophysics and astronomy.

DOE/HEP: The DOE HEP office is mission-oriented, involving several broad areas of scientific inquiry, one of which, the Cosmic Frontier supports projects that overlap with astronomy and astrophysics. As mentioned above, *NWNH* was the first decadal survey to include the DOE, in recognition of the DOE's increasing impact on and interest in the field of cosmology. The P5 federal advisory panel is the primary mechanism that the DOE uses for receiving and responding to community input; funding allocations are driven by the P5 prioritizations.

NASA/APD: The Decadal Surveys have historically recommended flagship observatories for NASA; the survey prior to *NWNH* recommended the JWST (see Section 4.5), and NASA committed to delivering it. The complexity and enormity of the effort meant that this responsibility continued into the *NWNH* decade, engendering constraints on NASA not fully accounted for at the time of the *NWNH* survey. Because NASA has a formal community-driven process to identify target science areas for future missions, the agency has already begun considering options for missions in the next decade as a means of preparing for the Mid-Decadal review, and the next Decadal Survey.

NSF/AST: The NSF is dedicated to a merit-review system for grants to allow ideas to emerge from the community. The Astronomy and Astrophysics Research Grants (AAG) program allows for rapid progress via small investigator grants; major facilities require longer term planning. Compared to most other NSF divisions, the AST budget is dominated by big facilities, even though the divestment process recommended by the Portfolio Review has begun to reduce the facility share.

4.3 Current Context: Extant Major Programs

Although the focus of our report is on the 2010 Astronomy and Astrophysics Decadal Survey (*NWNH*), the AAAC takes note of several large projects from prior surveys that are either under construction or recently completed and ramping up operations. These projects constitute large and ongoing financial commitments that influence the implementation of *NWNH*.

4.3.1 Ground-based Projects

ALMA: The Atacama Large Millimeter/submillimeter Array (ALMA) was inaugurated in March 2013. Current operations are a mix of early science and commissioning activities, as the capabilities of ALMA continue to be developed. Data from early science and from the first long baseline campaign are currently being analyzed and will be making their way into publications during this coming year. Cycle 3 observing began in fall, 2015, and the Cycle 4 call for proposals will be in March 2016.

LIGO: Advanced LIGO, the ground-based gravitational wave experiment, began installation and initial commissioning in Summer 2015 and started science operations on 12 September. Within just two days, on 14 September 2015, LIGO achieved the first direct detection of gravitational waves, from a merging binary pair of black holes of 29 and 36 solar masses. This remarkable result is a tremendous achievement for US physics, for the culmination of the efforts of the LIGO project over many years, and for the NSF, which provided funding for this project.

DKIST: Construction of the Daniel K. Inouye Solar Telescope (DKIST) is proceeding for a 2019 completion date, currently funded by the NSF MREFC line. The primary mirror was completed in December 2015, and the enclosure components are on site with civil construction nearing completion. The project is on track for scheduled completion in 2019. Anticipated operations form part of the NSF/AST budget planning process.

4.3.2 Space-based and Airborne Projects

JWST: The James Webb Space Telescope will be the most powerful telescope ever launched into space. Its four science instruments will operate in the near- and mid-infrared, where light is better able to penetrate regions of gas and dust and is well-suited to the study of highly redshifted stars and galaxies of the early Universe. On the 4th of February 2016, NASA announced that the full 18-segment primary mirror was completed marking a major milestone for the project. The primary optical system will be integrated with the other telescope components for testing of the observatory at Johnson Space Center in 2016 and 2017. JWST is on track for its planned October 2018 launch date.

SOFIA: The Stratospheric Observatory for Infrared Astronomy (SOFIA) is a 2.5 meter (100 inch) telescope mounted on a Boeing 747 that covers mid and far-infrared wavelengths, which are otherwise only accessible from space. This spectral region covers the peak wavelengths at which interstellar dust emits the most important spectral lines for cooling of the interstellar medium. The observatory is funded jointly by NASA and the German Aerospace Center. SOFIA is in 5 year prime operations, and the 2nd generation of the High-resolution Airborne Wideband Camera instrument will begin commissioning in spring 2016. The senior review for SOFIA will be in 2018.

4.4 The NSF/AST Portfolio Review: Implementation of Recommendations

In its efforts to follow the recommendations of *NWNH,* NSF has had to consider and prioritize budget obligations tied to the support of existing facilities. To do so, NSF/AST initiated a portfolio review process that outlined a plan for divestment from past projects to enable NSF to meet the scientific priorities of *NWNH*.

The AAAC recognizes the importance of a diverse investment plan by the NSF Division of Astronomical Sciences (NSF/AST), including not only the development of new capabilities for astronomy, but also the support of the existing facilities and research grants needed to pursue the priorities of *NWNH*. Constrained budgets, increasing AAG proposal pressure, the cost of operating existing facilities, and a growing number of obligations for starting the operation of new facilities in the near future makes it difficult for the NSF to maintain a balanced portfolio or to move forward with new investments. The *NWNH* decadal survey anticipated this challenge and recommended (*NWNH*, p. 32, 173) that the NSF/AST convene a Portfolio Review Committee (PRC) in 2011-2012 to advise on how best to realize the needed balance in the portfolio. The PRC reported to NSF in August of 2012. The committee's recommendations were formulated projecting that the funding level for the AST division (through 2022) corresponded to 65% and 50% of the more optimistic projections used in *NWNH*. The 2012 Portfolio Review Committee (PRC) produced several recommendations in order to accomplish the goals of the *NWNH* Decadal Survey. These included the possible divestment of several optical and radio facilities, assuming continued commitment to the funding of individual guest investigator grants, REUs, and the implementation of a Mid-Scale Innovations Program (MSIP), viewed as critical to both the development of the next generation of innovators and to the realization of the scientific goals of *NWNH*.

The AAAC finds that the NSF/AST division continues to make progress in responding to the PRC recommendations, including realizing divestment or partnering of some facilities while limiting the negative impact on the scientific community. NSF/AST has been making significant efforts to reduce the cost of operating existing facilities, minimize the cost of decommissioning facilities (through engineering studies), and minimize the loss of science opportunities by avoiding the permanent removal of key observational capabilities available to US researchers (i.e., by transferring the operation of a facility to someone else in the US system, e.g., the KPNO 2.1m telescope being transferred to a consortium).

NSF/AST faces significant challenges in implementing the PRC report recommendations. The Congress has asked to be kept fully apprised of the progress and any facility closures that are contemplated. To fully achieve the goals of the PRC, it is important to minimize policy constraints that would impede cost effective reallocation of resources. In particular, the requirement to maintain operations at both new and existing observatories as additional facilities come online in future years, will be extremely difficult to achieve.

The NSF/AST portfolio has been difficult to balance as recommended by *NWNH* given the difficulties in implementing swiftly the Portfolio Review divestments and the upcoming operations cost of new facilities. Taken together, the AAAC is concerned that the growing funding requirements already threatens the highest priority projects of *NWNH*, including the midscale funding opportunities, and individual research grants that are so critical to realizing the goals of *NWNH*.

Below we summarize the status on divestment and implementation of the PRC recommendations. The NSF/AST (with the help of a contractor) is currently concluding engineering studies and baseline environmental surveys for a number of telescopes and observatories, work that is required to inform any decision regarding divestment. NSF's goal is to understand the feasibility of alternatives including: (1) new partnership agreements, (2) conversion to a new mission, including scope reductions (3), mothballing of facilities or (4) decommissioning.

Status of Specific Facilities Impacted by PRC Recommendations:

NOAO/KPNO 2.1m telescope: As the result of a call for proposals, NSF selected a Caltech-led consortium that deployed a robotically operated autonomous laser adaptive optics (AO) system (Robo-AO) in November 2015. Robo-AO has taken over operations for FY 2016-2018. NSF has started a study of the feasibility of future options following the Robo-AO project.

WIYN telescope: The 40% NSF/NOAO open community time on WIYN will be replaced by a newly formed NASA-NSF partnership that will provide the exoplanet community with telescope access, including a new Extreme Precision Doppler Spectrometer supported by NASA. An NSF/NASA MOU is in place. The funding for the operations of the facility in support of this partnership continues to come from NSF. As a result, while this scientific partnership enables important *NWNH* supported science, it does not result in a reduction in the NSF's cost of operating facilities and does not contribute to the effort to realize a reduction in the cost of operating existing facilities. The new initiative contributes to the *NWNH* priority of high-precision radial velocity surveys of nearby stars in order to validate and characterize exoplanet candidates.

NOAO/KPNO Mayall 4m telescope: Planning continues for the installation of the Dark Energy Spectroscopic Instrument (DESI) on the Mayall 4m telescope in 2018. When installed, the instrument and wide-field of view Mayall 4m telescope will conduct a survey, with telescope operations and survey being funded by DOE. Some open community access in bright time or for some of the fibers is under discussion. The data from the survey will be made public. The program will address P5 and *NWNH* highly ranked science programs.

Green Bank Telescope: Future options for the Green Bank Telescope are currently under feasibility study and various partners have begun partial funding of operations.

SOAR: the Southern Astrophysical Research Telescope (SOAR) agreement expires in 2018 and the NSF will reassess at that time its participation in SOAR in view of its possible role in the LSST era.

VLBA: Future options for the Very Long Baseline Array (VLBA) are currently under feasibility study and various partners have begun partial funding of continuing operations. The VLBA project will be separated from NRAO in FY15.

McMath-Pierce Solar telescope (Kitt Peak) and Dunn Solar Telescope (Sacremento Peak): Operating partners are still being sought, and future options for both are currently under feasibility study.

GONG/SOLIS: The Synoptic Optical Long-term Investigations of the Sun (SOLIS) was moved off KPNO, and the Global Oscillation Network Group (GONG) is under refurbishment. An MOU with the National Oceanic and Atmospheric Administration (NOAA) is currently in draft form, and NOAA is partly funding space weather operations with GONG.

Arecibo: Future options for the Arecibo Observatory in Puerto Rico are currently under feasibility study. Responses were received on January 15, 2016 to a Dear Colleague letter seeking viable concepts for future operations. NSF evaluation of these responses is underway. The NSF Division of Atmospheric and Geospace Sciences (in the Directorate for Geosciences), which partners with NSF/AST and the NASA Planetary Sciences Division in funding Arecibo, expects to receive the report of their own portfolio review before summer 2016.

University Radio Observatories: NSF designated funding for these facilities was eliminated, but the opportunity to compete for continued funding was allowed through MSIP. The Combined Array for Research in Millimeter Astronomy (CARMA) was recently decommissioned and the site returned to its original state.

Our committee notes that divestments come with cost to the user community, especially those scientists working at institutions without their own telescope access. Telescopes proposed for divestment are still producing excellent science as outlined in the *NWNH* survey and many offer unique scientific capabilities. To mitigate these losses, NSF has actively explored partnerships, interagency cooperation and private resources so that the US community can maintain some access to these facilities and the capabilities they provide. Of particular note, the new partnership between NSF, NASA and universities have enabled a new program at the WIYN telescope of *NWNH* supported science.

Partnership of NSF/AST and DOE Cosmic Frontier (CF) on the DESI project has made it possible to repurpose the Mayall telescope to serve as a dedicated spectroscopic survey instrument for dark energy science prioritized by *NWNH*.

***FINDING:* The NSF Division of Astronomical Sciences has done a commendable job of finding creative solutions to respond to the recommendations made by the Portfolio Review Committee (PRC) while limiting permanent shut down of a number of facilities. These actions serve to reduce the amount the NSF/AST is spending on the operating budgets of legacy facilities and thus move closer to the desired balance in the portfolio recommended by the PRC.**

***FINDING:* Divestments recommended by the Portfolio Review are proceeding, but at a slower pace than anticipated due to the complexities of decommissioning and the ongoing searches for operating partners.**

***FINDING:* The loss of open access facilities results in a cost to the US user communities, in terms of loss of open nights and access to a variety of instruments.**

***RECOMMENDATION:* Strong efforts by NSF for facility divestment should continue as fast as is practical. Efforts to explore partnerships, interagency cooperation and private resources to maintain some access to facilities for the US community that may mitigate the loss of open access should continue. Transferring the cost of operating a facility outside of the NSF/AST budget is preferable to complete loss of a capability from the suite of capabilities used by US researchers.**

4.5 Implementation of NWNH Recommendations

Budget realities have been significantly harsher than anticipated in *NWNH*, and have fallen well below even the most conservative budget scenarios considered there. For NSF, the actual AST FY 2016 budget is over $100M, or nearly 40%, lower than assumed by *NWNH*. For P5 planning, the budget realities are between the lowest and middle scenarios.

Within this context, the AAAC finds that NASA, NSF and DOE are all making good efforts to address most of the underlying scientific priorities even though they are not able to fully fund some of the recommended projects. They have accomplished this by discontinuing lower-priority programs, by identifying areas where international collaboration might help to achieve the same goals (e.g., participation in the ESA led LISA pathfinder mission and the L2 Advanced Telescope for High Energy Astrophysics (ATHENA) X-ray satellite) by mid-scale programs that might be able to support initial studies or technology development for future large projects, or where a combination of mid-scale support and international participation may allow the US to continue to play a leadership role (e.g., DESI, Event Horizon Telescope, etc.).

Specifically, the agencies have made progress in addressing the *NWNH* priorities for the highest priority large projects as described in sections 4.5.1 and 4.5.2, below. Other details may also be found in the

NSF's March 2015 Dear Colleague Letter[ii] and the December 2014 NASA Astrophysics Implementation Plan[iii] Update.

4.5.1 Space-based Projects

WFIRST: The Wide-Field Infrared Survey Telescope (WFIRST) was the highest priority large space mission in the *NWNH* report. WFIRST is a NASA observatory designed to perform wide-field imaging and spectroscopic surveys of the near infrared (NIR) sky. The current Astrophysics Focused Telescope Assets (AFTA) design makes use of an existing 2.4m telescope designed for space. WFIRST will settle essential questions in exoplanet, dark energy, and galaxy evolution research. The final WFIRST Science Definition Team report was released in March 2015[iv]. The project has just entered the formulation stage (Phase A), in February 2016.

The Explorer Program: The Explorer Program provides frequent flight opportunities for innovative, streamlined space investigations within the astrophysics and heliophysics science areas. The FY15 budget request supports a growing Astrophysics Explorer program, with continued development of current missions such as the missions of opportunity (MOO) Neutron star Interior Composition ExploreR (NICER) currently planned for launch in early 2017 and the larger Transiting Exoplanet Survey Satellite (TESS) with a launch currently planned for August 2017. A recent Small Explores (SMEX) announcement of opportunity call led to concept studied of five candidate SMEX and MOOs. A Medium-class Explorer (MIDEX) Mission of Opportunity call is planned for 2016.

LISA: The Laser Interferometer Space Antenna is a space-based gravitational wave observatory ranked as a high priority for a strategic mission in *NWNH*. Budget constraints have slowed the pace of technology investment on the US side. A technology mission, LISA Pathfinder, led by ESA with NASA partnership was successfully launched on December 3, 2015 and began science operations in February 2016. NASA plans to partner with ESA on its L3 gravitational wave observatory mission, with a tentative launch date of 2034. The strength of the US gravitational wave community has grown considerably in recent years, driven by their leadership in LIGO resulting in the recent discovery of gravitational waves as the collaboration ramps up to full operations of advanced LIGO. Interagency cooperation and creativity are vital in parlaying the leading role of the US in the ground-based work into substantive participation in a space-based gravitational wave observatory.

IXO: The International X-ray Observatory (IXO) is a next-generation X-ray observatory also ranked as a high priority in *NWNH*. The constrained NASA budget limited planning for an international IXO observatory. In 2014, ESA selected a re-scoped X-ray mission, called Advanced Telescope for High Energy Astrophysics (ATHENA), with launch planned in 2028. NASA is working with ESA to define a possible NASA contribution.

4.5.2 Ground-based Projects

LSST: The Large Synoptic Survey Telescope is the highest priority *NWNH* ground-based project and was also highly ranked by the P5 report for the DOE/HEP Cosmic Frontier. LSST has now moved into the construction phase. The DOE and NSF have a joint oversight group, and regularly meet with OSTP and

OMB. The NSF has approved LSST construction under Major Research Equipment and Facilities Construction (MREFC) funding, and formal authorization was made on August 1, 2014. The monolithic primary mirror with integrated tertiary was completed with early private funds. DOE has approved funding for the LSST camera fabrication; the SLAC camera team successfully passed review of their full fabrication start (CD-3, critical decision 3, review) in August 2015.

NSF Mid-Scale Innovations Program (MSIP): The AAAC appreciates the efforts made by NSF/AST to advance the new MSIP program. This program replaces the Telescope Systems Instrumentation Program (TSIP), University Radio Observatories (URO), and other mid-scale programs. The first MSIP solicitation in FY2013 was for FY2014-2015 funds. Three full awards were made (the Zwicky Transient Facility, Advanced Atacama Cosmology Telescope Polarimeter, ACTPol, and the Event Horizon Telescope), as well as one development award for 2014 (Hydrogen Epoch of Reionization Array, HERA). In 2015, additional awards were given for the Simons/POLARBEAR array and NANOGrav (co-funding a Physics Frontiers Center). The deadline for full proposals to the most recent MSIP solicitation has just passed (February 2016).

GSMT: Due to budget restrictions, NSF has not been able to enter into a direct partnership with a Giant Segmented Mirror Telescope (GSMT), as recommended by *NWNH*. Two international consortia led by US institutions moving toward construction of the Giant Magellan Telescope (GMT) in Chile and the Thirty Meter Telescope (TMT) in Hawaii.

CTA: U.S and international scientists are partnering on a concept for a single large ground-based gamma-ray observatory, the Cherenkov Telescope Array (CTA). *NWNH* ranked a major partnership on CTA 4th for large ground-based projects priorities. P5 recommended investment in CTA "as part of the small projects portfolio if the critical NSF Astronomy funding can be obtained."[v] Due to budget constraints, the DOE and NSF have issued a joint statement about the difficulty in funding the CTA project at the level recommended in *NWNH*. US participation in CTA will have a significant impact in the science and continued US leadership in this important field even at lower funding levels as possibly available through competed NSF/AST MSIP and NSF/PHY Midscale programs.

4.6 The Mid-Decadal Review

In November 2014 the three agencies formally requested a mid-decadal review to evaluate progress on the *NWNH* goals, without re-prioritizing objectives. This review, in concert with the Decadal surveys, will also satisfy the NASA Authorization Act of 2005, which requires an assessment of the Science Division's progress every five years.

The Mid-Decadal Review Committee consists of fourteen scientists, and is chaired by Jacqueline Hewitt. Four meetings took place during the period October 2015 through February 2016, and the report will be published in May 2016.

4.6.1 The Mid-Decadal Review Charge

The mid-decadal statement of task is as follows.

The National Research Council shall convene an ad hoc committee to review the responses of NASA's Astrophysics program, NSF's Astronomy program, and DOE's Cosmic Frontiers program (hereafter the Agencies' programs) to previous NRC advice, primarily the 2010 NRC decadal survey, *New Worlds, New Horizons in Astronomy and Astrophysics* (*NWNH*). In the context of funding circumstances that are substantially below those assumed in *NWNH*, the committee's review will include the following tasks:

1. Describe the most significant scientific discoveries, technical advances, and relevant programmatic changes in astronomy and astrophysics over the years since the publication of the decadal survey;

2. Assess how well the Agencies' programs address the strategies, goals, and priorities outlined in the 2010 decadal survey and other relevant NRC reports;

3. Assess the progress toward realizing these strategies, goals, and priorities; and

4. In the context of strategic advice provided for the Agencies' programs by Federal Advisory Committees, and in the context of mid-decade contingencies described in the decadal survey, recommend any actions that could be taken to maximize the science return of the Agencies' programs.

The review should not revisit or alter the scientific priorities or mission recommendations provided in the decadal survey and related NRC reports but may provide guidance on implementation of the recommended science and activities portfolio and on other potential activities in preparation for the next decadal survey.

4.7 Coordination with P5 recommendations

DOE's Office of High-Energy physics (HEP) organizes its scientific program into several broad categories, one of which is the Cosmic Frontier. DOE HEP receives programmatic advice from two FACA committees, the AAAC and the High Energy Physics Advisory Panel (HEPAP). All three frontiers are under the purview of HEPAP, but only the CF projects are prioritized in *NWNH* and are assessed by the AAAC. In implementing the Cosmic Frontier program, DOE is guided by the *NWNH* decadal survey priorities, but takes its primary advice on project prioritization from the Particle Physics Project Prioritization Panel (P5) subpanel of HEPAP.

The P5 report groups Cosmic Frontier opportunities into two main areas: identifying the nature and new physics behind dark matter (DM), and understanding cosmic acceleration (both the dark energy responsible for the accelerating expansion of the Universe and inflation that drove the dramatic expansion in the first fraction of a second following the big bang). For dark energy (DE), a priority is to measure the expansion history of the Universe at relatively recent times through measurements of the formation history of large-scale structure and measurements of cosmic distances through standard candles like supernovae explosions. These measurements are accomplished through wide-field imaging surveys and spectroscopic surveys. Improved understanding of inflation will be accomplished through large-scale structure measurements of primordial perturbations and through measurements of CMB polarization. DOE works closely with NSF and NASA to identify for DOE support the portion of collaborative projects that makes optimal use of DOE's expertise and infrastructure.

DOE has started Cosmic Visions (CV) groups to provide a conduit between the agency and the HEP community on planning and status of the DOE/CF science program, the CMB CV, DE CV, and DM CV groups.

Motivated by the importance of the effort to understand dark energy, P5 gave the LSST top priority in CF. For dark matter, the report recommended proceeding to a generation-2 (G2) suite of experiments and emphasized the complementarity of direct detection (the G2 program) and indirect detection (through CTA, and accelerator searches). P5 recommended that the DOE invest in CTA if the critical NSF Astronomy funding can be obtained, as the 4th ground-based priority in *NWNH*. P5 recommended support for the DESI project, a wide-field spectroscopic instrument and survey, in all but the lowest future budget scenarios. The P5 report emphasized the importance of a DOE role in future experiments aimed at measuring detailed properties of the cosmic microwave background (CMB), advocating that work toward the next generation ground-based CMB experiment should become part of the planning portfolio.

Below we summarize the status of P5 recommendations in Astronomy and Astrophysics and involvement in other interagency projects with a substantial DOE/CF component.

LSST: The highest priority ground-based project in *NWNH* is also the highest priority for the CF in P5. LSST has moved into the construction phase and is discussed in 4.5.2. HEP is responsible for the 3 billion pixel camera, contributions to the operations phase and is supporting a Dark Energy Science Collaboration to deliver coordinated, precision science results.

DES: The Dark Energy Survey (DES) is an international project jointly funded by DOE, NSF, universities, and international agencies to conduct a large imaging survey to probe dark energy and the origin of cosmic acceleration. The DOE is responsible for the Dark Energy Camera (DECam), a 3-square-degree, 570-megapixel CCD camera, which is mounted on the Blanco 4-meter telescope at Cerro Tololo Inter-American Observatory (CTIO) operated by NOAO (NSF). The survey data on 300 million galaxies, millions of stars, and tens of thousands of transients addresses a broad range of astrophysics in addition to dark energy and provides scientific guidance to strategic development issues for the larger LSST project. DES released its first science results this past year and has completed its third observing season**.**

DESI: The Dark Energy Spectroscopic Instrument (DESI) is a new spectrograph to be installed in 2018 onto the Mayall 4-m telescope at KPNO operated by NOAO (NSF). In 2014, P5 encouraged support for DESI as part of a broad-based dark energy program. DESI will provide a three-dimensional map of distant galaxies and quasars obtained through spectroscopy that is complementary to the LSST imaging survey. DESI is an international project led by DOE/HEP, with contributions from NSF, universities, private foundations, and international agencies. DOE and NSF signed a MOA in 2014 to agree on a ramp up of DOE support, and a ramp down of NSF support for the Mayall telescope operations between FY16-FY18. In FY19 and beyond, DOE plans to fully support the Mayall telescope operations for the dark energy. Congressional appropriations for FY15 included DESI as line items for an Major Item of Equipment (MIE), allowing them to start fabrication of long-lead components this year. DOE/HEP approved the project baseline (CD-2) in September 2015. The DOE CD-3 full fabrication review will take place in May 2016.

Dark Matter: *NWNH* identified understanding the nature of dark matter as a science frontier question for advancing knowledge, underscoring the need for both direct detection and indirect detection. P5 agreed, stressing direct detection of dark matter in the Cosmic Frontier. Three G2 (generation 2) direct detection dark matter experiments were selected in June 2014, supported by DOE Cosmic Frontier and NSF/PHY Particle Astrophysics, as well as international and private contributions. Two experiments, Super Cryogenic Dark Matter Search (CDMS) and LUX-Zeplin (LZ) search for weakly interacting massive particles (WIMPs), and the Axion Dark Matter eXperiment (ADMX) is sensitive to axions. Congressional appropriations for FY15 included LZ and SuperCDMS as line items for an MIE, allowing them to start fabrication of long-lead components this year. ADMX, as a smaller project below the MIE threshold, is also moving forward.

Cosmic Microwave Background: Participation in CMB science through the development of a coherent ground-based Stage-4 CMB project (CMB-S4) in the next decade has been endorsed by P5. All three agencies have a long history in supporting CMB research. DOE's expertise with large-scale fabrication of science-grade detectors, with massive data sets, and with large, effective, and productive collaborations of scientists works well with the expertise and infrastructure of NSF and NASA. *NWNH* supported the development of CMB research and interagency coordination will be important for a successful (CMB-S4) implementation plan.

4.8 Summary Assessment of Agency Response to Decadal Surveys

The long-term assessment of agency response to *NWNH* will be given by the mid-decadal survey and future decadal surveys. In this report the AAAC identifies the current steps that have been made toward the priorities set forth in *NWNH*, and sets this progress in the context of the changing budget environment in the six years since the *NWNH* publication. The 2010 decadal survey was predicated on budgets forecast of 2009. In the case of the NSF, these forecasts were significantly overoptimistic, with a 40% overestimate of the current AST budget. The agencies have done an excellent job of trying to achieve the priorities of the decadal reviews in the face of constrained budget realities.

The AAAC commends the NSF for moving LSST, the top ground-based priority in *NWNH,* into the construction phase in August 2014. There is a productive and effective partnership between the DOE, which is funding the camera on LSST, and NSF in the construction and operations of this telescope. NSF has also initiated the MSIP program, another high priority of *NWNH*. While NSF/AST is strongly supporting the MSIP program, and has discontinued some existing programs to fund it, the program budget is limited and is highly oversubscribed. *NWNH* planned for $40M/yr funding for MSIP, to allow for the realization of two or three projects at medium scale. However, at the currently available $18M/yr for MSIP, it is not clear that the purpose for which the MSIP program had been envisioned by *NWNH* can be achieved. Moreover, it would not have been possible to support even this reduced MSIP program if AST were funding some other *NWNH* recommendations (such as the Cerro Chajnantor Atacama Telescope CCAT, the only medium-scale ground-based recommendation, and an increase in the base program) at this time.

NASA has moved WFIRST into the formulation phase (new start) in February, 2016. This mission has changed somewhat in concept since the writing of *NWNH*, with the acquisition of the AFTA telescopes and the addition of a coronagraph. It is encouraging that NASA has been able to adapt to the availability of the AFTA telescopes, proceed with mission concept development, and assemble the formulation science teams to enable the start of formulation for this highest ranked large space project in *NWNH* by mid-decade. Cost containment should be closely monitored for this top priority mission in order to maintain balance in the NASA program.

Astronomy and astrophysics is an increasingly international endeavor, with project budgets reaching a level such that duplication of effort is not possible; international cooperation can be the key element that allows US agencies to achieve more of the science goals of the community. In cases where the US cannot take a leading role due to budget constraints, participation in international projects can provide a mechanism for furnishing continuity of scientific communities in the US and for maintaining key infrastructure needed to keep the US competitive in the coming decades. Together with private partnerships, these international partnerships with the US agencies should adhere to the *Principles for Access to Large Federally Funded Astrophysics Projects and Facilities*[1] in order to ensure that the US scientific community is best served.

<u>FINDING</u>: The agencies are working together to ensure that the highest priorities of NWNH, WFIRST and LSST, are moving forward. WFIRST has recently successfully moved into the formulation phase under the guidance of NASA, and LSST is well into the construction phase, with the camera under construction under DOE support and facility construction in the MREFC line at NSF led by AST.

<u>FINDING</u>: The NSF MSIP program is funded at a level well below that envisioned in NWNH, but is becoming the only mechanism available for funding the high priority activities advocated in NWNH. NSF/AST is funding MSIP at the highest level commensurate with program balance. The program is supporting a larger number of projects with a lower budget and not able to support the higher cost projects as envisioned by NWNH.

<u>FINDING</u>: Budgetary constraints have not allowed progress on recommendations for a US partnership in an optical/infrared Giant Segmented Mirror Telescope (GSMT).

<u>FINDING</u>: Budgetary constraints have not allowed progress on a major new X-ray telescope (IXO). NASA is working towards US participation in the ESA ATHENA project providing future resources for the US astronomy and astrophysics.

<u>FINDING</u>: The international CTA consortium is moving forward to build the CTA observatory. US participation at a more modest level than envisioned by NWNH would still enable US access and leadership roles. US funding for CTA may be attainable through competed mid-scale funding such as the MSIP program in NSF/AST and mid-scale program of NSF/PHY.

<u>FINDING</u>: Gravitational wave astrophysics is now a reality. This exciting new field, at the frontier of physics and astrophysics, will benefit greatly from cooperation among agencies as it continues to develop and generate new science areas in its wake.

<u>RECOMMENDATION</u>: the AAAC encourages NASA to continue working toward a plan to develop a space-based gravitational wave observatory as envisioned by NWNH, through participation in the ESA L3 gravitational wave effort.

<u>RECOMMENDATION</u>: The agencies should continue to pursue international partnerships in order to further accomplish the goals of NWNH. The AAAC's "Principles for Access to Large Federally Funded Astrophysics Projects and Facilities" should guide the process.

5) Budget Summary and Impact

The overall discretionary spending level in FY17 was set in the bipartisan budget agreement in October of last year. That agreement raised the statutory budget caps in both FY16 and 17 and enabled a favorable treatment of astronomy and astrophysics programs in NSF, NASA, and DOE in the final omnibus appropriations bill (PL 114-113).

The President's budget request this year proposes to add to this top line discretionary spending limit by enacting a broad range of mandatory spending measures, primarily aimed at increasing Federal investment in university grants (DOE), and research and development in FY17. Astronomy and astrophysics funding lines are included in this overall budget strategy.

Despite the generally favorable treatment of these programs in the budget request, it is clear that strong political and jurisdictional opposition to the concept of mandatory spending on research will affect the outcome. Agency representatives have stressed that the choice in funding mechanism does not relate to the relative importance of the affected programs, and that full programmatic spending authority is needed, whether through direct appropriations or some other mechanism.

The AAAC learned of the final outcome of the FY16 appropriations process and the FY17 budget proposal at the time of the FY17 request on February 9. The following tables summarize the programs of interest. FY17 columns consist of discretionary spending, mandatory spending, and total spending. Each program includes selected subprogram areas discussed by the AAAC.

NASA

Program	FY15	FY16	FY17 Disc	FY17 Man	FY17 Tot
NASA Astrophysics[vi]	$730.7	$731.0	$671.5	$85.0	$756.5
WFIRST [vii]	$50.0	$90.0	$14.0	$76.0	$90.0
SOFIA	$70.0	$85.2	$83.8	$0	$83.8
HST	$98.6	$98.3	$97.3	$0	$97.3
Physics Cosmos	$104.1	TBD	$88.1	$6.0	$94.1[viii]
Research [ix]	$201.7	TBD	$223.1	$3.0	$226.1
JWST	$645.4	$620.0	$569.4	$0	$569.4
Total	$1375.4	$1351.0	$1240.9	$85.0	$1325.9

For the purposes of the AAAC, the budget for NASA Astrophysics and JWST are considered together. Together, the request is $1240.9 million in discretionary funding, and $1325.9 million in total program funding including proposed mandatory spending. For discretionary spending, this represents an 8% reduction below FY16 levels. Including the proposed mandatory spending, this represents a 1.9% decrease.

It is important to note that the projected funding level for FY17 included in the FY16 request was $1296 million. Thus proposed program level including mandatory spending would exceed this, the difference being the additional amount added in FY17 for WFIRST.

A key issue discussed by the AAAC has been the need for the Astrophysics Division to utilize the declining budget requirements for JWST and invest those funds in new mission concepts such as WFIRST. This transition will continue to be on track with the FY17 request, but would be substantially better if the full request of $756.5 million was achieved.

Another key issue brought to the attention of AAAC was the apparent "pinch point" in the WFIRST funding curve that would have occurred in FY17 without an addition to the notional amount projected in the FY16 budget. The FY17 request appears to address this concern if the full $90 million materializes. This would maintain an option for a WFIRST launch date in the mid-2020s time frame and reduce the overall mission cost. Scientifically, this would allow the great opportunity of an overlap of WFIRST with JWST operations, which will launch in 2018, and keep pace with EUCLID, now projected to launch in 2020.

NSF

Program	FY15	FY16	FY17 Disc	FY17 Man	FY17 Tot
R&RA AST	$245.2	$246.7	$247.7	$14.9	$262.6
Research	$67.7	$63.3	$58.3	$14.9	$73.2
Education	$5.5	$6.5	$6.0	$0	$6.0
Facilities	$148.5	$148.2	$155.2	$0	$155.2
MSIP	$13.0	$19.3	$18.0	$0	$18.0
Res. Resour.	$10.7	$10.5	$10.3	$0	$10.3
MREFC	$144.8	$200.3	$193.1	$0	$193.1
DKIST	$25.1	$20.0	$20.0	$0	$20.0
LSST	$79.6	$99.7	$67.1	$0	$67.1

The NSF Astronomical Sciences budget would increase by 6.4%, in line with other divisions within the Directorate for Mathematical and Physical Sciences. However, nearly $15 million of this is proposed as mandatory spending in the Research line. This is intended to support core activities, with special emphasis on investigators in the early parts of their careers.

The AAAC welcomes the overall emphasis on astronomy within the NSF budget and the special attention paid to the grants program. However, the uncertainty associated with the enactment of mandatory funding would place the grants program in jeopardy.

The AAAC has expressed strong concern over the declining success rate for grant proposals. The reduction of nearly 8% in grants funding (the primary element of the Research line of the above budget) that would occur if the funding identified for mandatory spending does not materialize would have deleterious effects on the community.

It should be noted that the research grants to facilities ratio increases from .45 to .47 from FY15 to 17 if the full amount for research grants is provided, reflecting the progress to date on the overall Portfolio Review implementation.

Astronomy related construction programs remain on track with proposed funding consistent with their respective program plans.

The AAAC also heard from the NSF Division of Physics (PHY). While this report will not cover the budget in detail, this is emerging as another valuable avenue for interagency collaboration in astronomy and astrophysics. Specifically, PHY funds the operations of Advanced LIGO, which has made the most ground-breaking astrophysical discovery of the year, as well as the ICECUBE neutrino observatory, and research programs in particle astrophysics and gravitational physics.

DOE

Program	FY15	FY16	FY17 Disc	FY17 Man	FY17 Tot
Science	$5068.7	$5350.2	$5572.1	$100	$5672.1
High Energy Phys	$766.0	$795.0	$817.9	TBD	TBD
Cosmic Frontier	$106.9	$130.6	$130.1	TBD	TBD
LSST	$35.0	$40.8	$45.0	$0	$45.0
DESI	$3.9	$10.3	$10.0	$0	$10.0
LZ	$3.1	$10.5	$10.5	$0	$10.5
SuperCDMS-SNOlab	$2.3	$2.5	$4.0	$0	$4.0

Overall funding for the Office of Science would increase by 4-6% in the FY17 request with $100 million proposed as mandatory funding for University Grants. Modest increases in High Energy Physics would appear to maintain a funding profile well above “Scenario B” of the P5 report, and allowing the new initiatives such as the DESI, LUX-ZEPLIN, and SuperCDMS-SNOlab to be maintained as part of the HEP portfolio.

***FINDING*: Spending for astronomy and astrophysics research continues to lag the optimistic scenarios included in NWNH. Lack of a consistent funding stream puts some of the agency programs at risk and does not support the long term planning needed to execute the decadal survey plan.**

***RECOMMENDATION*: We urge that the full programmatic funding required by the three agencies to execute their FY 2017 plans, as described in their budget requests, be provided.**

6) Competed Grants falling success rates

6.1 Overview

Over the last decade, budget pressures and a rise in the number of astronomy and astrophysics proposals submitted to DOE, NASA, and NSF have led to a steep decline in the fraction of proposals being funded, and to a dramatically larger workload on proposers, reviewers, and the agencies.

NWNH stressed the importance of achieving balance between funding construction and operations of new world-leading observatories and maintaining a healthy core program of PI-led research. However, over the last decade proposal success rates in Astronomy and Astrophysics at NSF and NASA have dropped significantly.

As discussed in the attached report*, Competed Grant Success Rates in US Astronomy and Astrophysics*, the decline in success rates is not the result of a decline in proposal merit, changing demographics or an increase in the average funding request per proposal (beyond inflation). Rather this is a consequence of flat or declining budgets for individual investigator grants, more investigators, and a larger proportion of multiple submissions and resubmission of proposals. The increase in the number of proposals puts a burden both on the agencies and on the community in preparing the proposals and then refereeing them.

The nation's investment in missions and state-of-the-art facilities is predicated on the belief that these facilities will enable scientists to produce world-leading science with them. This assumption is incorrect if support for the investigators decreases too significantly. Worse, severe pressure on the grants program could dissuade new researchers pursuing original and potentially transformative ideas. In the absence of budget increases the only options open to the agencies are process changes.

6.2 Declining success rates for proposals

The portfolio of competed grants for the US astronomy and astrophysics community is complex, agency dependent, and principally supported by NASA/ADP and NSF/AST. A productive increase in interdisciplinary interagency collaboration, notably with NSF/PHY and DOE/HEP, has helped to strengthen some areas of the program recommended by *NWNH*. However, NASA and DOE are largely mission or project oriented agencies, so NSF plays a special role in support of core science. Unfortunately, NSF's research budget devoted to individual investigator grants has not grown significantly and thus its funding rate has dropped. We expect even further tensions as facilities such as DKIST and LSST take an increasing share of the NSF AST budget.

NWNH states: “A successful federal research program must also be balanced. There is a trade-off between investing in the development and construction of ambitious new telescopes and supporting broad-ranging observational and theoretical research that optimizes the return from operating facilities.” (*NWNH,* p. 15)

Due to the slower-than-anticipated divestment of resources at NSF, and pressures at NASA and DOE, it is challenging to support the balanced program envisioned by *NWNH* in flat funding scenarios. With a fixed budget, the number of individual investigator awards is limited by existing or proposed commitments to space-based missions, ground-based facilities operations, ongoing projects, and new instrumentation.

From 2004 to 2014, the success rates in the NSF/AST AAG program declined from 30% to 17%; NASA/APD R&A declined from 30% to about 20%. Similar trends are observed in NASA Planetary (40% to 20%), NASA Heliophysics (35% to 15%), and NSF/PHY Particle Astrophysics (45% to 39%). DOE, as a mission-oriented agency, with investigators expected to participate throughout a project lifetime, from design through construction to analysis, cannot easily be compared in the same way.

If the number of meritorious proposals were remaining constant and the increase were due to a larger proportion of poor proposals, this would impact the agency and reviewer workload but not otherwise negatively impact the field. Unfortunately, the evidence suggests that an increasing fraction of highly meritorious proposals are not being funded. It is difficult to assess this trend across agencies, because reviewers' ideas of what constitutes an excellent proposal vary from panel to panel. However, NASA Astrophysics has tracked scores for many years and has reasonable confidence in the stability of the scale. Using NASA proposal selection data from all Science Mission Directorate ROSES programs from 2007 to 2012, we see that while the proportion of proposals rated "Very Good" to "Excellent" has remained roughly constant, success rates for "Very Good" proposals are rapidly falling. The data clearly indicate that the number of proposals submitted to NASA and NSF for individual investigator and midscale grants in Astronomy and Astrophysics, Planetary sciences and Heliophysics is increasing faster than available funding, causing a corresponding drop in success rate.

In addition to the lack of funding for meritorious proposals, the increase in proposal numbers increases the workload on the scientists preparing the proposals and the associated administrative staff. It increases the workload on the community in serving on more review panels each with more proposals to review. It also increases significantly the stress on the agencies, whose staffing levels have remained relatively flat in recent years despite the increase in proposal load.

Within a constrained budget, portfolio balance is one of the few adjustments that can be made to increase the fraction of individual research grants that are funded.

6.3 Summary of findings and recommendations

Due to the increased number of proposals being submitted, flat funding of the core program correlates with a significant decline in proposal success rates. The PIs submitting proposals remain a relatively stable demographic in terms of race, gender, number of years since PhD, and type of institution. The rise in proposals is driven largely by an increase in the number of investigators and an increase in multiple and resubmitted proposals.

Our goal should be to sustain the US astronomical research program with a competitive funding environment while maintaining the highest quality and productivity commensurate with US leadership in Astronomy and Astrophysics. However, while the quality of submitted proposals remains high, an increasing fraction of meritorious proposals can no longer be funded.

NWNH states: *"Realizing these and an array of other scientific opportunities is contingent on maintaining and strengthening the foundations of the research enterprise ... including technology development, theory, computation, and data management, and laboratory experiments, as well as, and in particular, human resources."* (*NWNH,* p. 2-3).

The impact of flat or declining funding has a direct, negative impact on the health of the field as many meritorious science projects go unfunded. This costs our field an immense amount of scientifically productive time and pushes investigators away from grant-supported research. Funding rates fall far short of US aspirations for leadership with a vibrant program that attracts the brightest young researchers into the field.

***FINDING*: Over the last decade proposal success rates in Astronomy and Astrophysics have dropped significantly. This is not principally the result of a decline in proposal merit, changing demographics, or an increase in the average funding request per proposal (beyond inflation). Rather this is a consequence of flat or declining budgets for individual investigator grants, more investigators, and a larger proportion of multiple and resubmitted proposals. In the absence of facility divestment by NSF/AST over the coming years, proposal success rate is expected to decline even further.**

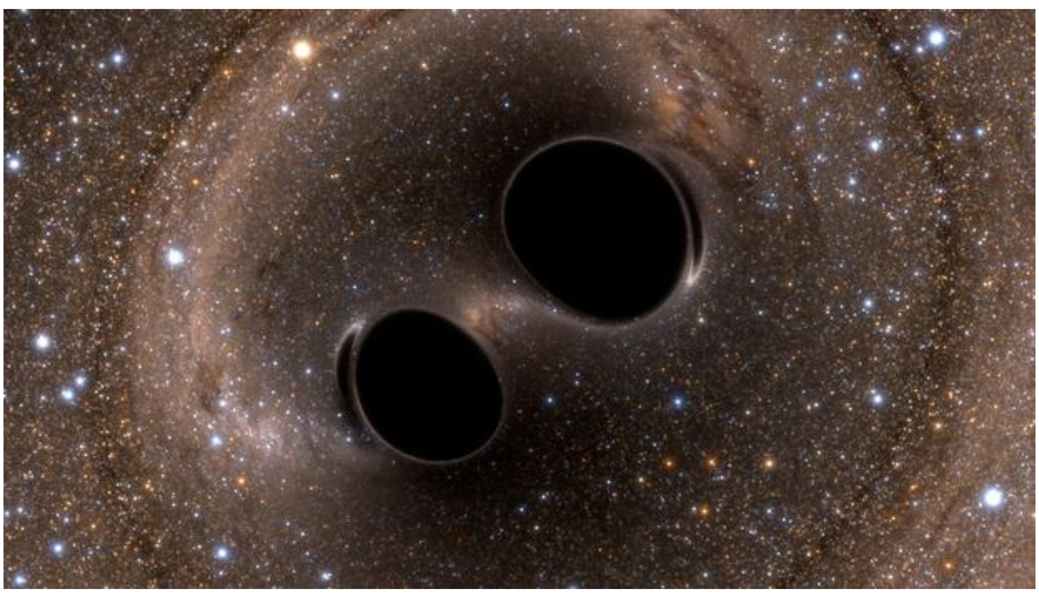
***FINDING*: A very low proposal success rate impacts both researchers and the agencies. Researchers spend more time resubmitting meritorious but unfunded proposals and serving on review panels. Some researchers may elect to leave the field or decide not to pursue original and potentially transformative research. Agencies must manage the increased workload, staffing problems, and increased costs associated with reviewing more proposals.**

***RECOMMENDATION*: Community based groups, such as the AAS and the APS, should study the recent and projected growth of the leading US astronomy and astrophysics research community for the next decadal survey planning exercise of the end of this decade.**

Appendix A: Recent Advances in Astronomy & Astrophysics

A1. First direct detection of gravitational waves:

In September 2015, the Advanced LIGO collaboration unambiguously detected gravitational waves from the merger of two massive black holes into a single yet-more massive black hole. This represents the first direct detection of gravitational waves, verifying predictions from the theory of General Relativity from a century ago. For this event, the black hole masses were estimated at 29 and 36 times the mass of our sun, while the final black hole mass was 62 solar masses; hence about 3 solar masses of energy were radiated as gravitational waves in just 0.2 seconds. The LIGO collaboration detected this event in both of their operational detectors, and the event was sufficiently above their noise threshold that it is visible by eye in the data as a "chirp" that increases rapidly in both frequency and amplitude. The observed signal includes part of the inspiral (when the black holes were orbiting at ~½ the speed of light), and possibly the merger event, and the ring-down. The measurement corresponds to identifying changes in lengths of ~4 km long bars in their interferometer at scales corresponding to ~1/10000 times the size of a proton.



Simulated image of the two massive black holes very shortly before they merge. Image credit: The SXS (Simulating eXtreme Spacetimes) Project.

Aside from representing a long-awaited verification of a prediction of General Relativity and the culmination of decades of work by the LIGO team, the system they detected is astrophysically very interesting, as black hole masses in this range are higher than expected, with implications for our understanding of stars and stellar remnants. The result has been hailed as the beginning of a new field of gravitational-wave astronomy, which promises to teach us much about black holes, neutron stars, and other astrophysical objects.

Following its launch in December 2015, the two cubes housed in the core of the LISA Pathfinder satellite were released into true free fall in February 2016, so that their motion is determined almost entirely by the curvature of space-time. Measurements in the coming year with unprecedented sensitivity at low frequencies will verify new technologies of sensing and control that will be needed to observe gravitational waves from space.

A2. Dark Energy Camera (DECam) finds missing satellites

The Dark Energy Camera (DECam) at the CTIO discovered new dwarf galaxies. For many years, astronomers puzzled over the number of satellite galaxies of the Milky Way, which seemed too low compared to theoretical expectations. In 2015, seventeen new Milky Way satellites -- dwarf galaxies that are gravitationally bound to our Galaxy -- were identified in data from the Dark Energy Survey (DES). Further studies of these galaxies using additional instruments will help uncover the formation processes of the smallest and most dark matter-dominated observable galaxies.

DECam is also being used to study the nearby Fornax Cluster, a gravitationally-bound cluster of galaxies 62 light years from us. The use of DECam imaging in 2015 enabled the discovery of a substantial number of dwarf galaxies in the Fornax cluster.

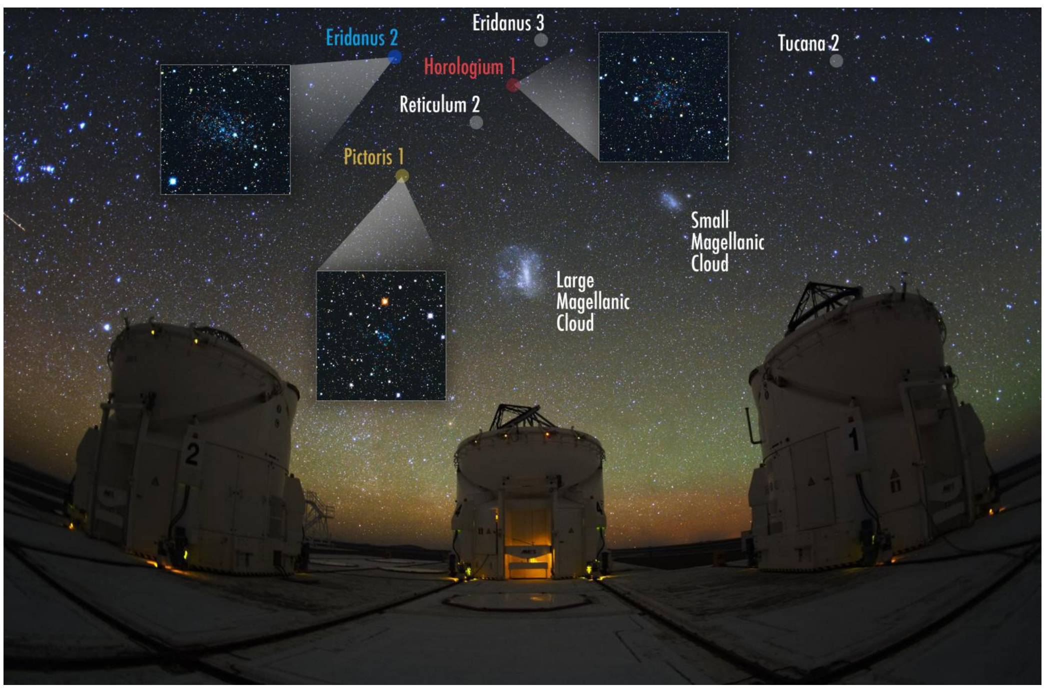
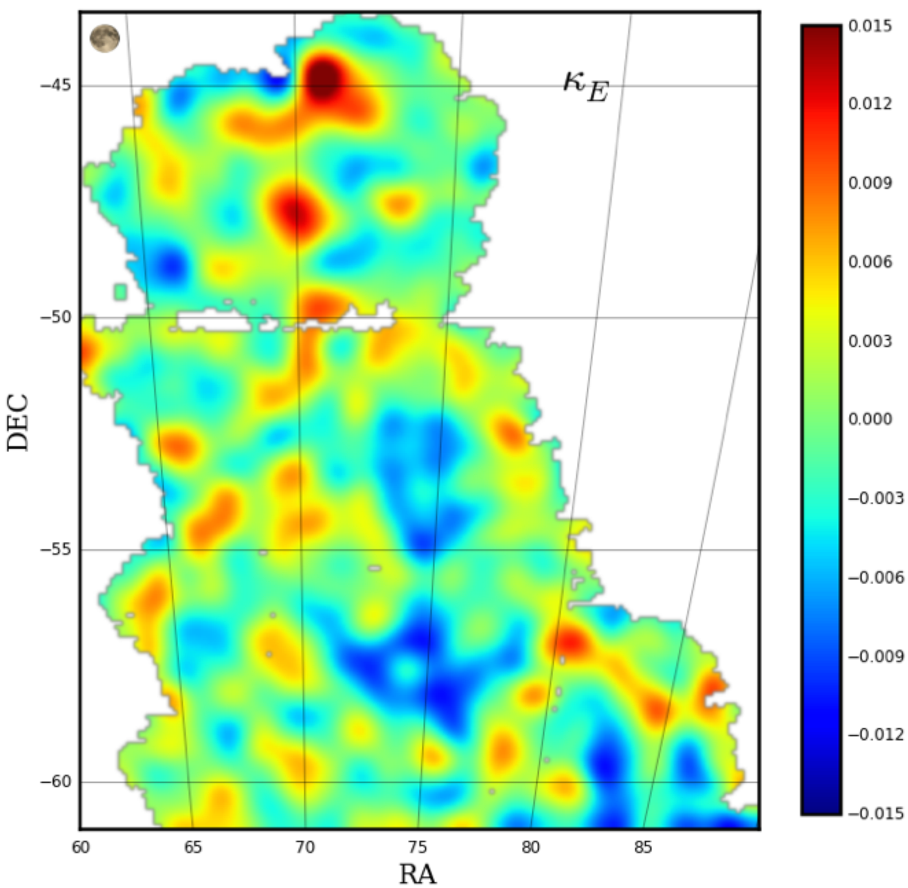


Illustration of the locations of six of the new Milky Way dwarf satellites on the sky, with reference to the positions of already known satellites (Large and Small Magellanic clouds). Image credit: V. Belokurov, S. Koposov (IoA, Cambridge). Photo: Y. Beletsky (Carnegie Observatories).

A3. First science from the Dark Energy Survey

The Dark Energy Survey (DES) released its first cosmology results in 2015. Among them were the largest-ever weak lensing mass map, which reveals structure in both regular and dark matter in the past several billion years. Gravitational lensing, the deflection of light by mass, allows for the use of background galaxy shapes to reconstruct the matter distribution in the more nearby structures that the light must pass by on the way to us. The growth of matter fluctuations due to gravity reveals the influence of dark energy, which causes accelerated expansion of the Universe and a slowing of the growth of cosmic structure.

In addition to these mass maps, the survey had a first release of cosmology results from their science verification data. These included a range of studies that used weak lensing and the clustering of galaxies, as well as the correlation with the Cosmic Microwave Background (CMB).

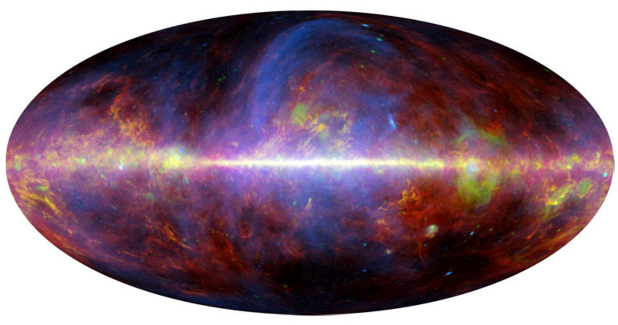


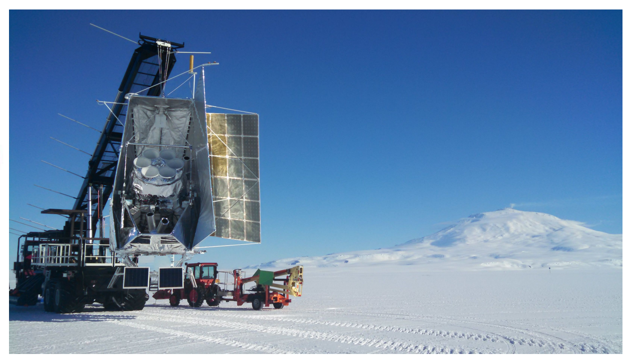
This map indicates the distribution of dark matter across a large sky area, from the Dark Energy Survey. The color scale shows the projected mass density, with red indicating overdense and blue indicating underdense regions. Image credit: Dark Energy Survey.

A4. Planck 2015 results, and the Spider mission

The Planck Surveyor mapped the sky across more than a decade of wavelengths, from the radio to the sub-mm, with intensity and polarization data from its successful four-year mission; their 2015 science papers use data from the entire mission. The composite image summarizes the information visually. In combination with high-resolution cosmic microwave background (CMB) data from the Atacama Cosmology Telescope (ACT) and the South Pole Telescope (SPT), these new data describe the Universe with a handful of cosmological parameters constrained to unprecedented precision. In fact, cosmological data from the CMB and optical surveys now provide tighter constraints on the sum of the neutrino masses than laboratory measurements. Further, the Planck maps reveal new details about the large-scale polarized emission from the Milky Way, simultaneously improving our understanding of our own galactic environment and paving the way for deeper searches for an inflationary gravitational wave (IGW) signature in the CMB.

The last year also saw NASA's successful flight of the most sensitive microwave receiver yet operated from any platform. Spider, pictured below on its launch pad in Antarctica, is a polarimeter that observed the CMB at large angular scales for 17 days in January 2015 from a long-duration balloon platform.

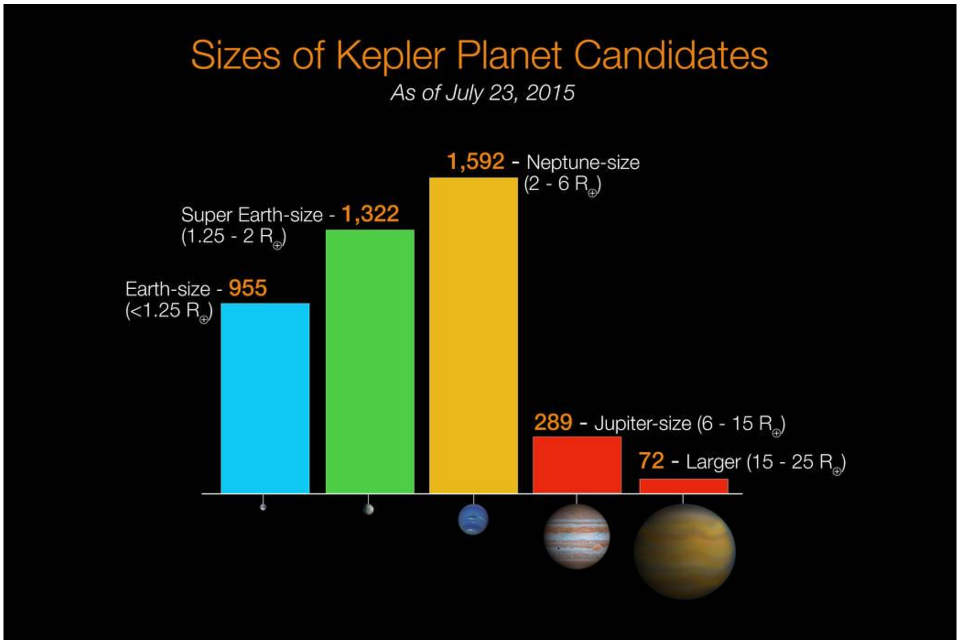




Left: all-sky map of foreground emission from the Milky Way, which is important for removing this contamination from Cosmic Microwave Background observations. (Image credit: ESA and the Planck Collaboration.) Right: The Spider polarimeter on its launch pad. (Image credit: the Spider collaboration)

A5. Thousands of exoplanets, first close-by rocky planets in the Habitable Zone, and first planets around White Dwarfs

Among the more than four thousand planetary candidates and over two thousand confirmed exoplanets to date from the Kepler and K2 space mission, several hundreds are planetary systems and about a dozen are small planets in the Habitable Zone of their stars. These add to the hundreds of exoplanets already detected from the ground by many different telescopes. The planets and their planetary systems show a wide variety of characteristics. Even though small rocky exoplanets (Earth-size or Earth-mass analogs) are still very hard to find, about one dozen detected exoplanets are small enough that they should be rocky like Earth and receive comparable stellar flux to Earth. In addition some of the exoplanets in the Habitable Zone detected by the K2 mission orbit close-by stars, making them very good targets for follow-up observations from the ground as well as NASAs future space mission JWST.

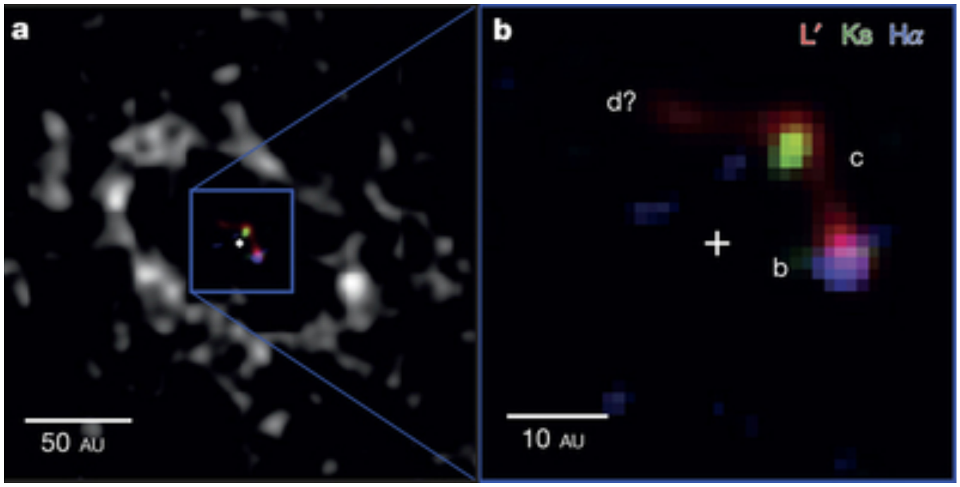


The distribution of Kepler planet candidates by size as of January 2015, showing the increase number of small planets found and the decreasing sensitivity of the instruments resulting in less detected candidates for small planets. credit: NASA Ames/W Stenzel

A6 Observations of early stage of planet formation around single and binary stars

ALMA observed the early stages of planet formation and accreting protoplanets in the LkCa 15 transition disk. Images of the disk around the star SZ91 show the first disk around a star that is less massive than ours - it has only half of the mass of our Sun. These observations simultaneously present a migration of dust particles from the outermost zones and evident signs of interaction between young planets with the disk in the innermost zone.

The disk around the planet-forming disc around HD 142527, a binary star about 450 light-years from Earth in a cluster of young stars known as the Scorpius-Centaurus Association, also shows the early stages of planet formation. The red arc in the artist’s image is free of gas, suggesting the carbon monoxide has “frozen out,” forming a layer of frost on the dust grains in that region. Astronomers speculate this frost provides a boost to planet formation. The two dots in the centre represent the two stars in the system.



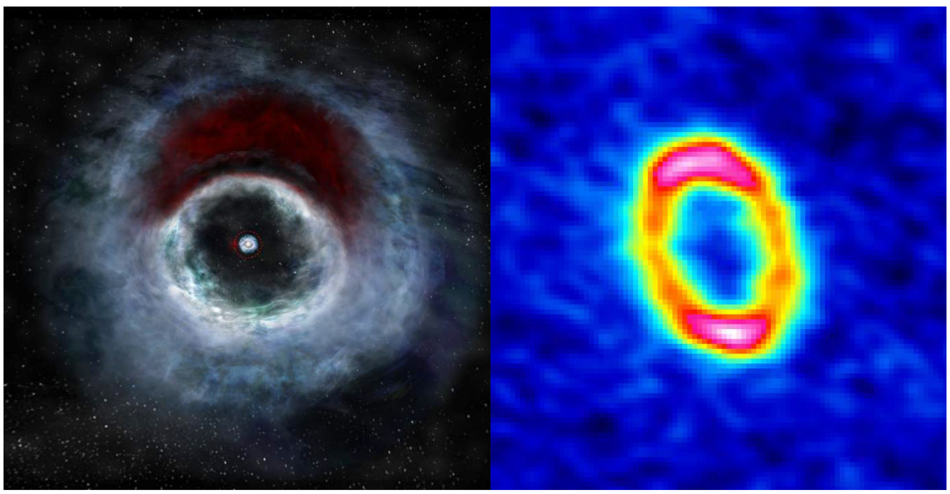


Fig. (top) Accreting protoplanets in the LkCa 15 transition disk, credit nature, bottom (left) Artist impression - Protoplanetary disk around HD 142527 binary star system. Image credit: B. Saxton (NRAO/AUI/NSF), (right) Image of the dust ring that surrounds the young star Sz 91.

Appendix B: Explanation of Acronyms

AAAC	Astronomy and Astrophysics Advisory Committee
AAG	Astronomy and Astrophysics Grant
AANM	The 2000 NRC report "Astronomy and Astrophysics for the New Millennium"
AAS	American Astronomical Society
ACTA (or CTA)	Atmospheric Čerenkov Telescope Array
ACTPol	Atacama Cosmology Telescope Polarimeter
ADAP	Astrophysical Data Analysis Program
ADMX	Axion Dark Matter eXperiment
AFTA	Astrophysics Focused Telescope Assets
ALMA	Atacama Large Millimeter/submillimeter Array
AO	Adaptive Optics
APRA	Astrophysics Research and Analysis
APS	American Physical Society
ATHENA	Advanced Telescope for High Energy Astrophysics
ATP	Astrophysics Theory Program
ATST	Advanced Technology Solar Telescope
CAA	The National Research Council's Committee on Astronomy and Astrophysics
CAPP	AAS Committee on Astronomy and Public Policy
CARMA	Combined Array for Research in Millimeter-wave Astronomy
CCAT	Cerro Chajnantor Atacama Telescope
CCD	Charged Coupled Device
CD	Critical Design review
CDMS	Cryogenic Dark Matter Search
CF	Cosmic Frontier

CMB	Cosmic Microwave Background Radiation
CTA (or ACTA)	Atmospheric Čerenkov Telescope Array
CTIO	Cerro Tololo InterAmerican Observatory
CV	Cosmic Visions, science theme groups in DOE/CF
DE	Dark Energy
DECam	Dark Energy Camera
DES	Dark Energy Survey
DESI	Dark Energy Spectroscopic Instrument
DKIST	Daniel K. Inouye Solar Telescope
DM	Dark Matter
DOE	Department of Energy
DOE/CF	Department of Energy High Energy Physics Cosmic Frontier
DPF	Division of Particles and Fields (of the American Physical Society)
ESA	European Space Agency
FACA	Federal Advisory Committee Act
FDR	Final Design Review
FOC	Full Operational Capability
FGST	Fermi Gamma-ray Space Telescope
FY	Fiscal Year
GONG	Global Oscillation Network Group
GSMT	Giant Segmented Mirror Telescope
HEP	High Energy Physics
HEPAP	High Energy Physics Advisory Panel
HERA	Hydrogen Epoch of Reionization Array
IceCube	IceCube Neutrino Observatory

ISIM	Integrated Science Instrument Module
ISS-CREAM	International Space Station Cosmic Ray Energetics and Mass
IXO	International X-ray Observatory
JAXA	Japan Aerospace Exploration Agency
JWST	James Webb Space Telescope
KPNO	Kitt Peak National Observatory
LSB	Long Duration Balloon
LIGO	Laser Interferometer Gravitational-Wave Observatory
LISA	Laser Interferometer Space Antenna
LSST	Large Synoptic Survey Telescope
LZ	LUX-ZEPLIN
LUX	Large Underground Xenon detector
MIDEX	Medium-class Explorer
MIE	Major Item of Equipment
MOO	Missions Of Opportunity
MOU	Memorandum of Understanding
MPS	Mathematical & Physical Sciences, NSF Directorate for
MREFC	Major Research Equipment and Facilities
MSIP	Mid-Scale Innovation Program
NASA	National Aeronautics and Space Administration
NASA/APD	National Aeronautics and Space Administration Astrophysics Division
NEO	Near-Earth Object
NICER	Neutron star Interior Composition ExploreR
NOAA	National Oceanic and Atmospheric Administration
NOAO	National Optical Astronomy Observatory

NSB	National Science Board
NRC	National Research Council
NSF	National Science Foundation
NSF/AST	National Science Foundation Astronomy Division
NSF/PHY	National Science Foundation Physics Division
NWNH	The 2010 NRC decadal survey report *New Worlds, New Horizons in Astronomy and Astrophysics*
OHEP	Office of High Energy Physics, DOE
OMB	Office of Management and Budget
OSTP	Office of Science and Technology Policy
P5	Particle Physics Project Prioritization Panel
PASAG	Particle Astrophysics Scientific Assessment Group
PRC	National Science Foundation Portfolio Review Committee
R&D	Research and Development
SDSS	Sloan Digital Sky Survey
SMD	Science Mission Directorate
SMEX	Small Explorer
SNOlab	Sudbury Neutrino Observatory Laboratory
SOAR	Southern Astrophysical Research Telescope
SOLIS	Synoptic Optical Long-term Investigations of the Sun
SOFIA	Stratospheric Observatory for Infrared Astronomy
SPT	South Pole Telescope
STEM	Science Technology Education Mathematics
SuperCDMS	Super Cryogenic Dark Matter Search
SXS	Soft X-ray Spectrometer
TESS	Transiting Exoplanet Survey Satellite

TSIP	Telescope Systems Instrumentation Program
URO	University Radio Observatory
VERITAS	Very Energetic Radiation Imaging Telescope Array System
VLBA	Very Long Baseline Array
WFIRST	Wide-Field Infrared Survey Telescope
WIYN	Wisconsin-Indiana-Yale-NOAO Telescope
WPS	WFIRST Preparatory Science
XRP	Exoplanet Research Program
ZEPLIN	ZonEd Proportional scintillation in LIquid Noble gases

[i] National Research Council. New Worlds, New Horizons in Astronomy and Astrophysics. Washington, DC: The National Academies Press, 2010. doi:10.17226/12951.

[ii] http://www.nsf.gov/pubs/2015/nsf15044/nsf15044.pdf

[iii] http://science.nasa.gov/astrophysics/documents/

[iv] http://wfirst.gsfc.nasa.gov/science/sdt_public/WFIRST-AFTA_SDT_Report_150310_Final.pdf

[v] http://science.energy.gov/~/media/hep/hepap/pdf/May-2014/FINAL_P5_Report_053014.pdf

[vi] In this table, STEM education is not included. STEM is not included in congressionally appropriated amounts, but is included in Administration requests. For clarity it is subtracted from the request level.

[vii] Astrophysics Decadal Strategic Missions

[viii] Following the Senior Review, specific budgets for operating missions will be determined and the FY17 number will be adjusted accordingly.

[ix] The Astrophysics Research budget request number includes (a) the Senior Review funding is bookkept here, (b) the SMD STEM education budget. Both of these are bookkept in this line but do not reflect the budget available for the astrophysics portfolio.

Competed Grant Success Rates in US Astronomy and Astrophysics

Astronomy and Astrophysics Advisory Committee

March 15, 2016

Executive Summary:

The 2010 Astronomy and Astrophysics decadal survey, New Worlds New Horizons (*NWNH*), stressed the importance of achieving balance between funding construction and operations of observatories and maintaining a healthy core program of competed grant research. This report summarizes the strains on the core program over the last decade.

Over the last decade a number of world-leading observatories began operations or construction. The science these projects will address continues to attract a vibrant new generation of investigators whose work is critical to ensure the best scientific return from these investments and continued US leadership in astronomy and astrophysics. However, over the same period that these major projects are coming into operation, the funds available for community-wide openly competed grants have remained largely flat in both NSF/AST and NASA/APD.

Flat funding of the core program correlates with a significant decline in proposal success rates. From 2004 to 2014, the success rates in the NSF/AST AAG program declined from 30% to 17% and NASA/APD R&A proposal success declined from 30% to about 20%. Similar trends are observed in NASA Planetary (40% to 20%), NASA Heliophysics (35% to 15%), and NSF/PHY PA (45% to 39%). During the same period no significant changes occurred in the distribution of proposal merit, and in proposer demographics (seniority, gender, and institutional affiliation).

Flat funding of the core program combined with the success of the field in attracting a modest (estimated to be about 2% to 2.5% per year) influx of new investigators partly explains the decline in success rates. The decline in success rates gets exacerbated by an increase in the number of proposals submitted by the same PI on a given year and by a shorter cadence of resubmissions.

NSF and NASA should continue to work toward balance of their portfolio. In the case of NSF/AST a vigorous implementation of the divestments recommended by the Portfolio Review Committee (PRC) can increase funding for the base program, help alleviate the proposal pressure crisis, and better realize the scientific potential of the leading facilities and missions.

Given the current crisis, community based groups such as the American Astronomical Society (AAS) and the American Physical Society (APS) should study the recent and projected growth of the leading US astronomy and astrophysics research community to inform the decadal planning exercise of possible strategies for the next decade.

1. Introduction

The 2010 Astronomy and Astrophysics decadal survey, New Worlds New Horizons (*NWNH*), stressed the importance of achieving balance between funding facilities and space missions and keeping a healthy core program of PI-led research. In page 132-133, *NWNH* states[1]:

“A significant challenge for the astrophysics program is how to maintain support for individual investigators pursuing a broad range of activities in a landscape where specific, large programs provide a fluctuating level of funding for associated analysis and theory. Realizing the scientific potential of existing facilities is of primary importance, but so is placing the broad range of results in appropriate context, providing young scientists with opportunities to develop their potential, and enabling the creative thinking that lays the foundations for the future.

As in most fields, the primary mechanisms for supporting research and training are competed grants programs. NASA funds both general mission-enabling grants programs and those supporting the specific science from operating satellites, such as the guest observer programs associated with Hubble, Chandra, Spitzer, and Fermi. NSF supports a general astronomy and astrophysics grants program as well as more specialized programs such as the CAREER awards and the Astronomy and Astrophysics Postdoctoral Fellow program. DOE supports centrally administered grants programs, those administered through specific DOE laboratories, and awards for young investigators.

In recent times, funding for these essential programs has flattened or even declined at NASA and NSF, especially when considered relative to the growth of the field.”

Unfortunately flat funding for basic sciences and the downward trend in the funding of the competed grants program has continued after the publication of *NWNH* in 2010 with a corresponding decrease in proposal success rates. The dynamics of such a decrease are nuanced, as the portfolio of competed grants for the US astronomy and astrophysics community is complex and agency dependent. The principal support for *NWNH* science comes from NASA Astrophysics Division (NASA/APD) and National Science Foundation Astronomical Sciences Division (NSF/AST). A productive increase in interdisciplinary interagency collaboration, notably with NSF Physics Division (PHY) and Department of Energy (DOE) High Energy Physics (HEP) Division, has helped to strengthen some areas of the program recommended by *NWNH*. NASA Planetary and Heliophysics Divisions also have strong traditional ties to the *NWNH* community in some areas of overlapping interest. The focus of this document is on the principal support of NSF/AST and NASA/APD from 2004 to 2014. Related efforts in NSF/PHY, NASA Planetary and Heliophysics are briefly discussed.

2. NSF Division of Astronomical Sciences (NSF/AST)

The Individual Investigator Program at NSF/AST includes a number of programs that individual investigators can compete for. The largest and broadest is the Astronomy and Astrophysics Research Grants (AAG) with an allocation of \$43.7M in FY14, which was about 18% of the total division budget of \$238.4M. Other competed programs and their FY14 budget include Astronomy and Astrophysics Postdoctoral Fellowships (AAPF) at \$2.05M, Advanced Technologies and Instrumentation (ATI) \$7.5M, Faculty Early Career Development Program (CAREER) at \$4.76M, Enhancing Access to the Radio Spectrum (EARS) at \$6.85M, Major Research Instrumentation Program (MRI) \$7.23M, and other smaller programs.

Given its size, impact, and breadth, the success rate in the AAG program is the most appropriate tracer of the health of competed grants at NSF/AST. Figure 1[2] shows the funding of AAG from FY90 to FY14 and the proposal success rate during the same period. Over the FY04 to FY14 decade, AAG funding increased from \$30.7M for FY04 to \$43.7M for FY14 (which corresponds to \$34.9M in 2004 dollars). Setting aside the American Recovery and Reinvestment Act of 2009, the growth of AAG peaked in FY10 to \$49.4M (\$42.7M in 2004 dollars) and has decreased from FY10 to FY14; over the same period the proposal success rate declined below historical minima.

From ~ 50% in the early 1990s to ~30% in the early 2000s, the success rate in AAG decreased significantly over the last decade reaching a value as low as ~15% in FY12 and just slightly higher at ~17% in FY14. In the absence of increased overall funding for NSF/AST and/or vigorous implementation of facility divestment as recommended by the Portfolio Review Committee, the increase in demand will drive the AAG success rate to decrease from ~15% in FY15 to below ~10% in FY19 (assuming the continuation of a 2% rise in total AAG dollar demand per year and the projected NSF/AST budget and portfolio without facility divestments out to FY19). Operations of the Large Synoptic Survey Telescope (LSST), the first priority for NSF in *NWNH*, will strain the budgets further in the next decade.

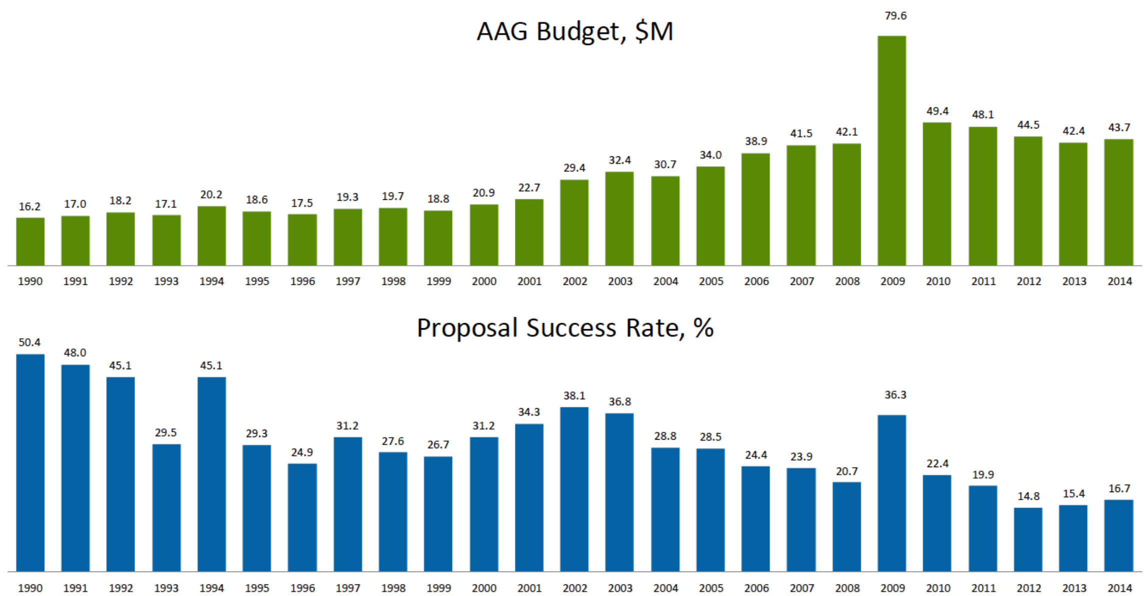


Figure 1: NSF/AST AAG Budgets and Proposal Success Rates from 1990 to 2014. The anomalous spike in FY09 is due to the one-time stimulus provided by the American Recovery and Reinvestment Act.

The low success rate is driven by a combination of flat funding and growth of number of submitted proposals. The number of submitted proposals roughly doubled from 379 in 2004 to 731 in 2014. The four fields that AAG proposals are reviewed in, Extragalactic Astronomy and Cosmology (EXC), Galactic Astronomy (GAL), Stellar Astronomy and Astrophysics (SAA), and Planetary Astronomy (PLA) all increased significantly (see figure 2). (Note that SAA and PLA assignments were restructured in 2013-14 by a move of extrasolar planet studies to PLA.)

Many aspects of the AAG statistics remained unchanged during the 2004 to 2014 period. The distribution of funding requests among budget categories (e.g., indirect costs, publications, computing, subcontracts, participant support, travel, equipment, fringe, personnel) remained nearly constant over the decade. Between FY08 and FY15, the fraction of AAG proposals that requested less than 3 months of salary per year also remained approximately flat (around 80% to 85%). The funding rate for women remained approximately equal to submission rate between FY04 and FY14 and the overall percentage of female PIs experienced a modest growth from below 20% in 2004 to about 25% in 2013. The distribution by type of institutions of proposing PIs also remained steady with 80% to 85% being PhD granting institutions.

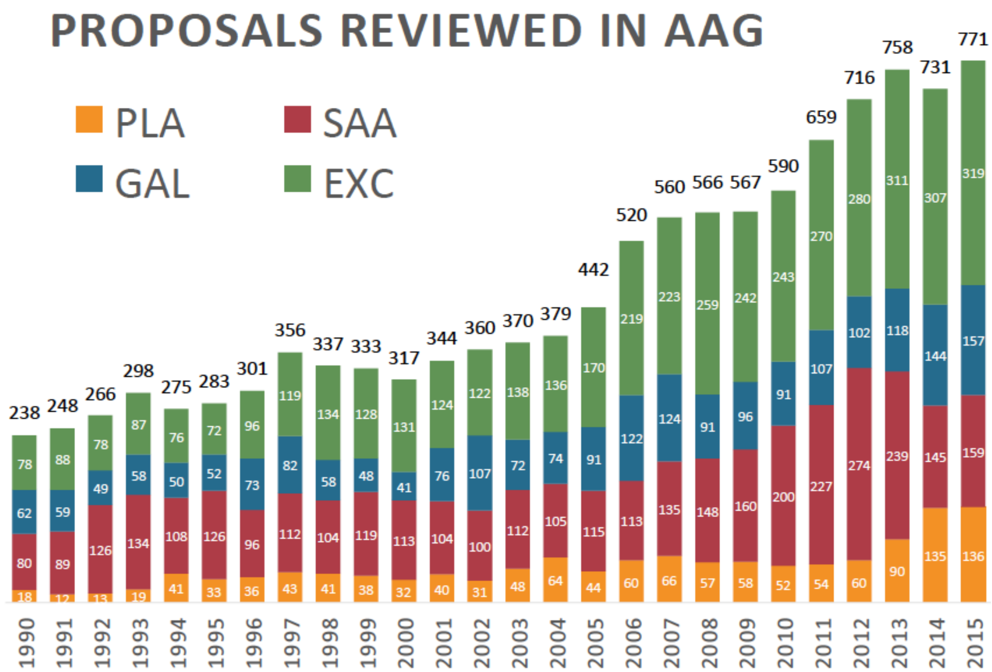


Figure 2: NSF/AST AAG Proposals divided by review sub-fields (EXC, GAL, SAA, PLA) from 1990 to 2015.

NSF/AST data indicate that proposal budgets are not growing out of line with inflation. The median proposal request for the AAG program has increased from \$93k/year to \$150k/year over the last 25-year period, which corresponds to a 12% reduction in constant 2015 dollars. Reducing the size of grant budgets exacerbates the proposal pressure, since a larger number of grants are required to support a viable research team, or the full salary of a key (non-academic) researcher.

The percentage of AAG proposals by PIs with 0 to 4 and 5 to 9 years after their PhD remained an approximately steady fraction of the overall distribution between 2006 and 2015 while the fraction of PIs with more than 25 years post-PhD increased from 25% to 29% from FY08 to FY15 as shown in Fig. 3. The success rate for first-time proposers has tracked the overall success rate over the years being only slightly lower: in FY14 the overall success rate was 17% while the new proposers success rate was 14.4%.

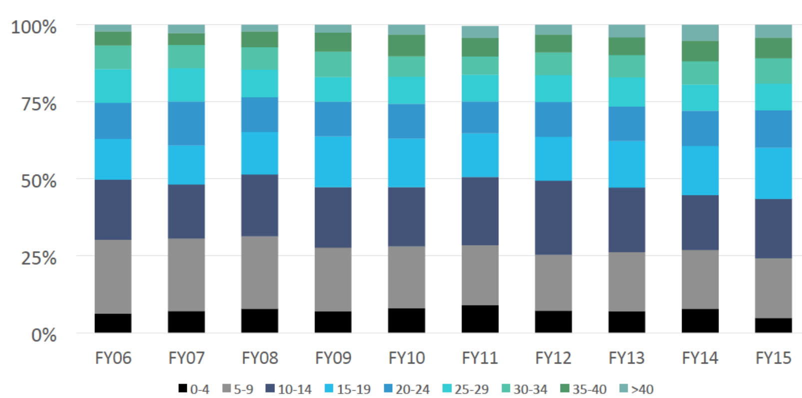


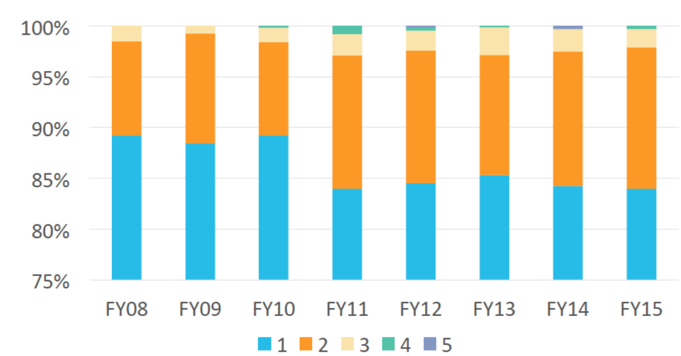
Figure 3: Distribution of submitted AAG proposal PIs versus seniority as measured by years after PhD.

The data show that there are no large trends in demographics or redistribution of proposals by subfield. The growth in submitted AAG proposals is most likely caused by the combination of new proposers joining the research effort, an increase in resubmissions of declined proposals, and an increase in the number of submitted proposals per PI.

The number of unique proposers per 3-year funding cycle has grown from 1025 during the 2008-2010 period to 1160 during 2013-2015, representing an average growth of 2.5% per year. This can be compared to the AAS full membership, which has grown from 3000 to 4500 over the years from 1990 to 2014, representing an average growth of 2.1% per year. Another indicator of new proposers is the growth in Astronomy faculty members of about 2.3% per year from 2006 to 2014, which was compiled by AIP[3].

From 2008 to 2015, the number of AAG proposals grew from 566 to 771 representing a 36% growth or an average ~5% growth per year. The character of this growth is sporadic with large fluctuations. To get a sense of the many factors involved one can assume the growth of the community to be about 2 to 2.5% per year on average, thus there is an additional factor of 2.5 to 3% per year that has affected the growth in number of proposals.

The number of single proposals submitted per PI in AAG has grown by about ~2.8% per year from 2008 to 2015. Multiple proposals submitted by the same PI to AAG on a given year can explain an additional average yearly growth of about ~2% from 2008 to 2015 on the total number of proposal. The contributions from multiple proposals nearly doubled from 56 in 2008 to 106 in 2015 with large fluctuations. In principle, this effect could be effectively controlled if NSF/AST limits the number of proposals submitted by individual PIs to AAG each year. Currently, NSF/AST strongly suggests that researchers voluntarily limit themselves in a “Note about FY16 AAG Proposals**”.**[4] While this limit is one option to lessen the burden on proposers and reviewers, one award may be insufficient to support the personnel and other resources needed for the success of a given project.



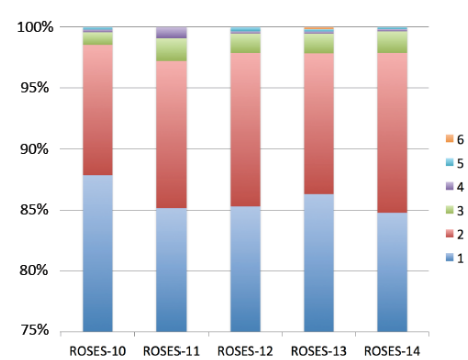


Figure 4: percent of PIs that submit multiple proposals to NSF/AST AAG from FY08 to FY15 (left[5]) and NASA/APD ADAP, APRA, and ATP from 2010 to 2014. Numbers next to each color represent the percent of PIs submitting 1, 2, 3, 4, and 5 proposals per year. (These numbers include only PIs, not Co-Is.)

As the success rate decreases it is likely that the number of resubmissions in subsequent years tends to increase. The typical AAG award is for 3 years, thus when success rates were higher, a larger fraction of investigators were likely to submit funding proposals once every 3 years. Agencies do not keep track of resubmissions following a failed proposal from the year before, but a study that compares the similarity of the text of a given proposal with any proposal submitted in the prior year[6] is consistent with the hypothesis that AAG PIs are resubmitting proposals more often in FY12 to FY14 then in FY08 and FY09.

Summarizing the findings in the case of NSF/AST AAG, a combination of a number of small effects over the decade have conspired to create an extreme ~50% growth in number of proposals during a decade of flat funding. Flat budgets combined with the ~2% annual growth of new researchers, the effect of multiple proposals per PI per year, and a faster cadence of annual resubmissions, produce a ~5% annual increase in the number of proposals. To alleviate this situation an increase in the NSF/AST budget combined with a vigorous implementation of the Portfolio Review recommendations can alleviate the stressed AAG program, avoid even lower success rates, and realize the scientific potential of leading facilities operating and under constructions in this decade. In addition, the impact of proposed changes designed to mitigate this situation should be studied by the upcoming AAS/APS survey.

3. NASA Astrophysics Division (NASA/APD)

Over the last decade, the funding for openly competed Research and Analysis (R&A) at the NASA Astrophysics Division (NASA/APD) through the Research Opportunities in Space and Earth Sciences (ROSES) programs has stayed approximately flat. The R&A program includes the Astrophysics Research and Analysis (APRA) program, Astrophysics Data Analysis Program (ADAP), Astrophysics Theory Program (ATP), Exoplanet Research Program (XRP), Nancy Grace Roman Technology Fellowships (RTF), and others. R&A was funded at $82M in FY05, suffered a 15% cut in FY07, and only reached $82M again in FY12. By FY15 it grew back to $90M (which is still below the inflation corrected value of FY05). In addition, the guest investigator programs associated with operating missions fluctuated from $68.9M in FY05 to $56.2M in FY15 with peak funding in FY07 of $78.4M. On a positive note, the funding available for named fellowships (Hubble, Einstein, and Sagan) grew steadily from $5M in FY05 to $13.6M in FY15.

The number of submitted proposals to the NASA/APD R&A program has increased from around 500 in FY04-05 to past 800 in FY15.[7] With some fluctuations, the number of selected proposals and the funding levels for selected proposals in NASA/APD have remained approximately constant, so the success rate for proposals has decreased from ~30% to ~20% over the decade. Including the NASA Astrophysics Guest Observer programs increases the overall success rate to approximately 25%.

NASA Astrophysics has tracked proposal scores for many years and has reasonable confidence in the stability of the ranking scale. The proportion of all submitted proposals that are rated Very Good to Excellent (VG, VG/E, E) has remained roughly constant, with some evidence for at most a ~10% decrease. Also stable across all programs are the success rates for proposals with VG/E and E ratings at >75% and >90%, respectively. However, the success rate of proposals in the VG category has fallen from 45% in 2007-2008 to 25% in 2012.[8] Thus, while the quality of submitted proposals appears to remain high, a greatly increasing fraction of meritorious proposals can no longer be funded.

While not as comprehensive as the available data from NSF/AST, data of the NASA APD competed grants programs show similar trends to NSF/AST. In 2014 there were 573 proposals from 476 unique PIs applying to NASA Astrophysics R&A programs. In 2008 and 2009, the number of proposals rose from 290 to 393. Thus we know that there were no more than 290 (393) unique PIs in 2008 (2009), compared to 476 in 2014. The pattern of increased number of PIs mirrors the situation for NSF/AST. As shown in figure 4, the number of PIs submitting only one proposal is around 80 to 85% similar to NSF/AST. The number of PIs submitting more than one proposal also increased in NASA's ROSES program from 2010 to 2015.

4. Other Related Programs

Another funding resource for some areas in *NWNH* comes from the NSF Particle Astrophysics (PA) program in the Division of Physics (PHY). NSF PHY/PA is a smaller program that studies astronomy and astrophysics with particles: cosmic rays, high-energy photons, neutrinos, and dark matter particles. Over the past decade, their budget has been a steady percentage of the Physics budget, around 7%. While the program is small compared to NSF/AST its success rate has also decreased. From 2005 to 2014 the number of proposals more than doubled (from 30 to 70), whereas funding increased by about 34% in the same period. The average success rate from 2005 to 2007 was 45%, while from 2012 to 2014 the success rate had decreased to 39%.

The solar and space physics community relies primarily on NASA Heliophysics (125 proposals per year) and the NSF Division of Atmospheric and Geospace Sciences (25 proposals per year in Solar-Terrestrial). Overall, inflation has steadily eroded the buying power of NASA Heliophysics research funding, which has remained essentially constant in real dollars since FY04. The success rate has decreased steadily over the last 8 years, dropping from ~35% to 17%.[9] The same story is generally true for NASA's Planetary Science Division. The Planetary budget for competed grants grew from $110M (2006) to $180M (2014) and the proposal success rate went from above 30% to around 23%.

Over the last decade the NASA Heliophysics program has increasingly emphasized a few larger missions at the expense of smaller missions and the competed research program. The Solar and Space Physics survey gave specific recommendations to rebalance the portfolio in the next decade, with an emphasis on research and analysis. NSF Division of Atmospheric and Geospace Sciences (AGS) is currently conducting its own portfolio review of geospace facilities in order to address this challenge of operating new facilities versus the expense of existing facilities and the competed research programs.

Since the AAAC is concerned with interagency coordination, it would be desirable to assess the extent to which PIs are submitting proposals to multiple agencies. At this time such an analysis is not possible, since the PI names of declined proposals are not public. A future APS/AAS survey may address this point and other limitations of the analysis presented here.

5. The Cost of the Review Process

The most serious consequence of a low proposal success rate is the loss in scientific productivity of the leading research efforts in US astronomy and astrophysics. The smaller fraction of meritorious science projects that are funded by openly competed grants limits the full realization of the scientific potential of existing facilities, and the creative thinking that lays the foundations for the future. At these historically low success rates a large percentage of very good to excellent science is not being supported.

The increased proposal load also poses significant review management challenges to the funding agencies. Although agency staffing has remained relatively flat in recent years, the number of panels and the number of proposals per panel have both increased. The organization and execution of just one panel takes 130+ hours of each NSF Program Officer's time. NSF has developed a number of tools to optimize the internal review processes, but another 30% increase in proposal volume over the next five years would not be manageable. In 2014, NASA/APD handled 832 proposals in its core R&A programs. The estimated yearly cost in NASA staff time and direct expenses for reviewer travel, meeting space, etc. to plan, execute, and document the evaluation and selection process is ~$3M.

In addition, recruitment of reviewers is another challenge. With an increase in submissions, conflict of interest disqualifies a large number of possible reviewers. In addition, reviewers are less likely to accept a task where most highly rated projects cannot be funded. Reviewer acceptance rates have been falling; currently only 20-25% of reviewers agree to serve when asked.

4. Conclusion

The last decade has witnessed the construction and operations of world-leading observatories with the potential to secure the long-term leadership of US astronomy and astrophysics. Over the same period funds available for community-wide openly competed grants have remained largely flat in both NSF/AST and NASA/APD. Balance between funding construction and operations of observatories and maintaining a healthy core program of competed grants is crucial for the future of the field as stressed by *NWNH*.

Flat funding of the core program strongly correlates with a significant decline in proposal success rates. The effect of flat funding of the core program combined with the success of the field in attracting a modest 2% to 2.5% per year rate of new investigators generates a decline in success rates. The impact of an increase in the number of proposals submitted by the same PI on a given year or in subsequent years, natural reactions to a declining success rate, exacerbates the decline.

NSF and NASA should continue to work toward balance of their portfolio including divestment and termination efforts that can increase funding for the base program, alleviate the proposal pressure crisis, and realize the scientific potential of leading new facilities and missions.

Community based groups such as the American Astronomical Society (AAS) and the American Physical Society (APS) should study the recent and projected growth of the leading US astronomy and astrophysics research community to inform the decadal planning exercise of the end of this decade. Such a study should include a measure of the impact of proposed remedies to the falling success rates.

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[1] National Research Council. New Worlds, New Horizons in Astronomy and Astrophysics. Washington, DC: The National Academies Press, 2010. doi:10.17226/12951.

[2] http://www.nsf.gov/attachments/131083/public/Dan-Evans_AST_Individual_Investigator_Programs-AAAC_Meeting.pdf
[3] numbers provided by Rachel Ivie, Director Statistical Research Center at the American Institute of Physics
[4] http://www.nsf.gov/div/index.jsp?org=AST
[5] http://www.nsf.gov/attachments/131083/public/Dan-Evans_AST_Individual_Investigator_Programs-AAAC_Meeting.pdf
[6] http://www.nsf.gov/attachments/131083/public/Dan-Evans_AST_Individual_Investigator_Programs-AAAC_Meeting.pdf
[7]http://science.nasa.gov/media/medialibrary/2015/01/07/AAS_Townhall_Hertz_Jan2015_FINAL.pdf
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[9] http://science.nasa.gov/researchers/sara/division-corner/heliophysics-division-corner/