REPORT of the COMMITTEE OF VISITORS
Division of Astronomical Sciences
National Science Foundation

June 18–20, 2019

COMMITTEE MEMBERS

Thomas Ayres, University of Colorado
Roger Brissenden (Chair), Harvard-Smithsonian Center for Astrophysics
Chris Carilli, NRAO
Debra Fischer, Yale University
Bob Goodrich, GMTO
Catherine Hunt, University of Virginia
Craig Kulesa, University of Arizona
Jennifer Marshall, Texas A&M University
Robert Mathieu, University of Wisconsin-Madison
Vikram Ravi, Caltech
Seth Redfield, Wesleyan University
Lisa Storrie-Lombardi (Vice-chair), Las Cumbres Observatory (formerly JPL)
Donald Terndrup, The Ohio State University
Lucianne Walkowicz, Adler Planetarium

Table of Contents

9 September 2019

1 Executive Summary

The Committee of Visitors (COV) convened at the National Science Foundation (NSF) Headquarters in Alexandria, Virginia, 18–20 June 2019. The committee's charge was to assess:

- the integrity and efficacy of processes in the Grants Program used to solicit proposals, select panelists, carry out proposal reviews, and document outcomes
- oversight and management of the facilities in the portfolio of the Division of Astronomical Sciences (AST)
- program balance between awards and Division research priorities, as well as relationships to NSF-wide objectives
- response to prior COV report(s), and those of other advisory committees
- any additional issues the COV might wish to address.

The backdrop for the review was a remarkable wave of NSF-funded discoveries in recent years, led by three ground breaking results: first direct imaging of the event horizon of a supermassive black hole; a Nobel Prize awarded for the first detection of Gravitational Waves (GW) from the cosmos; and the rise of Multi-Messenger Astrophysics, with the panchromatic follow-up of a GW-detected kilonova.

Other significant results spanned the full range of astrophysics, and speak to the strength of the AST program. A few examples:

- a joint project with the National Aeronautics and Space Administration (NASA) on the WIYN telescope to characterize exoplanet candidates via Doppler-reflex
- radio-wave searches for chemical biomarkers in proto-planetary environments, using the Atacama Large Millimeter Array (ALMA) and the Karl G. Jansky Very Large Array (JVLA)
- aggressive pursuit of Time-Domain Astronomy, in anticipation of the commissioning of the Large Synoptic Survey Telescope (LSST)
- further investigations of mysterious "Fast Radio Bursts," which provoked much interest in the popular press
- experiments to detect HI 21 cm emission from the epoch of reionization early in the Universe;
- exploring the subtle nature of cosmic acceleration and dark energy, probed by the Dark Energy Survey (DES) on National Optical Astronomy Observatory (NOAO) telescopes with Department of Energy (DOE)-contributed giga-pixel cameras
- identifying the first supermassive black holes, including distant quasars and star-forming galaxies, by Gemini and ALMA
- the dawn of the most powerful solar telescope ever built, the Daniel K. Inouye Solar Telescope (DKIST), working toward first light in late 2019

This report discusses the schedule and process followed by the COV (§2); science highlights from the AST portfolio (§3); the grants programs and proposal review process (§4); facilities oversight and management (§5); electromagnetic spectrum management (§6); AST management (§7); and strategic planning and implementation, including the Division's response to the 2010 Decadal Review, the 2012 Portfolio Review, and earlier COVs (§8). This COV's responses to the review Core Questions are listed in Appendix A. A compilation of the COV recommendations can be found in Appendix B. The "Nashville Recommendations," introduced in §4.10 with regard to fostering inclusion and equity, are replicated in Appendix C. A list of common acronyms used in the report is provided in Appendix D.

Here, we provide an overall summary, followed by individual digests of the areas mentioned above.

1.1 Overall Summary

The 2019 COV ***heartily commends*** former AST Director (DD) Dr. James Ulvestad and current DD Dr. Richard Green, former Division Deputy Directors (DDDs) Drs. Patricia Knezek, David Boboltz, and Ed Ajhar, and current DDD Dr. Ralph Gaume, and the entire AST staff, for their excellent management of AST over the four years under review.

As found by previous COVs, the current committee finds that ***increasing Program Officer (PO) staffing within AST remains a priority***. Among the drivers are: extensive regulations associated with mandated facility divestments; major construction projects nearing completion and moving into full operations; proposed new facilities on the horizon; and on-going intense proposal pressure in the Grants Program. ***This COV also emphasizes the value of increasing the diversity among the permanent POs and Division leadership to promote inclusivity and equity.***

In parallel, the COV recognizes the value of the Division Rotators. They represent an opportunity, especially within the Individual Investigator Programs (IIP), for deeper community presence and connectivity, particularly with institutions traditionally considered underserved.

The management of the Astronomy & Astrophysics Research Grants (AAG) program, including panel selection, conducting and documenting reviews, has maintained high standards during the period of review. The open AAG competition exemplifies flexibility and responsiveness to fast-evolving scientific priorities, such as exoplanet research in recent times. The COV identified the review of the Broarder Impacts statement as an area to be addressed by AST, recommending ***as a priority that the Division implement a more rigorous approach to Broader Impacts in all aspects of the review process***.

Management of the special programs, crucial for workforce development, also has been commendable. Unfortunately, success rates of Astronomy & Astrophysics Postdoctoral Fellowships (AAPF) and Faculty Early Career Development (CAREER) grants have been only half those of the AAG overall, and some consideration should be given to diverting additional resources to these vital programs.

The AAG funding showed a steady increase from \$17M (equivalent to \$31M in 2018 dollars) averaged over FY1990–1993, to \$48M over FY2015–2018. This represents an increase of about 2%/yr in inflation-adjusted dollars over the past three decades. While the positive trend is laudible, the

funding has not matched increased demand: proposal success rates have fallen from roughly 45% to 20% over the same period.

Success rates in the overall Grants Program appear to be gender-blind, but the demographics of the proposers themselves do not reflect society as a whole. This COV concludes that further progress toward increased diversity, inclusion, and equity should be a priority. ***We recommend that the AST Division take a leadership role in developing a*** Science, Technology, Engineering, and Mathematics ***(STEM) workforce that reflects the rapidly changing demographics of the United States.***

AST's Mid-Scale Innovations Program (MSIP) has been responsive to the 2010 Decadal Survey's high priority call for a mid-level funding program, and its management has led to effective outcomes. A significant gap between the current MSIP funding and the Decadal recommendations has been driven by lagging budget growth. The committee also commends AST for its integration of their Divisional response within the agency-wide Mid-Scale Research Infrastructure (MSRI) program.

AST likewise has been responsive to previous COV reports, to the extent that resources have permitted. In cases where changes were not practical, AST has provided solid justifications.

The COV lauds the good communication between AST and the NASA Astrophysics Division (APD), which has yielded important collaborations and coordination. Largely informal at present, the ***COV encourages a more codified relationship to ensure durability***. In parallel***, effective lines of communication should be established and maintained between AST and another key partner, the Office of Science at the DOE.***

The COV commends AST for accommodating the 2012 Portfolio Review's charge to divest facilities to free up resources for new opportunities. This was a serious challenge, logistically and politically, which was handled effectively, with notable care for those most affected. The outcome was an array of scientifically vibrant facilities largely operated on non-NSF funding. While we hope that the tortuous divestment process will not be needed again, ***we recommend that AST document and maintain its expertise in procedures and compliance with governing laws in the event that circumstances dictate revisiting this option***.

At the same time, a major lesson learned was the cost of divesting facilities can be high, and the savings less than anticipated. Large projects on the horizon, such as 30-m class telescopes recommended by the 2010 Decadal Survey, or any major new facilities endorsed by the upcoming 2020 Decadal Survey, cannot be accommodated within a relatively flat budget by any sensible further divestments of remaining highly productive facilities or without irreparably damaging the Grants Program. ***This critical juncture emphasizes that a new NSF-wide paradigm for large-facility operations is sorely needed.***

AST has done an excellent job in developing and managing reorganizations to position the ground-based system for success in the new era of Time-Domain Astronomy (TDA). The flagship optical/infrared (OIR) facility will be LSST, slated for commissioning in the near future. Notable also is the major National Center for Optical-Infrared Astronomy (NCOA) initiative for broader TDA coordination of public (and private) ground-based facilities. The radio astronomy community is maneuvering to play a key role as well.

Oversight of large-facility construction has been superb. During this period two challenging Major Research Equipment and Facilities Construction (MREFC) projects – LSST and DKIST – have proceeded close to schedules and within budgets. Further, operations of ALMA have ramped up smoothly in an environment of intense community engagement, achieving impressive forefront discoveries.

Electromagnetic Spectrum Management (ESM) is a vital activity within AST, but remains underappreciated in the Astronomical Community. At present, sensitive radio bands used by Astronomy are under increasing pressure from commercial interference. The ESM office maintains active representation on several committees that advise regulatory bodies, both nationally and internationally. Continued growth of these proactive regulatory activities, as well as increased awareness in the astronomical community, would be beneficial.

Finally, the COV urges AST to continue to support a substantial and vigorous IIP to sustain the intellectual vitality of the community. At the same time, maintaining access to the state-of-the-art observatories and instruments upon which the community relies also must be a priority. The committee acknowledges this ongoing tension of balancing funding priorities between individual investigator awards and large facility construction and operations, in the face of the limited budget growth the NSF has faced over the past three decades. Budget pressure will increase significantly in the near term with new operations costs for DKIST and LSST, with a shortfall over the next decade potentially exceeding $60M per year, even with an offset of approximately $35M from the divestment initiative. This is a critical issue, and the COV urges AST to work with Mathematical and Physical Sciences (MPS) and the NSF leadership to explore solutions to avert the impact of such a potential funding crisis.

1.2 Grants Programs

The COV commends the Division, especially IIP Coordinator Dr. James Neff, for curating the proposal portfolio in advance of the COV meeting, and preparing the ancillary statistics needed to place the program in a broader context. This was the second COV for which “Jacket” information (see section 4.1) was made available to the committee prior to the review. These materials allowed the COV to follow the full proposal life-cycle, yielding detailed insight into the logic of the decision-making needed to develop panel recommendations into specific awards, or for the vast majority, justify declines. This documentation was crucial for assessing the effectiveness of the program.

Overall, the COV finds that the review process was well organized and executed, and the outcomes were managed fairly and thoughtfully. The choice of review method for each proposal in the sample portfolio (in-person panel, remote panel, use of ad hoc reviewers, or site visits) was found to be appropriate. PO review analyses generally were thoughtful and well-constructed, although sometimes it was unclear how the Broader Impacts evaluation weighed in the PO’s decision. For only a small percentage of the AAG Jackets was the rationale provided to Principal Investigators (PIs) deemed insufficient to fully explain the decision. The COV concluded that, in general, panels had adequate scientific expertise to provide informed reviews, and panelists represented sufficiently different types of institutions and career stages. On the whole, individual reviewers provided substantive comments and solid evaluations. However, there was considerable variation in the quality of reviews, which the committee believes partly is symptomatic of the peer review process itself.

We recommend that AST should explore additional avenues to identify potential reviewers. Taking steps to proactively demystify the review process might provide access to a wider community of potential panelists; to ensure that the reviewer pool is as diverse as possible, intellectually and demographically.

The committee commends AST for the numerous process improvements made over the review period. These included increased use of mixed panels (in-person plus remote participants), and the introduction of pre-panel briefings. The latter is especially lauded, and should be strengthened. For example, reviewers could be given a firm, advance deadline to deliver their reviews, to allow POs the opportunity for feedback. Furthermore, the central role of the panel review should be stressed, with clear expectations for its contents.

We recommend that AST implement a more rigorous approach to Broader Impacts in all aspects of the review process. The vast majority of individual *reviewers* did not directly address all five elements in the two NSF mandated review criteria for Intellectual Merit and Broader Impacts. For the latter, a significant number of individual reviews and panel summaries provided little in the way of substantive guidance. Possible remedies: the pre-panel briefing sets the expectation that reviewers evaluate the Broader Impacts criterion with similar rigor as for Intellectual Merit; review panels have appropriate scholarly expertise to evaluate Broader Impacts; and POs reinforce the commitment to high-quality Broader Impacts activities in their proposal funding recommendations.

The COV notes that diversity and equity in the Grants Program can be improved, and should be a priority for AST in the context of STEM workforce development. Success rate – the number of proposals selected vs. the number submitted – for female PIs was about the same as for male PIs, and the rate was flat over the years encompassed by the review. Statistics for PIs of color were not strong to begin with, and success rates appeared to be falling. Proposer and reviewer demographics were consistent with each other. No major issues with success rates were noted for geographical considerations or the type of proposing institution. Although the success-rate parity, at least for women, seems to suggest a lack of bias in the review process, the important metric is the comparatively small pool of female and other underrepresented groups in the overall numbers of proposers. Guiding the demographics of proposers (e.g., $\sim$ 20% women) closer to that of the country as a whole (e.g., $>$ 50% women) would benefit from shifting investments toward early-career scientists, as well as encouraging awards to underrepresented mid-level researchers who are in a position to mentor others.

We thus recommend that POs reinforce a priority to diversify the astronomy workforce by increasing equity for underrepresented groups in the portfolio of awards. To allow the POs flexibility to exercise that role, reviewers could be instructed to group proposals into coarse categories – **"Highly Competitive," "Competitive,"** and **"Not Competitive"** – in lieu of a numerically ranked list. The PO then could recommend suitable projects from the first group, with increased equity as a balancing factor. Furthermore, avoiding a detailed ranking exercise would allow more time for writing thoughtful and constructive panel summaries.

We further recommend that AST consider the integration of double-blind (anonymous) reviews into the proposal process. Other agencies (e.g., NASA Astrophysics Science Division) are adopting this strategy to help thwart implicit bias in peer reviews (see Physics Today, 1 March 2019, 10.1063, Strolger, L. & Natarajan, P). Anecdotal evidence suggests that implicit bias can serve as a drag on success rates for underrepresented groups (see 2014, Reid, N.). Concerns that previous accomplishments, or lack of same, would not be accounted properly in the review could be balanced by the unique role of the PO, who would have full knowledge of the proposers' capabilities from the un-blinded proposal, and who would be responsible for any final award recommendations.

The COV recommends, with Astronomy Community input, that the Division develop metrics, like those utilized by the facility Managing Organizations (MOs), according to Intellectual Merit and Broader Impacts, for consideration by future COVs. This COV noted that specific success metrics were lacking for the AST, beyond science highlights, awards, and managing the available funds appropriately. The importance of the latter is not to be minimized, but in the end, it is a mix of Scientific and Broader Impacts outcomes that must be counted as well.

1.3 Facilities

AST was challenged during the review period by recompetition efforts, changes in management scopes, complex construction projects, and a mandate to divest existing, lower priority facilities. The COV studied representative examples: recompeting management organizations at Gemini Observatory; recompetition and divestment at Arecibo Observatory; changing Cooperative Agreements (CAs) for NOAO and the National Radio Astronomy Observatory (NRAO); and construction oversight of the new DKIST facility.

The COV concluded that AST has performed remarkably well in all these efforts. Nevertheless, supporting any future large facilities will be challenging, because construction and operations costs inevitably will increase. Further divestment of existing facilities will not significantly help. These already have been squeezed as much as practical without sacrificing highly productive components of the National System. Further, shifting funds from the Grants Program to facility operations is equally unpalatable, because individual investigator support is the critical link in the effective utilization of the existing, and future, AST portfolio.

1.3.1 Transitioning Facilities Management: Gemini and Arecibo # Observatories #

Gemini Observatory

AST is to be commended for its efficient and effective execution of the Gemini recompetition. The proposal solicitation was widely disseminated, and engagement with potential proposers occurred at all stages of the process. Altogether it was a fair and open competition. Members of the review panel had a commendably wide range of expertise and backgrounds, while avoiding conflicts of interest. Nevertheless, the COV encourages AST to seek greater expertise in education and public outreach on such panels, where some deficiencies were identified in the Gemini review.

At the same time, we recommend that AST explore competing major new Gemini instruments through MSIP, while maintaining a smaller internal Gemini instrument upgrade program. The development of facility instrumentation for Gemini has not fully leveraged the wide user base in the U.S. community, or innovative opportunities in a rapidly evolving scientific environment.

Arecibo Observatory

AST is to be commended for achieving future operations of Arecibo Observatory with substantially reduced NSF funding. The Arecibo recompetition was conducted within the context of the 2012 AST portfolio review, and a companion 2015 Division of Atmospheric and Geospace Sciences (AGS) effort, both of which (in broad terms) recommended that NSF reduce its financial stake in Arecibo. The new CA will enable continued high-impact science at this unique facility, while helping AST balance its portfolio. Nevertheless, there is some risk that the new Management Organization will fail to secure funding partners to fill in the scheduled ramp-down of NSF support over the next five years.

We acknowledge the extraordinary efforts on the part of AST staff required to achieve this management transition for Arecibo, given the complexity of the recompetition process running in parallel with an extensive review of closure options under the guidance of the National Environmental Policy Act (NEPA), the National Historic Preservation Act (NHPA), and the Endangered Species Act (ESA). The transition was further complicated by hurricane damage to the telescope and infrastructure.

An important lesson from the Arecibo effort is that during any major transition, whether change in management, significant staff reorganization, or defining a new mission for the facility, particular attention should be paid to retention of key staff. It is unclear whether more could have been done in this regard in the case of Arecibo, considering that the transition occurred during particularly trying times dictated largely by external circumstances.

Nevertheless, NSF (AST and AGS) should be proud of the net result, brokered by the tremendous efforts of both staffs, of an Arecibo that will continue to produce important science, as well as carry on local outreach and education.

1.3.2 Management of Facilities through CAs: NOAO and NRAO

AST oversight of NOAO, through the CA, remains solid. NOAO South continues to offer open access PI and survey programs, including support for the Blanco 4-m and the Southern Astrophysics Research (SOAR) 4.1-m. At NOAO North (Kitt Peak), the primary focus is major scientific surveys including the Dark Energy Spectroscopic Instrument (DESI) on the Mayall 4-m, and the NN-EXPLORE Exoplanet Investigations with Doppler Spectroscopy (NEID) on the WIYN 3.5-m. The Kitt Peak Visitor Center continues to serve many tens of thousands of patrons per year. NOAO has been actively building toward a transition to the NCOA, which will encompass NOAO, Gemini, and LSST operations, plus extensive data management activities.

AST oversight of NRAO, through the CA, also remains solid. NRAO facilities have played central roles in multiple recent ground-breaking science results: ALMA is approaching operational maturity, the JVLA with its boosted sensitivity continues to explore new territory, and the Very Long Baseline Array (VLBA) remains a valuable player in high-angular resolution radio astronomy. AST also supports the Central Development Laboratory (CDL), which fosters technology and expertise for current and next-generation radio astronomy instruments*.* Partial divestment of VLBA, bringing on the US Naval Observatory (USNO) as an equal partner, was a positive step, and consistent with recommendations of several earlier reviews.

1.3.3 Oversight of MREFC Projects in Development: DKIST

The COV is impressed with AST's oversight of DKIST, currently under construction in the MREFC program. The fact that the project is expected to meet budget and schedule is taken as evidence of the success of NSF's facility management. DKIST is a state-of-the-art solar facility that incorporates a specially-designed 4-m telescope together with an extensive multi-spectral suite of instruments, including adaptive optics (AO). DKIST will explore fundamental processes in the solar surface layers and atmosphere, in unprecedented detail and clarity. Full-up operations in mid-2020 are eagerly awaited by the solar community.

1.4 Electromagnetic Spectrum Management

The COV commends the ESM office for maintaining active representation on several committees that advise regulatory bodies concerning radio interference and spectrum access. We urge the continued growth of these activities, as well as raising the awareness of ESM efforts in the broader Astronomical Community. As radio astronomy receivers and signal-processors become ever more sophisticated, they also become increasingly susceptible to interference generated by commercial activities, encroaching on the few special frequency windows protected for astronomical research. AST hosts the ESM office, which fulfills a vital role in representing the interests of NSF, especially the heavily vested radio astronomy community, in managing the radio-frequency interference (RFI) environment and spectrum access, both nationally and internationally. Unfortunately, this important role is underrecognized and underappreciated in the Astronomical Community. It would be beneficial to have such awareness elevated. Further, AST could explore partnering with commercial bodies, especially those that can influence the drafting of requirements and guidelines forindustry.

2 Schedule and Process

The 2019 COV review process began with the appointment of the chair and vice-chair in October 2018. In the November – April time frame, the chairs coordinated with AST leadership to select the committee members and develop the charter and agenda. This period included the government shutdown, 22 December 2018 – 25 January 2019. Most COV members participated in an introductory webinar on 8 May 2019. There were presentations on confidentiality and conflict of interest issues; the types of documentation to be available for COV review; and the charge to the committee. The webinar also included tutorials concerning access to the *eJacket* website, where a representative selection of proposal materials was compiled; and *SharePoint*, where documents related to the facilities, and other information, were posted.

Initial Jacket and document reviews were assigned to individual COV members on 19 May, and adjustments were made for any previously unrecognized conflicts. All proposal Jackets considered by the COV had two reviewers, primary and secondary. The committee held one pre-meeting coordination telecon on 11 June to discuss the status of Jacket reviews, the meeting agenda, and writing assignments for the COV report. **Having all the documentation available electronically well in advance of the review contributed greatly to the efficient use of time during the COV meeting, and made it possible for all COV members to participate in, and contribute to, topics for which they did not have direct responsibility.**

The COV met at the NSF Headquarters in Alexandria 18–20 June 2019. The morning of Day 1 was devoted to presentations by AST staff. DD Richard Green and DDD Ralph Gaume addressed review procedures, conflicts of interest, and an overview of the AST. James Neff, the IIP coordinator, provided an overview of the IIP, and discussed merit review and awards. The morning closed with Chris Davis, the Gemini and NOAO Program Officer, describing the role of the NSF and of the MOs with regard to facility oversight and MOs.

The afternoon of Day 1 began with a welcome from Dr. Anne Kinney, Assistant Director (AD) for MPS. The majority of the afternoon was occupied by two sets of parallel committee break-out sessions, for in-depth presentations and discussions. COV members self-selected panels based on their Jacket, or other, assignments. The break-outs are listed below (AST staff members who participated are noted in brackets).

Break-out Session #1

1. AAG1: Extragalactic Astronomy & Cosmology (EXC); Galactic Astronomy (GAL) [Richard Barvainis, Peter Kurczynski, Nigel Sharp, Glen Langston]
2. Special Programs: AAPF; CAREER; Research Experience for Undergraduates (REU); Partnerships in Astronomy & Astrophysics Research and Education (PAARE); Education & Special Programs (ESP); NSF-wide programs [Linda French, Matt Benacquista, Harshal Gupta, James Neff]
3. Facilities 1: Gemini: Recompetition; Arecibo: Recompetition/Divestment [Christopher Davis, Joe Pesce]

Break-out Session #2

1. AAG2: Stellar Astronomy & Astrophysics (SAA); Planetary Astronomy (PLA); Solar & Planetary Grants (SPG) [Linda French, Luke Sollitt, Hans Krimm]
2. IInstrumentation & Technology: Advanced Technologies & Instrumentation (ATI); Major Research Instrumentation (MRI); MSIP [Richard Barvainis, Peter Kurczynski]
3. Facilities 2: Management & Oversight of NOAO and NRAO; MREFC Oversight of DKIST [Christopher Davis, Joe Pesce, David Boboltz]

Day 1 ended with a brief discussion with AST staff, followed by a COV working session. All presentations were made available to the committee on SharePoint, which greatly facilitated the COV in-meeting deliberations, and subsequent development of the final report.

Day 2 began with a short COV working session. Most of the rest of the morning was spent on various presentations. Leading off were Electromagnetic Spectrum Management (Ashley Zauderer and Jonathan Williams) and the Mid-Scale Innovations Program (Richard Barvainis). Then, AST DD Green described the NSF-AST response to advice from the Astro2010 Decadal Survey, 2012 AST Portfolio Review, mid-Decadal review, and 2015 National Academy Report "Optimizing the U.S. Ground-Based Optical and Infrared Astronomy System." That concluded the formal presentations to the committee, and was followed by a brief discussion session before lunch.

The afternoon of Day 2 was a COV working session to discuss results from the break-out sessions, and synthesize thoughts concerning the AST presentations. The committee reviewed and updated report writing assignments, and outlined topics to be covered in the Day 3 out-brief to MPS management. The late afternoon included a session with the AST DD and DDD for further discussions, and answers to final questions raised by the COV. **Throughout the process, the COV was impressed with the responsiveness of the AST staff to requests for information or clarifications.**

Day 3 was spent filling out the template of specific Core Questions for the COV, solidifying recommendations, drafting text for the report, and preparing slides for the out-brief that afternoon. At 2 pm, the major COV recommendations were presented to MPS AD Anne Kinney and MPS Deputy Assistant Director Deborah Lockhart, followed by a reprise for the AST staff.

The report was delivered to AST for fact checking on 29 July 2019. The final report was submitted on 9 September 2019, in support of the MPS Advisory Committee meeting scheduled 23–25 October 2019.

3 Science Highlights: Inspiring Society through NSF-AST Science

Transformative science is defined as science that transforms not just a specific profession, but impacts society itself. Over the reporting period, the NSF-AST had funded multiple scientific efforts that clearly met that high standard. Such programs reflect the effective NSF stewardship of an ambitious science vision for the U.S. community.

NSF-AST support provided the foundation for the recent achievement of the almost unimaginable: the direct imaging of the event horizon of a supermassive black hole, in this case in the active galaxy M87, at the unprecedented scale of 20 microarcseconds (Figure 1). The feat, once considered the realm of science fiction, provides perhaps the ultimate test of strong-field general relativity. It was widely acclaimed in the popular press across the globe: the black hole image was viewed by an estimated four billion people! While the result was published after the COV review period, the lion's share of the extensive ground work was performed during the review period and substantially funded by NSF-AST. The development work required to perform phase-coherent, very-long-baseline interferometry (VLBI) at ~ 1 mm wavelength, with ALMA as the fundamental enabling element, was carried out by a collaborative effort between U.S. Universities, a large NSF facility, and the international research community; a solid blueprint for future endeavors of this nature.

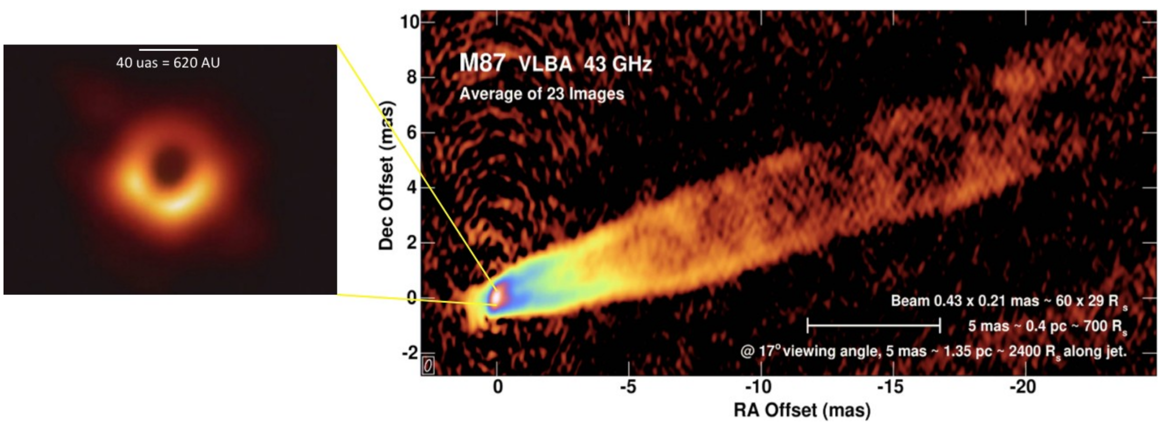

Figure 1: ***Left*****: Event Horizon Telescope (EHT) 230 GHz image of the black hole in M87 at the unprecedented resolution of 20 microarcseconds. The image shows the general relativistic shadow caused by the severe bending of space-time around the Schwarzschild radius of the black hole, seen as a bright ring with a dark center, indicating the orbits of the last photons able to escape the extreme gravitational field of the 6 x $10^9\,M_\odot$ BH (EHT Collaboration 2019, ApJ, 875, L1).** ***Right*****: VLBA image of the relativistic jet from M87 at 43 GHz (Walker et al. 2018, ApJ 855, 128). Multiple epochs of observations indicate apparent motions of jet knots accelerating up to twice the speed of light, an illusion due to relativistic beaming effects.**

These studies are just beginning, with further discoveries expected in the coming years, including imaging the black hole at the Galactic Center, monitoring the event horizon structure in M87, and finding other candidates. We commend the NSF/AST for their perseverance and vision in supporting this very challenging, somewhat risky, but extremely rewarding, scientific enterprise.

The review period also saw a Nobel Prize awarded to an NSF-funded research program: the first detection of Gravitational Waves from the cosmos. This discovery opened a novel, non-electromagnetic window on the Universe, ushering in the era of Multi-Messenger Astronomy. This new window has profound implications for myriad areas of physics and astronomy, for example: tests of strong-field general relativity; the demographics of binary neutron stars and black holes; nucleosynthesis, especially the generation of r-process and trans-iron elements; and even the determination of the Hubble constant. NSF-AST played a crucial role in supporting the multiwavelength, electromagnetic follow-up of the Laser Interferometer Gravitational-Wave Observatory (LIGO) sources, with remarkable success (Figure 2). The identification of a LIGO/Virgo event, GW170817, as a kilonova in a distant galaxy, involved supporting observations by NSF-funded facilities, including University optical telescopes, Cerro Tololo Inter-American Observatory (CTIO), the VLA, and the VLBA. The combination of optical and radio light curves, and high-resolution long-baseline radio interferometric imaging, not only confirmed the kilonova identification, but also the “smothered jet” model to explain the aftermath of a neutron star merger. LIGO already is detecting events at ten times the commissioning rates, and a dedicated suite of ground and space telescopes is poised for the next round of follow-up opportunities.

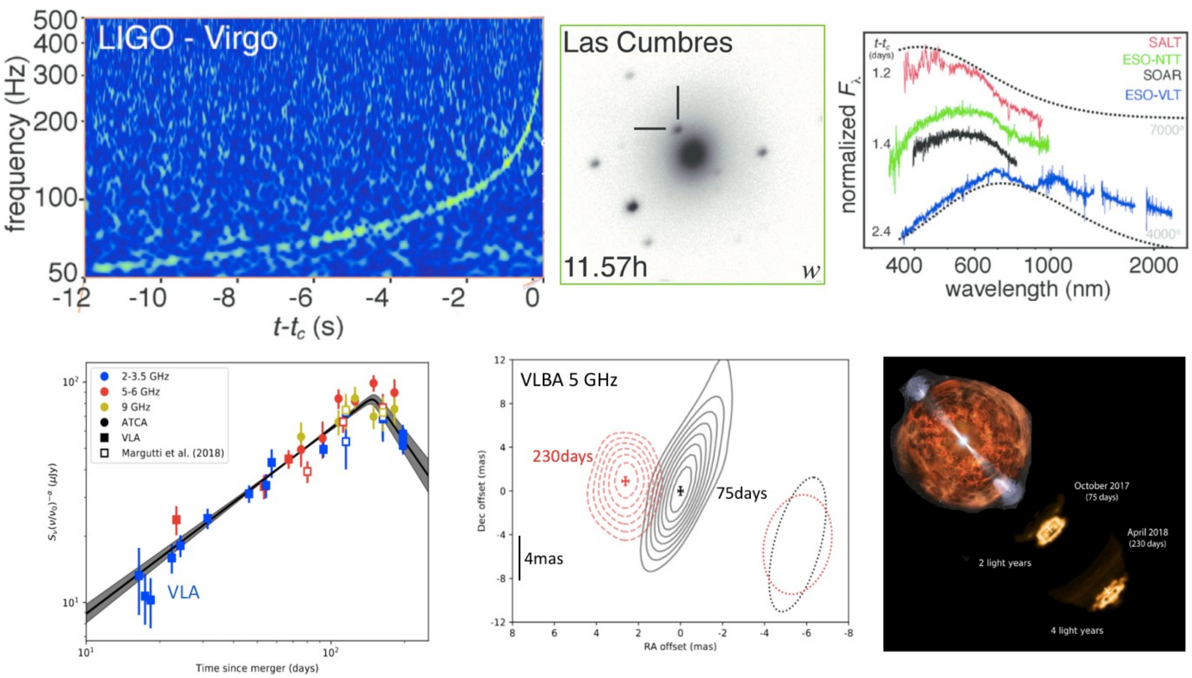

Figure 2: ***Upper left*: LIGO detection of gravitational waves from the merging binary neutron star system, GW170817 (LIGO Collaboration 2017, Phys. Rev. Lett. 119, 161101). *Upper center*: optical identification of the afterglow from the associated kilonova with a galaxy at a distance of 40 Mpc. *Upper right*: optical light curves of the kilonova (LIGO Collaboration 2017, ApJ, 848, L12). *Lower left*: radio light curve, showing the turnover predicted when the initially “smothered relativistic jet” emerges from its nascent cocoon of neutron star debris (Dobie et al. 2018, ApJ, 858, 15). *Lower center*: VLBA imaging of the emerging jet at 4 milliarcsecond resolution. Multiple VLBA epochs imply an apparent jet motion of 4 times light speed (Mooley et al. 2018, ApJ, 868, L11), again a relativistic illusion. *Lower right*: artist impression of the emerging smothered jet model.**

The field of gravitational wave astronomy now is upon us, thanks in large part to the foresight and cooperative efforts of the NSF Divisions of Physics and Astronomy. The future is bright: the upcoming LSST will be a particularly powerful tool to identify and characterize GW sources.

Nothing captures the imagination of scientists and the general public alike more than the possibility of life beyond the Earth. Over the reporting period, the study of exoplanets and planet formation, and the search for prebiotic and biosignatures, have become mature fields, funded substantially by NSF-AST. Direct images of exoplanets, and planet-forming disks, in systems similar to our Solar system, have become iconic; familiar not just to astronomers, but also broader society (Figure 3). The search is on for evidence of prebiotic molecules, including simple amino acids, using new radio bands at ALMA and the JVLA; and for atmospheric biosignatures, such as molecular oxygen, in the infrared with Gemini. The WIYN telescope now has joined exoplanet research, as a collaborative effort between NSF-AST and NASA-APD Transiting Exoplanet Survey Satellite (*TESS*) mission. The next big steps will be to push imaging of exoplanets and planetary disks to sub-astronomical-unit scales, and to characterize planetary atmospheric conditions and chemistry in the search for life. These goals represent key science drivers for future large optical and radio facilities, such as the Extremely Large Telescopes and the Next Generation VLA (ngVLA).

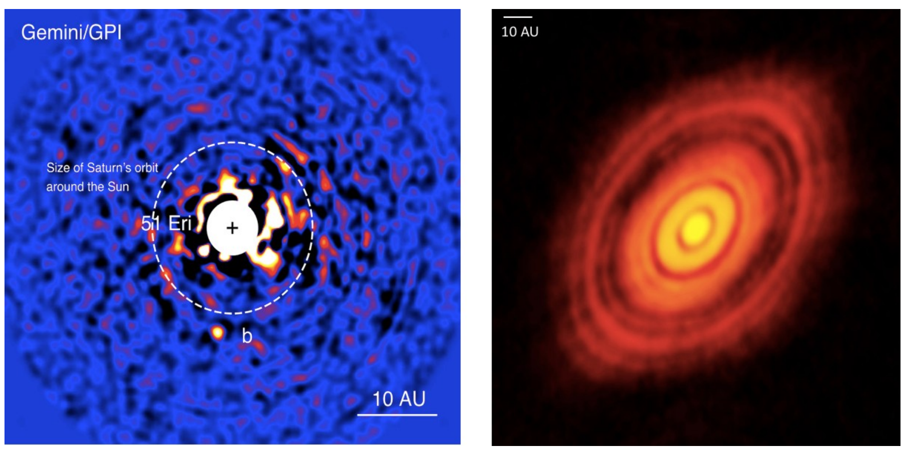

Figure 3: *Left*: Gemini image of 51 Eridani b (marked with 'b'); the exoplanet most similar to our Solar System's gas giants so far (Macintosh et al. 2015, Science, 350, 64). *Right*: ALMA 1 mm image of HL Tau at 30 milliarcsecond resolution (ALMA Partnership 2015, ApJ, 808, L3). HL Tau has a dusty protoplanetary disk surrounding a 1 Myr old, solar-mass protostar; an analog of the early evolution of our own Solar System. The rings and gaps are direct indications of planet formation, due to the clearing of dust by orbiting planets.

Perhaps the largest growth area in astronomy is exploration of the time domain. With the advent of NSF-supported LSST in the near future, studies of the transient sky are poised for a revolution. In the near term, AST has funded numerous programs that are opening up this rapidly growing field. For example, the Global Relay of Observatories Watching Transients Happen (GROWTH), comprised of a world-wide network of telescopes including several supported by the NSF, produced the first image of a type Ia supernova in a strongly lensed galaxy at redshift z = 0.4. Likewise, NSF facilities played crucial roles in identifying, localizing, and characterizing the recently discovered, microsecond duration, "Fast Radio Bursts" (Figure 4). This enigmatic phenomenon might shed light on the most extreme explosions in the Universe. It also might provide a unique probe of the intergalactic medium, with possible insight into the “missing baryons” problem.

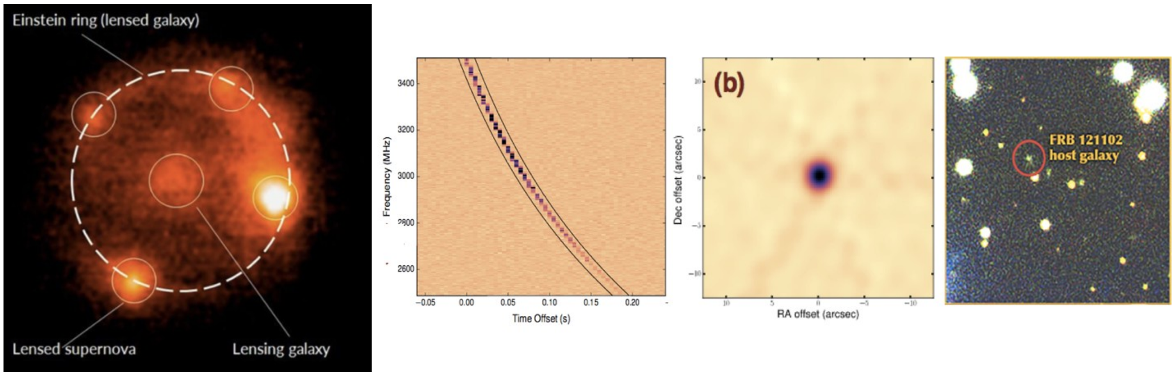

Figure 4: ***Left*****: The strongly lensed images of a type Ia Supernova at *z* = 0.4 seen by the GROWTH survey (Goobar et al. 2017, Sci, 799, 106).** ***Right*****: Arecibo discovered a repeating Fast Radio Burst, which then was localized by the JVLA to an arcsecond. Subsequent optical follow-up associated the source with a low metallicity dwarf galaxy at *z* = 0.2 (Tendulkar et al. 2017, ApJ, 834, 7; Chatterjee et al. 2017, Nat, 541, 58).**

Not to be outdone, the cosmology community has launched massive imaging and spectroscopic surveys to determine the nature of cosmic acceleration and dark energy, leveraging the redshift evolution of the angular scale of the Baryon Acoustic Oscillations. The DES program represents a true success story in multiagency science cooperation, with DOE-funded major instruments operating on NSF-funded large telescopes. The preliminary results from DES already have yielded constraints on key cosmological parameters, such as the cosmic matter density and “clumpiness” of dark matter, approaching those from the European Space Agency *Planck* mission (Figure 5).

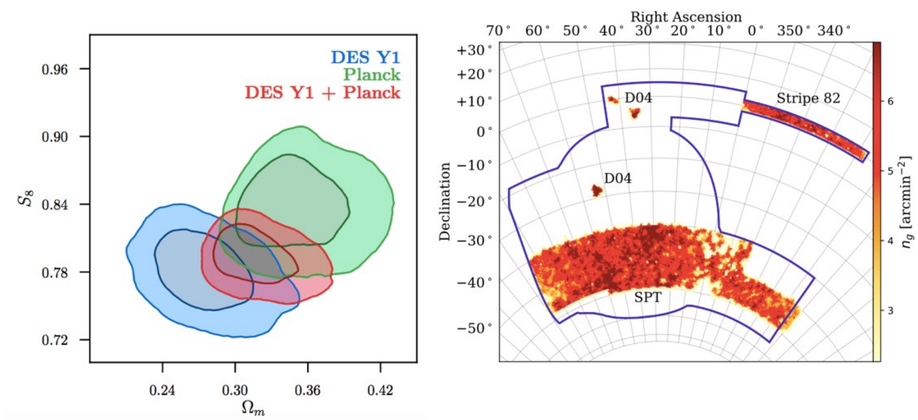

Figure 5: ***Left*****: First year DES constraints on the dark matter density of the Universe (Ω_m), vs. the clumpiness of dark matter (S_8), derived from galaxy clustering and weak lensing (blue contours). These are compared to, and combined with, *Planck* results (DES collaboration 2017, Phys Rev D, 98, 042536).** ***Right*****: the galaxy areal density for the DES year 1 survey (Zuntz et al. 2017, MNRAS).**

The study of galaxy formation is reaching toward its final frontier: the very first galaxies and black holes, within 1 Gyr of the Big Bang. NSF facilities, such as Gemini and ALMA, are at the forefront of the field; identifying the first supermassive black holes, including the most distant quasar to date, at $z \sim 7.5$, and star forming galaxies out to redshifts $z \sim 9$. In parallel, the NSF is funding University experiments to detect HI 21 cm emission from large scale structure during cosmic reionization, and the preceding Dark Ages, probing structure to within 200 Myr of the Big Bang (Figure 6).

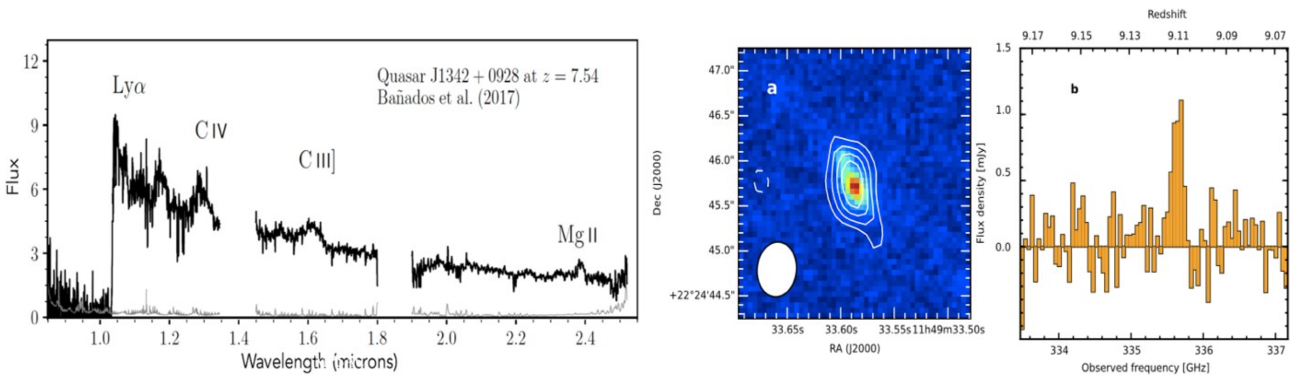

Figure 6: *Left*: Discovery of the highest redshift quasar to date, at $z = 7.5$, by Gemini: the black hole mass is $\sim 10^9\ M_\odot$. The formation of such massive black holes so early in the Universe presents a major challenge to models of cosmic structure formation (Banados et al. 2017, Nature, 7689, 473). *Center*: ALMA [O III] 88 μm fine-structure line emission (contours), superimposed on a Hubble Space Telescope (HST) F160 near-IR image of a $z = 9.1$ galaxy. *Right*: the corresponding ALMA spectrum (Hashimoto et al. 2018, Nature, 557, 392). ALMA observations of the atomic fine-structure lines represent a unique method to determine redshifts for $z > 8$ galaxies. In this case, the [O III] feature indicates a metal-enriched interstellar medium at just 500 Myr after the Big Bang.

Closer to home, the Big Bear Solar Observatory, in collaboration with the National Solar Observatory, continues to improve Multi-Congugate Adaptive Optics technology, through an NSF-supported program. MCAO has revealed the intricate structure of the solar photosphere, and magnetic active regions, over wider fields in unprecedented detail (Figure 7), as a pathfinder for the next generation MCAO systems on the up-coming solar flagship facility, DKIST.

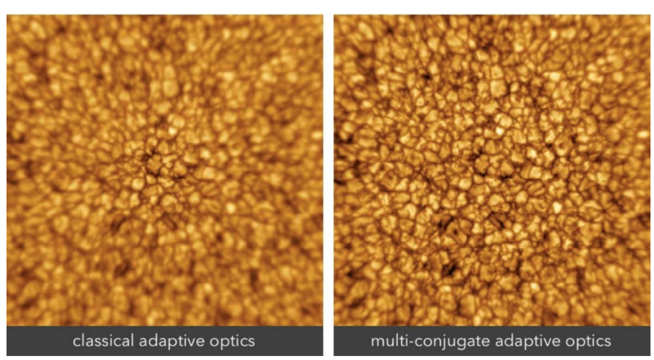

Figure 7: Recent imaging using Solar Multi-Conjugate Adaptive Optics (right frame) at Big Bear Observatory (Schmidt et al. 2016, A&A, 597, L8); left hand panel shows the same field, but with the tiny area corrected by classical AO.

4 Grants Programs and Proposal Review Process

4.1 Overview

The IIP represents AST's principal mechanism for building and maintaining intellectual vitality in the astronomical sciences. The competition for IIP grants remains fierce, and the extreme proposal pressure noted by the 2011 and 2014 COVs continues largely unabated. Within the AAG program alone, almost 2800 proposals were processed from FY2015 through FY2018, during a period when the AAG funding remained level at about $50M, approximately 20% of the total AST budget. A shallow 10-15% reduction in incoming proposals, from a mid-decade peak, combined with a flat funding profile, boosted the proposal success rate from 18% in FY2015 to nearly 23% in FY2018. However, the committee notes that the preservation of AAG came partly at the expense of the ATI program, which has been underfunded in recent years, and put on hold in FY2018.

Proposals to the Individual Investigator Program are submitted and processed electronically, through NSF's Fastlane system, with some aspects of program management performed through research.gov. All pertinent information for a given proposal is contained in Fastlane Jacket entries, which might consist of some, or all, of the following elements:

1. The Proposal Summary and Project Description
2. PI information
3. Proposal reviews
4. Review panel information
5. Panel summary
6. PO review analysis
7. Communications between PI and PO

For the 2019 COV, AST assembled a representative suite of 178 Jackets, intended to be a fair snapshot of the AST's full portfolio. The sample Jackets included:

- 88 awards, 85 declinations, 2 returned without review, 3 withdrawn
- 102 proposals from the AAG program (EXC, GAL, SAA, PLA, and SPG)
- 9 ATI, 6 MRI, 3 MSIP
- 16 AAPF (postdoctoral), 11 CAREER
- 4 REU programs
- 1 Rapid Response Research (RAPID), 2 Early-concept Grants for Exploratory Research (EAGER)
- 2 Enhancing Access to the Radio Spectrum (EARS)
- 1 Integrated NSF Support Promoting Interdisciplinary Research and Education (INSPIRE), 2 PAARE, 3 ESP-specific
- 7 supplemental funding

With the full contents of the Jackets available for examination, it was possible for committee members to follow the complete life cycle of an AST proposal: from submission; individual reviews;

synthesis of panel summaries and panel rankings; through the PO's analysis and recommendations to the DD.

The COV commends the Division, and in particular IIP Coordinator Dr. James Neff, for curating the proposal portfolio in advance of the COV meeting, and preparing the ancillary statistics to place the program in context. AST's careful attention to data-driven proposal management furnished the information needed to assess the effectiveness of the program, logic of the decision making, equity in demographics, fairness of the process, and long-term trends.

4.2 Proposal Portfolio Analysis and Findings

The 178 proposals in the portfolio were divided among six committee members for detailed review with regard to the Core Questions posed to the COV:

1. Are the review methods appropriate?
2. Are both merit criteria addressed in individual reviews, panel summaries, and PO analyses?
3. Do individual written reviews include substantive comments to explain the assessments of the proposals?
4. Do the panel summaries adequately describe the rationale for the panel consensus (or reasons consensus was not reached)?
5. Does the documentation in the Jacket provide the rationale for the award/decline decision?
6. Does the feedback to the PI explain the rationale for the award/decline decision?

Each committee member considered their assigned proposal Jackets in light of these six questions. In addition to written notes, a matrix in "stoplight chart" format captured an at-a-glance view of that panelist's portion of the portfolio, and highlighted patterns and trends. One committee member then collected the notes and charts from the other five panelists, and synthesized the responses to provide a cumulative stoplight matrix for the full Jacket sample provided to the COV.

Observations and findings were as follows:

- The choice of review methods for each proposal in question (whether an in-person panel, remote panel, use of ad hoc reviewers, or site visits) was entirely appropriate.
- The documentation in each Jacket, taken in full, provided solid justifications and explanations for the award/decline recommendations. Overall, PO analyses were found to be excellent, and thoughtfully constructed, at least for the Highly Competitive and Competitive proposals.
  - For proposals found Not Competitive, boilerplate responses for PO analyses often were the norm. These forms typically did not provide guidance beyond that of the panel summary, thus placing extra onus on the quality of that summary.
  - It sometimes was unclear how the Broader Impacts evaluation weighed into the PO's decision to recommend or decline a proposal.
- For 5% of the AAG Jackets, the information provided to PIs (individual reviews and panel summary) was insufficient to fully understand the rationale for the decision. Most of these

cases were for declines. Because the latter constituted approximately 80% of proposal decisions, but only about 50% of the COV portfolio, it is likely that the true fraction is closer to 10% for the full sample of proposals.

- The vast majority of individual reviewers do not address directly all five suggested review elements for the Intellectual Merit or Broader Impacts criteria. Only a small fraction (15%) organized their reviews by element; about 50% addressed one or more elements directly, and the remaining 35% seemed to review the proposals by their own private criteria, seemingly tethered to the NSF criteria. The actual quality of the review appears to be independent of the adherence to criteria guidelines. However, if individual reviewers leave this information out of their review, it makes subsequent review analysis by the PO more difficult.
- A significant number of individual reviews (22%) lacked evaluative language, providing instead simple digests of the main points of the proposal.
- The vast majority of panel summaries were adequate, although sometimes tersely written, for Intellectual Merit. Only 5% of the panel summaries were found to be severely lacking in this regard.
- For Broader Impacts, a considerably larger fraction of individual reviews (20-25%) and panel summaries (15-20%) provided little in the way of substantive comments and/or an inadequate synthesis of panel discussions. Generally, reviewers did not apply the same level of evaluative rigor to a proposal's Broader Impacts as they did for Intellectual Merit.
- The review panels encompassed by these Jackets had 30% female reviewers, based on self-declared and publicly available data. This represented a 8% higher proportion than is typical of self-declared AST panelists in a given year.
- Success rates for female PIs were approximately the same as for men, and flat over the years of the COV review. Statistics for PIs of color were affected by their small numbers, but success rates appeared to be falling through this period (from 25% to 15%).
- Based on publicly available data, the majority of reviewers in the COV proposal portfolio who did not provide gender information to NSF were male. If the unidentified gender population across AST proposers is skewed toward male participants more than astronomers overall, published gender statistics could overestimate the success rates of female PIs. Improving the completeness of gender and minority reporting will address this concern.
- Most of the awards in the portfolio reviewed by the COV were deemed Highly Competitive. Of these proposals, those led by a male PI were rank-ordered either first or second 54% of the time, and those led by a female PI were ranked first or second 63% of the time. The difference is not statistically significant. The implication is that awards to female PIs stem from the panel review process, and are skewed neither positively nor negatively.

Overall, the panel finds that the review process itself is well organized and executed, and the results are managed fairly and thoughtfully. The committee commends AST for the numerous improvements made over the review period. Of these, the pre-panel briefings were judged to be especially valuable. Indeed, the committee suggests augmenting these briefings to amplify their impact, as discussed in §4.5.

4.3 The Panel Review Process

AST usually relies upon panel reviews, in which typically 15–24 proposals are evaluated by 5–8 panelists. Each proposal will have a primary reviewer and a secondary reviewer, who submit evaluations in advance of the panel meeting. A third panelist is assigned as scribe, meant to synthesize a panel summary from the discussion. For programs where specialized knowledge is required, a PO often will seek additional ad hoc reviews. This is most common for instrumentation proposals in the ATI, MRI, and MSIP categories.

4.4 Selection of Reviewers

Members of the COV discussed reviewer selection with AST staff during breakout sessions, and at other times. Selection of reviewers remains a time-consuming task, especially because only about a quarter of potential reviewers accept a request to participate on a panel. This situation has not changed over the past decade, based on the experience of current POs and as indicated in the 2011 and 2014 COV reports. The introduction, and greater use, of mixed (in-person and remote participation) review panels unfortunately has not markedly improved the efficiency of assembling panels. The COV recognizes this difficulty, and applauds the NSF staff for their tireless efforts to make progress on this issue. It appears to the COV that, on average, most panels have adequate scientific expertise to provide informed reviews of Intellectual Merit, and, further, that panelists come from different types of institutions and are at a wide range of career stages.

The 2014 COV report stated that "[r]elying on recruiting volunteers at American Astronomical Society (AAS) meetings is not sufficient to broaden the pool of potential reviewers." This remains the principal way that POs seek qualified and experienced reviewers outside of the existing NSF investigator pool, although some POs make use of the NASA Astrophysics Data System[1] abstract service, the Astrophysics arXiv[2], and other on-line resources to gather information concerning potential reviewers and their experience.

This COV recognizes that the recruitment of reviewers, while challenging, is of essential importance to maintain a robust review process. One way to address this challenge is to grow the pool of potential panelists beyond those who: (1) already have had contact with AST staff; or (2) are sufficiently familiar with the AST review process that they self-select (either by visiting the AST booth at the AAS, or by signing up to serve as a panelist online). By taking steps to proactively demystify the review process, AST might be able to access a wider community of astronomers who would be willing to serve as panelists.

[1] https://ui.adsabs.harvard.edu/

[2] https://arxiv.org/archive/astro-ph

Recommendation 1. AST should explore additional avenues to identify potential reviewers, in order to lighten the burden on AST staff of recruiting panelists, while simultaneously ensuring a reviewer pool that is as diverse as possible (with respect to both scientific and educational expertise, institution type, career stage, and demographics).

The COV considered several avenues to accomplish this goal, including: (1) host stand-alone information sessions and/or workshops on the review process, at AAS or other community meetings; (2) enhance existing efforts to educate community members on the overall proposal process by giving more attention to the review side (the COV notes that participating in a peer review is one of the best ways to understand how to write a competitive proposal); and, (3) build connections to organizations that advocate for underrepresented groups within Astronomy (for example: the AAS Committee on the Status of Minorities in Astronomy, AAS Working Group on Accessibility and Disability, etc.) to recruit potential reviewers from communities who, historically, have had less access to informal, word-of-mouth networks.

4.5 Individual Reviews

On the whole, individual reviewers provided substantive comments and solid evaluations of a proposal's Intellectual Merit. However, there was considerable variation in the quality of reviews, in the proposal sample considered by the COV, which the committee believes partly is an unavoidable byproduct of the peer-review process itself. Given the voluntary, but time-critical, nature of proposal reviews, it is a persistent challenge to identify changes to the process that will improve outcomes. Here, we focus on three findings mentioned in §4.2, which the committee believes can provide constructive guidance. Reviewers tend to write reviews that: (1) only obliquely reference NSF's review criteria; (2) sometimes parrot the proposal's main points, rather than provide evaluative language; and (3) often are lacking critical, thoughtful consideration of a proposal's Broader Impacts. To counteract these tendencies, the POs can provide guidance prior to the panel meeting. We believe that such advance guidance will result in better outcomes.

Recommendation 2. Strengthen the pre-meeting briefing to improve the quality of reviews by emphasizing the importance of NSF's several Merit criteria; provide examples of specific evaluative language; and encourage critical and thoughtful consideration of Broader Impacts. (See Priority Recommendation 7, §4.9.)

Furthermore, we recommend setting a deadline for the pre-meeting written reviews, to allow sufficient time for the Program Officers to provide feedback.

Recommendation 3. For individual reviews, AST should establish a deadline of ~7 days prior to the panel meeting for panelists to deliver their evaluations.

4.6 Exploration of a Double-Blind Review Process at AST

Other agencies have been experimenting with "double-blind" (anonymous) reviews, to help thwart implicit bias (see [Physics Today, 1 March 2019, 10.1063, Strolger, L. & Natarajan, P]). The NASA-APD announced in June 2019 that all upcoming proposals to use *Chandra* X-ray Observatory, TESS, Nuclear Spectroscopic Telescope Array (*Nu-STAR*), Neutron Star Interior Composition Explorer telescopes (*NICER*), Neil Gehrels Swift Observatory (*Swift*), and *Fermi* γ-ray telescope will be evaluated through a double-blind process. Anecdotal evidence suggests that implicit bias can serve as a drag on success rates for underrepresented groups ([see 2014, Reid, N.).] Concerns that previous accomplishments, or lack of same, would not be properly accounted in the AST reviews could be balanced by the unique role of the PO, who would have full knowledge of the proposers' capabilities from the un-blinded proposal, and who would be responsible for any final award recommendations.

Recommendation 4. AST should undertake a trade study to explore the potential positive impact of double-blind (anonymous) reviews for AAG, ATI, AAPF and CAREER.

4.7 Panel Summaries and Feedback to the PI

The Panel Summary plays a special role in the review process. It represents a synthesis of the panel discussion and culmination of the consensus view, or an explanation why consensus was not reached. The qualified use of Major/Minor Strengths and Weaknesses should indicate how the panel viewed the Intellectual Merit and Broader Impacts of the proposed work, and should relate how the proposal might be improved. The language of the panel summary should be concise, but also must be constructive: it represents the main conduit by which feedback is provided to the PI, and the evidence that a thoughtful, competent, fair review of the proposal took place. This is particularly important for early-career scientists, for whom constructive feedback is essential to improve their future chances for career success.

As discussed in §4.2, the Jacket sample revealed some variations in the quality and constructiveness of panel summaries. To improve the consistency and tone, it is suggested that POs leading IIP panels provide specific guidance for constructive language to use when sculpting a panel summary. It might also be helpful to arm panelists with a checklist to capture the most common shortcomings:

- **Highly Competitive** proposals should not have Major Weaknesses in their summaries, unless there is additional information documenting why the panel rated the proposal highly even though weaknesses were identified.
- **Competitive proposals** should have some indication where there is room for improvement, in the event the proposal cannot be funded.
- **Not Competitive** proposals should have clearly-stated reasons for their ranking, with constructive suggestions for improvement.

Recommendation 5. The current pre-panel briefing, which initiates participants to the review process, should highlight the critical nature of the panel summary, and outline clear expectations for its contents.

Recommendation 6. Panelists should be instructed to focus their efforts to bin proposals into categories of **Highly Competitive**, **Competitive**, and **Not Competitive**; and divert attention, previously paid to detailed order ranking, toward writing thoughtful, constructive panel summaries. (See Priority Recommendation 8, §4.10.)

4.8 Post-Panel Review Process

The COV examined the individual reviews, panel summaries, and panel rankings in the context of the PO review analyses. Despite the variability in the quality of individual reviews and panel summaries, the Jackets, for the most part, provided adequate documentation of the post-panel review process, clarifying the rationale for the decision recommended to the Division Director. For Highly Competitive and Competitive proposals, the POs' review analyses generally were explicit and thorough. However, Non-Competitive proposals often were accompanied by a "form letter" review analysis indicating, in essence, that "the program officer agrees with the findings of the panel." This is acceptable if the panel summary was comprehensive and the PO did indeed agree with the findings, but in several cases the reviews and panel summary provided very little information to justify the proposal rating. When presented with a deficient panel summary for a Non-Competitive proposal, the committee suggests that the PO should indicate, in the Jacket notes, that the summary did not capture all the information required for a recommendation.

4.9 A Critical Look at Broader Impacts

The NSF's Proposal and Award Policies and Procedures Guide (PAPPG) defines the merit review principles; the two main criteria, Intellectual Merit and Broader Impacts; and five elements to consider in the evaluation of both. As previously discussed, few individual reviews documented all five elements for Intellectual Merit. While almost all reviews and panel summaries addressed, at some level, both Intellectual Merit and Broader Impacts, the evaluation of Broader Impacts, on average, lacked intellectual rigor, both absolutely, and compared to the evaluation of Intellectual Merit.

The committee recognizes the significant time pressure PIs feel in driving both ambitious science and BI programs. The review of the Broader Impacts of a program should be performed with the same critical thinking that governs the review of Intellectual Merit. The PAPPG stresses that, "Both criteria are to be given full consideration during the review and decision-making processes; each criterion is necessary, but neither, by itself, is sufficient. Therefore, proposers must fully address both criteria."

Furthermore, "When evaluating NSF proposals, reviewers will be asked to consider what the proposers want to do, why they want to do it, how they plan to do it, how they will know if they succeed, and what benefits could accrue if the project is successful. These issues apply *both to the technical aspects of the proposal and the way in which the project might make broader contributions*" (emphasis in the original).

Therefore, this COV urges the AST to encourage reviewers to assess Broader Impact statements more critically and thoughtfully than in the past. Many analogues from Intellectual Merit reviews apply well to Broader Impacts:

- qualifying or quantifying societal benefits if the program is successful
- establishing engagement within the community
- including collaborators from the community to be served, when applicable
- familiarity with the literature
- addressing assessment methods to determine effectiveness and impact

AST should also take steps to set higher expectations for Broader Impact statements through the solicitation process, which might take the form of Dear Colleague Letters (DCLs), AAS meeting presentations, and/or division-specific wording in the solicitations themselves.

As Broader Impact statements evolve to become more thoughtful and detailed, increasingly specialized review expertise might be required. POs should endeavor to select panelists with experience in Broader Impact activities, either on the panel itself or as ad hoc reviewers; and to structure the process so that Broader Impacts are explicitly evaluated in both pre-panel reviews and the panel summary. Expanding reviewer participation could include scientists and educators whose scholarly expertise and daily activities are in formal or informal education, education research, broadening participation, or workforce development, even if their scientific specialization is less closely related to the subjects being reviewed.

Priority Recommendation 7. We recommend that AST implement a more rigorous approach to Broader Impacts in all aspects of the review process.

We recommend the following specific actions:

(a) AST should utilize the pre-panel briefing to set expectations for reviewers to consider the Broader Impacts criterion with similar rigor as for Intellectual Merit.
(b) AST should take steps to ensure that review panels have appropriate scholarly expertise associated with evaluating Broader Impact scopes of work. This might require different recruitment sources, and accepting panel members with expertise in Broader Impacts, but less so with the principal scientific themes.
(c) AST Program Officers should reinforce the commitment to high-quality Broader Impact reviews in their proposal funding recommendations.

4.10 Building Equity and Inclusion

The COV considered the distribution of proposals, reviewers, and awards with respect to underrepresented groups, geographics, and types of proposing institution. To perform this evaluation, the committee reviewed demographic information retrieved from the NSF database by the IIP Coordinator. In fact, the data-driven approach to documenting the proposal decision flow was instrumental for tracking trends. The main findings were that proposer and reviewer demographics were consistent with each other, and success rates were driven mainly by proposal pressure. It is important to note that the 2011 and 2014 COV reports had similar findings. At the same time, it also was clear that progress towards equity in the astronomical sciences, as exemplified by IIP proposal submissions and ultimate awards, largely had stalled.

Indeed, in some cases the trends were worrisome. For example, the number of AAG proposals decreased by about 100 per year after 2015 through 2018. A disproportionate fraction of the downturn came from the miniscule fraction (5%) of PIs who identified as people of color. That trend was amplified by a drop in proposal success rate for these same PIs – from 25% to 15% – at the same time the overall success rate was climbing (from 18% to almost 23%). While small-number statistics certainly play a role, that point is exactly the crux of the problem. In particular, the fraction of AST proposals led by people of color has remained stubbornly stuck at around 5% for at least 15 years.

To address this impasse, NSF has clear guidance. The NSF Strategic Plan for FY2018-2022[3], "Building the Future: Investing in Discovery and Innovation," advocates a vision for diversity and equity in science; specifically in its Strategic Objective 2.2 – STEM Workforce: "Foster the growth of a more capable and diverse research workforce and advance the scientific and innovation skills of the Nation."

In addition, the astronomical community itself has articulated its own vision to make Astronomy more inclusive: the recommendations of the 2015 Inclusive Astronomy meeting[4] (colloquially known as "The Nashville Recommendations") include near-, mid-, and long-term goals and policy actions for stakeholders across the field, including agencies. Of particular importance to the NSF are the recommendations regarding "Inclusion and Access to Power, Policy, and Leadership," which we replicate in Appendix C.

We note that the COV review period, 2015–2018, covered the subsequent three years *after* the Nashville Recommendations. To adopt the phrasing used in those Recommendations, equitable access to astronomy cannot be a mere goal, it must be a *priority* for all stakeholders within the astronomical community. **The COV urges AST to take a leadership role in this regard**.

Prioritizing equity in astronomy must be a part of the review process, as well as in NSF leadership itself. The COV notes that the POs, while undeniably dedicated individuals, suffer from the same lack of demographic diversity as the proposers. In order to achieve the diversity goals endorsed by the astronomical community, a greater degree of inclusiveness must be attained at every stage of the proposal process, from PIs, to POs, to review panelists.

[3] https://www.nsf.gov/pubs/2018/nsf18045/nsf18045.pdf

[4] https://aas.org/posts/news/2017/02/inclusive-astronomy-nashville-recommendations

To address equitable access to policy-making and leadership roles, we encourage AST to actively recruit POs from a wide swath of the astronomical community, especially reaching out to underrepresented and under-resourced researchers and institutions. There are numerous possible avenues to achieve this goal, many of which are synergistic with the Committee's recommendations regarding recruitment of panelists. The pathway to positions of power (of which the important work of NSF POs is one example) often are opaque to community members, especially those who do not have access to extensive informal professional networks. AST should proactively work to demystify the pathway to service as part of their recruitment efforts.

The Committee also noted the challenges associated with tracking progress with respect to inclusion, owing, for example, to reliance on demographic information self-reported by PIs. The Committee encourages AST to continue its efforts to track progress to the best of its ability, and consider expanding the range of possible proposer gender types to include modern alternatives.

> **Priority Recommendation 8.** To address NSF's strategic goals for the future, we urge that AST take a leadership role toward developing a STEM workforce that reflects the rapidly changing demographics of the United States.
>
> We recommend the following specific actions:
>
> (a) Program Officers should reinforce the commitment to diversify the astronomy workforce by increasing equity for underrepresented groups in the awards portfolios.
>
> (b) To allow POs appropriate flexibility to exercise that role, reviewers should be asked to categorize proposals as "**Highly Competitive**", "**Competitive**" and "**Not Competitive**," in lieu of a detailed numerical ranking. (Recommendation 6, §4.7.)

5 Facilities

The COV studied five facility examples: transitioning management organizations at Gemini and Arecibo; on-going Cooperative Agreements (CA) for NOAO and NRAO; and construction oversight of DKIST. AST was challenged during the COV review period by a mandate to divest older, less productive facilities to free up resources for current and future initiatives. At the same time, AST was carrying out several management recompetitions; as well as reorganizations of existing management structures to better position the aggregate portfolio for a rapidly changing landscape of Astronomy.

AST has performed remarkably well in these efforts. Nevertheless, funding future initiatives will be challenging, because construction and operations costs inevitably increase over time, especially as aspirations of the community for bigger, better facilities continue to grow. Further divestments of existing facilities will not help significantly, because they have been squeezed as much as practical, and additional cuts would risk damaging key components of the U.S. National System.

5.1 Transitioning Facilities Management: Gemini and Arecibo Observatories

5.1.1 Gemini Observatory: Recompetition

The Gemini Observatory operates two 8.1-m telescopes, one on Mauna Kea, Hawai'i, the other on Cerro Pachón, Chile. These are the largest-aperture OIR telescopes with open-access for the U.S. Astronomy community. The current U.S. share of observing time is about 70%. The Gemini International Agreement codifies the role of the Gemini Board, the NSF as the Executive Agency, and the MO for operating the observatory. The Gemini Board sets overall policy direction, is responsible for oversight, and concurs with agreements between the NSF and the MO. The NSF distributes funding from the international partners to the MO, and provides financial oversight, communicates Board resolutions to the MO, ensures fiscal compliance, and periodically recompetes the MO. The MO is responsible for the management and operations of Gemini, and implements the vision of the Board. Since inception of the Gemini project in 1994, the Association of Universities for Research in Astronomy (AURA) has filled the role of MO through a CA with the NSF.

In accordance with the National Science Board (NSB) resolution NSB-08-12 on the Competition and Recompetition of NSF Awards, a proposal solicitation was made in August 2014 (NSF 14-594) for potential Gemini MOs. This was delayed by a year, from the original timeline, to offset NSF facility recompetitions from each other, and allow a new International Agreement to be in place before the CA was negotiated. The new International Agreement, approved in 2016, provided for a limited-term partnership, and extended the 23% budget reduction caused by the withdrawal of the UK from Gemini in 2012. After site visits of potential proposers, hosted by the incumbent MO, letters of intent were followed by full proposals in February 2015. A 17-member review panel delivered written reports three weeks prior to a meeting (of 14 panelists) in April 2015. The review criteria, as specified in the solicitation, spanned the management model; budgeting and financial plans; and the benefits, risks, and cost efficiency of the proposed approach. During the review, the panelists had the opportunity to solicit feedback from the proposers. Following submission of the panel summaries, the proposing teams had face-to-face meetings with the NSF in July 2015. AST and the Gemini Board discussed the merits of the proposals over the ensuing six months. A recommendation was made to the NSB in February 2016, which subsequently approved the selection. The new CA commenced in January 2017.

The NSF is to be commended on its thoughtful process for the Gemini recompetition, which resulted in a seamless continuation of Gemini's core mission, in a challenging international funding environment. The proposal solicitation, which included three widely disseminated DCLs and engagement with potential proposers at all stages, enabled a fair and open competition. The selection process for the panel members yielded a commendably wide range of expertise and backgrounds. Panelist conflicts were avoided through an initial screening based on the proposers' letters of intent, and self-reporting following NSF conflict-specific briefings. However, the COV encourages AST to seek greater expertise in education and public outreach in such panels, even by approaching panelists from outside Astronomy, given the critical role of Broader Impacts in the merit review process. For example, only one of the 17 Gemini panel members was listed as having partial expertise in education and public outreach.

The Gemini Observatory is preparing for integration into NCOA, and a strategic shift toward more nimble operations (partially through the Gemini In the Era of Multi-Messenger Astronomy [GEMMA] initiative). Nevertheless, the development of facility instrumentation for Gemini has not fully leveraged the wide user base of Gemini in the U.S. community, as well as opportunities in a rapidly evolving scientific environment.

> **Recommendation 9**. NSF should explore competing major new Gemini instruments through MSIP, while maintaining a smaller internal fund for instrument upgrades.

5.1.2 Arecibo Observatory: Recompetition and Divestment

Figure 8: A bird's-eye view of the massive, 1000-foot diameter radio dish.

The Arecibo Observatory (AO) operates a 305-m diameter radio telescope, one of the crown jewels of U.S. radio astronomy and until recently largest single dish in the world (Figure 8). The observatory is located near the city of Arecibo, Puerto Rico. AO conducts radio-astronomical observations, solar system radar studies, and measurements of the Earth's upper atmosphere and ionosphere. Historically, funding for Arecibo was shared between AST in MPS, AGS in the NSF Directorate for Geosciences, and NASA. Arecibo was operated by an MO through a CA until 31 March, 2018. After that, a new MO, selected through the recompetition process described below, assumed that role.

The Arecibo recompetition was conducted within the context of the 2012 AST portfolio review, and a parallel 2015 AGS effort, both of which recommended, in broad terms, that the NSF reduce its financial involvement in Arecibo by the end of the decade. A similar recommendation later was made by the "New Worlds, New Horizons: Midterm Assessment" in 2016. The possibility of significantly reduced NSF investment triggered a mandatory Environmental Impact Statement (EIS). Community input was sought, via a DCL in October 2015, to identify potential alternative futures for Arecibo. A draft EIS was released in October 2016, outlining a number of possible outcomes for AO, including the agency-preferred "Collaboration with Interested Parties for Continued Science-focused Operations." The community was informed, via a DCL, of a solicitation for proposals from potential MOs, focusing on the agency-preferred alternative. The solicitation was released in January 2017.

That solicitation invited proposing teams to visit Arecibo. The site visit, in March 2017, was hosted by NSF staff with the participation of key AO personnel. **We suggest that future site visits of this nature be designed to better acquaint proposers not only with the physical infrastructure, but also the programs, staff, and scientific potential of the facility.**

A panel to consider the MO proposals met in June 2017. Conflicts of interest had previously been screened through vetting the proposal data and self-reporting. The panel provided written reviews prior to their meeting, which the AST synthesized to solicit answers to specific questions given to the proposers. The panel also had the opportunity for further anonymous interaction with the proposers. NSF staff with significant facility management expertise were invited to observe the panel discussions. They helped develop further lines of inquiry, based on risk/benefit assessments. The major risk identified was that the new MO might not be able to secure sufficiently strong financial partnerships to compensate for the scheduled ramp-down of NSF funding over the five-year duration of the agreement. Finally, the NSF met with the proposers to discuss responses to a last set of questions based on issues raised by the panel.

Overall, the recompetition review process was fair and comprehensive. The NSF made a significant effort to address issues raised by the external reviewers through repeated engagement with the proposers. The panel was sufficiently diverse in its composition and expertise. **Although we appreciate that the unique nature of the Arecibo recompetition/transition necessitated the involvement of panelists with significant facilities management experience, it would be preferable in similar future cases to also include members with expertise on the Broader Impacts side, for example education and outreach.**

Upon conclusion of the review process, a Record of Decision formally selecting the agency-preferred alternative was released in November 2017. The process was completed with an award to the new MO in February 2018. The transition was complicated, however, by the one-two punch of Hurricanes Irma and Maria, which devastated parts of the island and damaged the telescope and several support buildings. Congressional funding for hurricane repairs currently is being managed by NSF through the new MO.

The hurricanes also destroyed much of the power generation and other infrastructure on the island, leaving Arecibo and its employees under difficult living conditions. These challenges, combined with the move to a new MO, led to significant turnover in personnel, especially among the scientific staff.

The knowledge and experience of the staff of any facility is a crucial asset. **During a major transition, whether new management, significant staff reorganization, or defining a new mission for the facility, particular attention should be paid to retention of key staff.** It is unclear to the COV whether more could have been done in the case of Arecibo, especially since the transition occurred during particularly trying circumstances dictated largely by external events.

Nevertheless, NSF AST is to be commended for achieving its preferred alternative for future operations of Arecibo with substantially reduced NSF funding. This will allow continued high-impact science from the unique facility, while helping AST balance its portfolio. We acknowledge the extraordinary efforts on the part of AST staff required to divest from Arecibo, given the complexity of the recompetition process, while also ensuring compliance with mandated assessments (NEPA, NHPA, and ESA). **The scale of the effort, together with the uncertainty faced by the Arecibo user community and observatory staff, should serve as a cautionary tale for future divestments.**

5.2 Management of Facilities through CAs: NOAO and NRAO

5.2.1 National Optical Astronomy Observatory

NOAO is the U.S. national center for ground-based OIR astronomy, currently managed by AURA under a CA with the NSF. The fundamental mission of NOAO is to enable discovery in ground-based OIR astronomy for all qualified researchers by ensuring open access to state-of-the-art observational facilities, data products, and data services. NOAO also facilitates community-based planning for future facilities, instrumentation, and data services. NOAO has undergone a dramatic transformation during the past five years, which will continue in the near future.

NOAO South (CTIO) offers open-access for PI and survey programs, and supports operations and maintenance for the Blanco 4-m facility on Cerro Tololo, including the Dark Energy Camera (DECam). CTIO also operates the SOAR 4.1m telescope on Cerro Pachón on behalf of the SOAR partnership.

The primary focus at NOAO North (Kitt Peak) is shifting toward major scientific programs centered on DOE and NASA projects. These include DESI for the Mayall 4-m and NEID for the WIYN 3.5-m. The popular Kitt Peak Visitor Center continues to serve about 50,000 patrons per year.

The NOAO Community Science and Data Center provides: (1) support for US users of the Gemini Observatory; (2) data management operations for NOAO facilities; (3) design of LSST community science support, consistent with the National Research Council OIR System Optimization Study and subsequent NSF directives; and (4) data services, including the NOAO Data Lab. ANTARES, a joint project between NOAO and the University of Arizona, coordinates community event-brokering for LSST, Zwicky Transient Facility, and other time-domain surveys. The mission of the NOAO Data Lab is to enable efficient exploration and analysis of the large datasets currently delivered by instruments on NOAO, and other, wide-field telescopes. Debut of NOAO Data Lab services was in June 2017, at the summer meeting of the AAS. The Data Lab now includes the FY2018 DES Public Release 1.

NOAO has been actively working toward a FY2020 transition to NCOA, a single NSF-sponsored center that will integrate NOAO, Gemini, and LSST operations.

This COV strongly endorses the dramatic restructuring that NOAO has accomplished over the reporting period, in the face of difficult budgetary circumstances. New opportunities, now and on the horizon, should make a bright future for U.S. OIR astronomy.

5.2.2 National Radio Astronomy Observatory

NRAO conceives, designs, builds, operates, and maintains world-class radio telescopes used by scientists from around the globe to study virtually all types of astronomical objects, from bodies in our own Solar System to galaxies in the distant universe. NRAO is managed by Associated Universities, Inc. (AUI) under a CA with the NSF. In 2016, AUI was selected to continue management of NRAO through 2026. (The details of that recompetition were not reviewed as part of this COV.)

NRAO observing facilities currently include the mm/sub-mm interferometer ALMA, in Chile; the large cm array JVLA, near Socorro, New Mexico; and the continent-spanning cm interferometer VLBA, with antennas at ten sites in Hawai'i, St. Croix, and across the U.S. In FY2018, the NSF approved the re-integration of VLBA with NRAO after successful efforts to secure a partnership with the USNO to split operations costs.

In addition to the observatories mentioned above, NRAO also hosts the CDL, in Charlottesville, VA, whose mission is to maintain and support NRAO's existing facilities, and to provide technology and expertise needed to build the next generation of radio astronomy instruments. Current work includes: low-noise amplifiers; mm and sub-mm detectors; optics, including feeds; and electromagnetic components, such as digital signal processors, integrated receivers, and other new receiver architectures. CDL's long-range technology development strategy is constantly evolving, and the laboratory continues to play a key role in NRAO as well as radio astronomy in general.

ALMA is reaching operational maturity. Observing time continues to be heavily oversubscribed: ~1800 proposals now are submitted each cycle. On the JVLA side, NRAO designed and implemented, with substantial community input, a major new Sky Survey (VLASS). It began in 2017 and will map 80 percent of the sky in three epochs over seven years. VLASS is expected to catalog a remarkable 10 million radio sources.

In addition to supporting key facilities for current science, NRAO is planning how to maximize its impact in the next decade, as Multi-Messenger Astronomy and the transient universe provide major new opportunities that will strongly benefit from multiwavelength collaborations. NRAO also is studying a next-generation large radio facility, the ngVLA, which aims to achieve unprecedented resolution and sensitivity at cm wavelengths.

This COV is impressed with the solid progress of NRAO over the review period, and especially lauds the forward thinking of the organization with regard to rapidly evolving future prospects.

5.3 Oversight of MREFC Projects in Development: DKIST

DKIST (Figure 9) is a $344M project within NSF's MREFC program, one of two such efforts currently underway for AST (the other is the LSST, which was not considered by this COV). The 4-m solar telescope is an unconventional off-axis design, to accommodate the necessary active cooling of the focal plane due to the intense heating by the primary beam, and maintain an unobstructed aperture for cleaner polarization and mid-IR performance. The large aperture, together with AO, delivers remarkably high-resolution imaging of the Sun, below 70 km (a key scale length of the radiation transport), but mainly is needed to provide sufficient light for sensitive spectro-polarimetric measurements on small spatial scales with fast cadences to follow dynamic phenomena in the solar plasma. The facility incorporates an extensive multi-spectral suite of instruments working in tandem, to explore fundamental processes in the solar surface layers and atmosphere, in unprecedented detail and clarity, especially magnetoconvection.

Solar magnetism not only represents a class of phenomena that occurs widely in the cosmos – for example, magnetospheres of planets and neutron stars, and magnetized accretion disks of T-Tauri objects and Active Galactic Nuclei – but transient magnetic events on the Sun, like flares and mass ejections, can adversely affect the Earth and its inhabitants. DKIST is unique in the international Solar Astronomy community: no comparable facility is in even an early stage of development in Europe, or elsewhere. Initial construction began in 2012, in the State of Hawai'i on the summit of Haleakala, Maui; after a few years delay to meet environmental and cultural challenges. The facility now is more than 90% complete. First light is expected in late 2019, and full operations in mid-2020. Projections put DKIST within budget when construction is finished.

Figure 9: Nearly completed DKIST facility on the summit of Haleakala, Maui.

Given the unconventional design and sophisticated instrument suite, the DKIST engineering is complex and challenging. As a key NSF MREFC project for Astronomy, DKIST construction has received considerable scrutiny and oversight. At the heart is the Integrated Project Team (IPT), the core of which consists of the AST PO, the Grants and Agreements Officer, and a liaison from NSF's Large Facilities Office (LFO). Other members of the IPT are drawn from relevant divisions and offices within NSF. Meetings with the full IPT membership are held quarterly. Scheduled telecons, and frequent informal contacts, between the AST PO and the DKIST team maintain an essential dialog in the oversight process.

Progress assessments are based on monthly reports from the DKIST project; an Annual Report; an external Program Review every year; and other non-program efforts including business systems, independent risk assessments, software quality assurance, and various financial audits. A construction project of the magnitude and complexity of DKIST involves numerous Change Requests, more than 970 to date, requiring various levels of approval by NSF. This applies to contingency drawdowns, as well.

In addition, there are a series of Stakeholder interactions involving the AST PO and the directors' offices of National Solar Observatory and DKIST; interested parties such as the National Park Service (which manages the Haleakala summit), the University of Hawai'i Institute for Astronomy (from whom the DKIST site is leased), and the United States Air Force (which operates facilities on the summit); various advisory committees such as the AURA Solar Observatory Council and DKIST Science Working Group; and ad hoc discussions at public venues such as AAS Solar Division meetings.

The COV is impressed with the multiple layers of assessments, reviews and audits of this MREFC project, and considers the fact that DKIST is expected to meet budget and schedule as evidence of the success of the NSF oversight.

6 Electromagnetic Spectrum Management

Radio astronomy continues to push the boundaries of receiver and signal-processing technology; moving towards lower noise levels, wider bandwidths, and ever more advanced detection and analysis algorithms. At the same time, the 2015–2018 COV review period saw an increase in commercial bandwidths and modulation complexity; growth in cm-wavelength systems; and an overall proliferation of communication and remote sensing activities. NSF-AST funds a large and important suite of radio astronomy facilities and MSIP radio experiments. Loss of data to RFI, from various fixed and mobile sources, represents lost scientific opportunities.

In order to manage the RFI environment and increase spectrum access, NSF-AST hosts the office of ESM, which fulfills a crucial role representing the interests of NSF-funded researchers both nationally and internationally. At present, ESM encompasses radio bands up to $\sim$ 1 THz. Although the existence of the ESM office is not widely known within the Astronomy community, its role in advocating for astronomical interests cannot be overstated. ESM is the face of the NSF at the National Telecommunications and Information Administration (NTIA), serving on ten subcommittees including the Interdepartmental Radio Advisory Committee (advisory to the NTIA). ESM also coordinates with the Federal Communications Commission (FCC). ESM participates in U.S. delegations to the Inter-American Telecommunications Commission, and the World Radiocommunication Conference of the International Telecommunications Union (ITU-R). In the latter, ESM leads Working Party 7-D (radio astronomy). NTIA and FCC regulate domestic access to the electromagnetic spectrum, while ITU-R implements international rules.

In March 2018, ESM set up the NSF ESM coordination group, currently chaired by Dr. Williams. This group has representatives from other NSF divisions, including previous ESM lead Dr. Sharma, enabling effective coordination among the interests of multiple research areas, a more unified voice for external representation, and the sharing of techniques and technology. The coordination group also is charged with updating the more than decade-old NSF Long Range Spectrum Plan.

ESM further interacts with the community by supporting (together with NASA) the Committee on Radio Frequencies (CORF) of the National Academies, whose membership includes radio astronomers. In addition, the NSF previously funded the EARS program, which was replaced in 2016 by “Spectrum Efficiency, Energy Efficiency, and Security” (SpecEES) [Engineering Directorate - Electrical, Communications and Cyber Systems Division].

Through the coordination and representation described above, AST ESM aims to keep protected wave-bands as free of RFI as possible, and to use technological advances to increase spectrum availability. This is a challenging task, because immense commercial interests, both on the ground and in space, make spectrum access extremely valuable. For example, the 2008 US wireless spectrum auction raised nearly $20B.

The ESM office is to be commended for maintaining and enhancing active representation on key committees that advise regulatory bodies, and for leading the formation of the NSF ESM coordination group. We urge the continued pursuit of these activities.

> **Recommendation 10**. AST should raise the profile of the ESM office and related NSF programs in the astronomical community, enabling a better flow of relevant information and transfer of knowledge.

We offer several avenues to support this recommendation. First, ESM-relevant language could be written into solicitations for proposals to build and operate radio-astronomical instrumentation. This might involve, for example, requesting proposers to outline their strategies for managing RFI, or include ESM-specific information in their reporting requirements. Second, the ESM office could reach out directly to PIs on relevant programs to raise awareness of available resources. Third, there could be greater coordination with the NRAO, Green Bank Observatory (GBO) and Arecibo Users' Committees. Finally, ESM could explore partnering with commercial entities, especially those that can influence the drafting of requirements and guidelines for industry.

7 AST Management

The management of the AST is in an excellent state. This COV heartily commends DDs Drs. James Ulvestad and Richard Green, DDDs Drs. Patricia Knezek, David Boboltz, Ed Ajhar, and Ralph Gaume, and the entire AST staff for their superb work over the four years under review.

The managements of the individual investigator programs are reflective and data-driven in a way that allows continuous improvement. The open AAG call promotes flexible response to evolving community priorities. A notable example is the dramatic growth of exoplanet research during the COV period, from basic discovery initially, to broad, intensive study now.

The management of the special programs, crucial for workforce development, also has been very good. Unfortunately, success rates of AAPF and CAREER grants have been only half those of the AAG overall, and some consideration should be given to diverting additional resources to these vital programs.

The management and oversight of large facility construction projects has been superb. During the COV period, two MREFC projects – LSST and DKIST – have proceeded very nearly on time and on budget, while operations of recently completed ALMA have ramped up smoothly, with intensive community use and an impressive yield of forefront discoveries.

7.1 Program Officer Staffing

7.1.1 Staffing Level

The previous two COV reports both called for an increase in the PO staffing of AST. The current committee finds that after four years this recommendation remains a priority.

> **Recommendation 11.** Rapidly recruiting additional AST POs and replacements for key AST staff must be a high priority for NSF.

The Facilities POs, for example, have been especially overburdened during this period with the combination of extensive regulations associated with mandated facility divestments, major observatories under construction, new enterprises moving into operations, and ever-increasing requests for reports and accountability.

Further, the COV recognizes the special value of, and important contributions by, Division Rotators. They represent an opportunity to enhance community presence and connection, especially in the Independent Investigator Program.

7.1.2 Staff Demographics

The COV notes the need for the demographics of AST leadership and POs to better reflect that of the changing astronomical community.

> **Recommendation 12.** AST develop and implement plans to achieve a more representative Program Officer and Division leadership.

The COV recognizes that any change in demographics must involve active recruitment and fostering the interest of underserved communities. As possible avenues, the COV suggests targeting Hispanic-Serving Institutions, Historically Black Colleges and Universities, and advocacy organizations (e.g., Society for Advancement of Chicanos/Hispanics and Native Americans in Science, Society of Black Physicists); incentivizing more early-career astronomers, possibly by new internships, as well as through the on-going American Association for the Advancement of Science fellowship program; and recruiting from non-academic pathways or regional State Universities, which might bestow more merit reward for NSF service than traditional Universities.

7.2 Planning and Implementation

The Division consistently provided excellent planning, prioritization, and management in response to multiple advisory committees[5], immediately prior to and during the COV period. We highlight several examples below.

The COV particularly commends AST for meeting remarkably well the charge from the 2012 Portfolio Review to divest or reorganize a number of facilities to free up funds for new opportunities. Doing so was a serious challenge, logistically and politically, which was handled effectively, with notable care for those most affected. The outcome was an array of scientifically vibrant facilities largely operated on non-NSF funding.

That said, there were important lessons learned from the divestment exercise. For several reasons, the effort did not recover entire operations budgets, with a yield of only ~50%. Furthermore, the cost of divesting facilities can be high, especially to comply with complex regulations, such as the ESA, NEPA, and NHPA. The committee commends the Division staff for the effort devoted to accomplishing the Portfolio Review mandate, but the question remains whether the outcome was cost-effective, financially and scientifically, for AST and the community as a whole.

A primary strategic opportunity during this period was Time-Domain Astronomy, looking forward to the commissioning of LSST in the near future. AST has done an excellent job in developing and managing strategic restructurings to position the ground-based OIR system for success in this new era. Particularly notable are the Gemini-Blanco-SOAR coordination, ANTARES, and the major NCOA

---

[5] Astro2010 Decadal Survey, the 2012 AST Portfolio Review, the mid-Decadal review, and the 2015 National Academy Report – "Optimizing the U.S. Ground-Based Optical and Infrared Astronomy System."

reorganization for public ground-based OIR facilities. Parallel efforts are on-going in the NSF-supported radio community as well.

The 2010 Decadal Survey highly prioritized a mid-scale funding program. The MSIP has been responsive to that call, and its management has led to effective outcomes. Although the internal funding for MSIP has not attained the Decadal Survey goal, due mainly to budgetary constraints, the committee commends AST for its wise integration of their Divisional response within the agency-wide MSRI program, to leverage additional resources.

Lastly, the COV lauds the excellent communications between AST and NASA-APD, which is yielding important collaborations and coordination. These channels now are largely informal, and dependent on current individuals. Given the demonstrated success, the COV advocates making these channels more formal to enhance sustainability. The COV also urges similarly effective lines of communication to be established between AST and its other major U.S. partner, DOE.

Recommendation 13: AST formally designate interagency liaisons for NASA and DOE.

7.3 Overarching Thoughts

The COV noted that AST lacked concrete success metrics, beyond science highlights and managing the available funds appropriately. The importance of the latter is not to be minimized, but in the end, it is the full sweep of scientific and broader impact outcomes that must be counted as well. The COV notes that some of the MOs have adopted success metrics as part of their evaluative structures, and we urge AST to develop a parallel set to aid the work of future assessment committees.

Recommendation 14. AST, with Astronomy Community input, develop Division metrics according to Intellectual Merit and Broader Impact for use by future COVs, and others.

Developing useful metrics is a tricky business, of course. For example, instrumentation programs, such as ATI, produce long-lasting results, enabling a variety of science goals for years to come. However, a metric that follows the output of an ATI grant only through the end of the grant period neglects these significant future benefits.

Finally, the committee noted the challenge of managing relative budgetary priorities, especially between individual investigator awards and large facility operations. **The committee echoes previous COVs in urging the AST to continue to ensure a substantial and vigorous IIP.**

8 Strategic Planning and Implementation

8.1 Response to 2010 Decadal Survey

The committee received a detailed briefing from DD Green concerning the AST response to the 2010 Decadal Survey and the subsequent Mid-Decade Progress Review. He also summarized actions taken in response to the 2012 Portfolio Review, and discussed annual Division updates to recommendations from the previous COV.

The AST was able to make progress on only two of four major recommendations of the Decadal Survey: (1) start LSST in the MREFC queue; and (2) implement a robust MSIP with anticipated funding of $40M/yr. The first item was successfully done, and the second was implemented, but at a budget only about half that recommended. There also was a small investment toward the design of a partnership model for the Thirty Meter Telescope. However, the other two major recommendations could not be acted upon: [3] immediate selection by the NSF of one of the two U.S.-led Giant Telescope projects, with a goal of a 25% share; and [4] U.S. participation in construction and operations of the Atmospheric Čerenkov Telescope Array, at approximately $100M over the decade.

As was addressed by the previous COV, there remains a significant gap between the actual funding of MSIP and the Decadal Survey recommendation, driven mainly by budget considerations. We find that the Division has made reasonable choices to achieve a strong MSIP, given the current funding environment.

DD Green also discussed additional Decadal Survey recommendations specifically for the AST. Here, progress has been considerably slowed, again because of budgetary limitations. The largest item was to increase the AAG to $54M/yr (ca. 2010). The FY2018 budget for AAG was only $51M, however, albeit a significant recovery from a low of $42M in FY2013. The COV noted that in *inflation-adjusted* dollars, the current AAG budget falls well short of the 2010 Decadal aspiration. This accounting further emphasizes the lack of growth in the AAG budget over the past decade, which undoubtedly will catch the attention of the 2020 Survey as well.

We commend the AST for its careful stewardship of the Division budget, under difficult funding circumstances, and for the care it has taken in implementing the highest-ranked recommendations of the 2010 Decadal Survey.

8.2 Response to 2012 Portfolio Review

DD Green also presented the Division's response to the numerous recommendations of the 2012 Portfolio review. The COV finds that the Division was highly responsive to these recommendations, where budget and other constraints permitted action, and we commend AST leadership and staff for their dedication and hard work in this area.

The most significant recommendation was that AST divest several facilities and programs. AST managed to achieve significant cost savings from this process, about $36M/yr (although not as much as hoped). The divestment activities at Sacramento Peak, Arecibo, and GBO required a tremendous amount of labor from AST staff, the LFO, and the Office of the General Counsel. Most of the divestment was achieved because other partners were found who would continue to operate the facility in one manner or another. At the same time, upcoming LSST and DKIST operations costs are expected to reach a steady state of about $66M/yr, which will put greater pressure on funding for the other facilities remaining in the AST portfolio, as well as on the grants program itself.

The COV applauds AST for its diligent and dedicated efforts to implement the recommendations of the 2012 Portfolio Review. In undertaking the divestment effort, AST has developed internal expertise, as well as strong working relationships with salient Offices within NSF, including the General Counsel, Legislative Affairs, and Large Facilities. While we hope that the laborious divestment process will not be needed again in the near future, we anticipate that further divestments might be required in response to Congressional mandates, or to maintain an effective grants program in an era of flat AST budgets.

> **Recommendation 15.** AST should preserve its expertise in the divestment process, including compliance with governing laws, and maintain interfaces with the key Offices within NSF.

8.3 Anticipation of the 2020 Decadal Survey

The COV was provided with detailed trends of the AST funding since FY1990, as distributed over individual awards and supported facilities. It has long been the goal of AST, as strongly advocated by the community, to maintain sufficient funding for a vigorous IIP. The largest of the grants programs in IIP is the AAG; MSIP is only about 40% of the size of AAG.

The trends in AAG funding show a steady increase from $17M ($31M in 2018 dollars) averaged over FY1990–1993, to $48M over FY2015–2018. This represents a tepid growth of about 1.8%/yr (over inflation) for AAG over the past 25 years (the U.S. population grew at 0.9%/yr during that time). While any growth certainly is welcome, the current funding has not matched increasing demand: proposal success rates have fallen from roughly 45% to 20% over the same period.

DD Green presented budget projections for AST forward to FY 2024, based on scenarios for which the AST budget either remains flat or increases by 2.5% per year. Both models assumed no further reductions in facilities budgets over that interval, and that AST would take on only part of the LSST operating costs. Even in the optimistic scenario of a small annual increase, the IIP programs would receive about $60M–$65M in FY 2024, roughly equal to the amount spent in FY 2018 (in constant dollars). A flat budget would more severely strain the IIP, significantly reducing the inflation-adjusted budget by FY2024. Even worse, if AST must bear the full cost of LSST operations, the IIP program would decline to only about 6% of the AST budget in FY2024 (from about 25% today).

These budget scenarios leave no room for any possible large initiatives recommended by the 2020 Decadal survey, unless new MREFC funding is accompanied by a substantial increase in the AST operating budget for current and, especially, future facilities.

Appendix A: Core Questions

Briefly discuss and provide comments for *each* relevant aspect of the program's review process and management. Comments should be based on a review of proposal actions (awards, declinations, returns without review, and withdrawals) that were *completed within the past four fiscal years*. Provide comments for *each* program being reviewed and for those questions that are relevant to the program(s) under review. Quantitative information may be required for some questions. Constructive comments noting areas in need of improvement are encouraged.

I. Questions about the quality and effectiveness of the program's use of merit review process. Please answer the following questions about the effectiveness of the merit review process and provide comments or concerns in the space below the question.

QUALITY AND EFFECTIVENESS OF MERIT REVIEW PROCESS	YES, NO, DATA NOT AVAILABLE, or NOT APPLICABLE
1. Are the review methods (for example, panel, ad hoc, site visits) appropriate? Panel and ad hoc reviews are used appropriately for Individual Investigator Proposals. Ad hoc reviews are invoked properly when topical knowledge is required to properly evaluate a proposal. **Data Source: EIS/Type of Review Module**	Yes
2. Are both merit review criteria addressed? a) In individual reviews? b) In panel summaries? c) In Program Officer review analyses? Individual reviews generally do a good job evaluating the intellectual merit of a proposal. However, the evaluation of broader impacts has much greater variance and on the whole is not well-addressed. Panel summaries reflect on the whole a greater synthesis of evaluation than the individual reviews. They however follow a similar trend and only somewhat improve the thoughtful consideration of broader impacts. **Data Source: Jackets**	 Yes Yes Yes

3. Do the individual reviewers giving written reviews provide substantive comments to explain their assessment of the proposals? a) In individual reviews? b) In panel summaries? c) In Program Officer review analyses? Individual reviewers, on average, perform good written reviews with substantive comments for intellectual merit. Individual reviewers, on average, do not provide substantive comments for broader impacts. **Data Source: Jackets**	**IM: Yes** **BI: Variable**
4. Do the panel summaries provide the rationale for the panel consensus (or reasons consensus was not reached)? On average, panel summaries provide a reasonable synthesis of the panel discussion for intrinsic merit, but with rather less substance for broader impacts. There are exceptions where significant discrepancies in individual reviewers' evaluations are not reconciled in the panel summary. The panel summaries show considerable variance in constructive feedback provided to reviewers. **Data Source: Jackets**	**Yes**
5. Does the documentation in the Jacket provide the rationale for the award/decline decision? The Jacket documentation provides good rationale for the award/decline decision. **Data Source: Jackets**	**Yes**

6. Does the documentation to the PI provide the rationale for the award/decline decision? In most cases, the documentation to the PI is adequate to relate the rationale for the award/decline decision. However, thoughtful panel summaries are central to this process, and considerable variation in summary quality exists. The lowest-quality fraction of panel summaries may not transmit to PIs a clear perception that a competent, fair and thoughtful review was performed. **Data Source: Jackets**	**Yes**
7. Additional comments on the quality and effectiveness of the program's use of merit review process:	

II. Questions concerning the selection of reviewers. Please answer the following questions about the selection of reviewers and provide comments or concerns in the space below the question.

SELECTION OF REVIEWERS	YES, NO, DATA NOT AVAILABLE, or NOT APPLICABLE
1. Did the program make use of reviewers having appropriate expertise and/or qualifications? The level of commentary on Broader Impact is markedly less than that for Intellectual Merit. It is not possible to tell solely from the Jackets whether the panels lack expertise on Broader Impact or the panelists are not given sufficient instruction in how to evaluate Broader Impact. The committee recommends that (1) program officers take care to find reviewers with expertise and experience in the spectrum of broader impact activities, and that (2) the program directors provide more detailed instruction and supervision about evaluating Broader Impact. **Data Source: Jackets**	Yes
2. Did the program recognize and resolve conflicts of interest when appropriate? Handling conflicts of interest was clearly documented in the Jackets. **Data Source: Jackets**	Yes
3. Additional comments on reviewer selection: The committee recognizes that obtaining reviewers is a difficult task, and we commend the efforts of AST to ensure panelists who have the required expertise and who represent diverse backgrounds.	

III. Questions concerning the management of the program under review. Please comment on the following:

MANAGEMENT OF THE PROGRAM UNDER REVIEW
1. Management of the program. The management of AST is in an excellent state. The management of the individual investigator programs are reflective and data-driven in the spirit of continuous improvement. The open AAG call continues to permit flexible responsiveness to community definition of scientific priorities, with a notable example being the evolution of exoplanet research beyond discovery during this period. The management of the special programs, crucial for workforce development, has also been very good. The management and oversight of large facility construction projects has been superb. The committee is very impressed with the several major projects being, on the whole, very near on time and on budget. The committee has noted the challenge of managing the relative budgetary priorities, especially between individual investigator awards and large facility operations. The committee urges the AST to continue their excellent work in ensuring a substantial and vigorous individual investigator program.
2. Responsiveness of the program to emerging research and education opportunities. A primary strategic opportunity during this period was time-domain astronomy, recognizing the commissioning of LSST in the near future. AST has done an excellent job in developing and managing several restructurings to position the ground-based system for success in this new era. Particularly notable is the Gemini-Blanco-SOAR coordination and the major NCOA reorganization for coordination of public ground-based facilities. Similarly, the 2010 Decadal Survey highly prioritized a mid-level funding program. Again, the MSIP program is highly responsive to that call, and its management has led to effective outcomes. Although the internal funding for MSIP has not reached its goal, the committee commends AST for its wise integration of their Divisional response with the agency-wide MSRI programs. Primary responses to education opportunities lie in workforce development programs - REU, AAPF, CAREER. The management of these programs has been very good, with particular note of the continued attentiveness during this period to the AAPF program. Unfortunately, success rates of AAPF and CAREER grants are only half those of the AAG overall, and some consideration should be given to diverting additional resources to these vital programs.

There has been minimal response to other education opportunities. Diversity opportunities have unfortunately decreased as a result of the ending of the PAARE program without offsetting involvement in the INCLUDES initiatives.
3. Program planning and prioritization process (internal and external) that guided the development of the portfolio. During the review period the Division consistently provided good planning, prioritization and management in response to multiple advisory committees immediately prior to and during this period. AST has met remarkably well the charge from the 2012 Portfolio Review of divesting or reorganizing a large number of facilities to free up funds for new facilities. Doing so was a serious challenge, logistically and politically, that was handled effectively, with notable care for those most affected. The management yielded an array of scientifically interesting facilities largely operated on non-NSF funding. That said, the community needs to think carefully before going down this path again. For an array of reasons, the effort did not recover entire budgets, with a yield of approximately 50% of available funding. The effort was far more work than realized due to regulations, such as the ESA, NEPA, and NHPA. The committee commends the division staff for the amount of effort placed into accomplishing this charge (and their expertise should be maintained), but it still begs the question of whether the implemented process was cost effective for AST and for the community. More broadly, the committee noted that success metrics for the AST were not provided to the committee, beyond awarding and managing all the available funds appropriately and science highlights. These last are not to be minimized, but in the end, it is the scientific and broader impact outcomes that are the most important metrics. (See priority Recommendation 7.)
4. Responsiveness of program to previous COV comments and recommendations. AST has done an excellent job in responding to the 2014 COV comments and recommendations with the constraints of budget. AST has been very transparent in their responses.

IV. Questions about Portfolio. Please answer the following about the portfolio of awards made by the program under review.

1) %Does the program portfolio have an appropriate balance of awards across disciplines and sub-disciplines of the activity?

Yes. Fields change over time, sometimes rapidly, and the philosophy of responding to proposal pressure allows the NSF to stay nimble and responsive with a balance of awards across disciplines. Over the past two years, the NSF has experimented with accepting grant programs year-round. However, one benefit of having fixed submissions is that this allows for optimal differential comparison.

The NSF also directly supports instrument development through the ATI, MRI, and MSIP programs. These programs provide outstanding training that is critical for development of a globally competitive technical workforce.

2) %Are awards appropriate in size and duration for the scope of the projects?

Yes. Most proposals request a standard time interval of 3 years with budgets that appear to be tailored to the median dollar awards. However, there are also examples of projects that are done in shorter 2-year intervals as well as 4-year intervals, suggesting that the community is designing research programs that have appropriate scope and budget.

3) Does the program portfolio include awards for projects that are innovative or potentially transformative?

Yes. This is an extremely productive time and science results that emerge from the grants program are making headlines. Some examples include: the ground-breaking image of the supermassive black hole in M87 by the EHT; the radio-wave detection of the first stars that formed after the Big Bang obtained by the EDGES program; breath-taking images of protoplanetary disks around young stars obtained by ALMA; gravitational waves from merging black holes and neutron stars by the LIGO project; the origin of high-energy neutrinos and cosmic rays with the IceCube Neutrino Observatory.

Many of these discoveries were enabled by earlier support of design concepts through the ATI program. The ATI program is an avenue for funding high-risk, high-reward innovations that set the stage for mature technologies that drive the field: charge coupled devices, infrared detectors, AO, laser frequency combs, multi-object spectrographs. The seed corn of discovery from the ATI program led to development of the LSST and EHT. It is of concern that financial planning constraints within the NSF resulted in cancellation of the ATI program in 2018 with the plan of offering ATI every other year (alternating with the MSIP program). Citations are one metric of research success and the citation profile for ATI awards is comparable to pure science programs such as Planetary awards. This is despite the fact that instrumentation and techniques developed by ATI grants have ongoing scientific impact well beyond the end of the grant, and this is not counted in the publication metrics for the ATI awards. The MRI and MSIP programs are also critical components of the NSF portfolio. Without this ensemble of instrumentation programs, it would not be possible to develop new instruments that enable transformative scientific discoveries.

4) Does the program portfolio include inter- and multi-disciplinary projects?

Yes. Cross-field collaboration has been especially critical for instrumentation. Engineering, physics and astronomy collaborations were needed for the EHT and the polar programs such as IceCube. Geophysics, physics and astronomy collaborations improve our understanding of exoplanet atmospheres and interiors. The portfolio includes grants to data scientists, statisticians and astronomers to develop new analysis methods. Multi-messenger astronomy, LIGO, radio astronomy are all cross-cutting transdisciplinary projects. As noted by the NSF Director Dr. France Córdova, the ground-breaking image of the supermassive black hole at the heart of M87 (March, 2019) demonstrates the power of collaboration, convergence and shared resources.

5) Does the program portfolio have an appropriate geographical distribution of Principal Investigators?

Yes. Proposals are received from nearly every state in the U.S. and research grants are awarded throughout the U.S. There are small number fluctuations in the percentage of proposals awarded to each state, but in broad strokes, all sections of the country are supported at a nearly uniform level.

6) Does the program portfolio have an appropriate balance of awards to different types of institutions?

Yes. The balance of institutions appears appropriate. The proportion of proposals submitted and proposals accepted is very similar when viewed by institution type. However, only three categories are used: (1) Academic - PhD, (2) Academic - Bachelor's/Master's, and (3) Other. The strong majority of proposals and awards fall in the Academic - PhD category at approximately 80%. We recommend that NSF provide more granularity in the definition of institution type for this category. Possible metrics that could be used to add detail would be: number of astronomy PhDs, institution size, number of astronomy faculty, undergraduate to graduate student ratio.

7) Does the program portfolio have an appropriate balance of awards to new and early-career investigators?

We are concerned that the success rate for CAREER and AAPF programs are half that of the rest of the portfolio. CAREER and AAPF programs exclusively support early career scientists. Within the AAG program (excluding CAREER and AAPF), roughly 15% of proposers are early career scientists (< 10 years post-PhD) and this percentage doubles for astronomers that are 10 – 20 years out from their PhD. This is not unexpected since most astronomers complete one or two postdoctoral positions and institutions often do not allow postdoctoral fellows to serve as PIs on grants. We emphasize the value of the CAREER and AAPF programs for new and early career scientists.

8) Does the program portfolio include projects that integrate research and education?

Broader impacts help to ensure the integration of research and education. We note that broader impacts would benefit from, better proposals, better reviews and more robust comments by the program officers.

9) Does the program portfolio have appropriate participation of underrepresented groups?

This is a challenge that needs to be addressed. It clearly is a problem that is much larger than the NSF, but one in which the broader astronomical community is very engaged in and where the NSF can play an important role. We commend the division and program officers for their continued attention and efforts in monitoring and acknowledging this issue. Success rates for PIs of proposals and awards seem consistent for gender and other underrepresented groups, but the numbers are low. However, there is a clear trend that shows awards to early career astronomers (e.g., AAPF and CAREER) are at or near the gender balance in our field as a whole, while the largest awards (e.g., MSIP and ATI) fall far short of that level. We acknowledge that there may be differences in gender balance in various subfields. We recommend that the NSF continue monitor the levels of participation by underrepresented groups, provide transparency to the field, and explore best practices for addressing this challenging issue. For example, a pilot study could be performed using a double-blind format for review panels.

10) Is the program relevant to national priorities, agency mission, relevant fields and other constituent needs? Include citations of relevant external reports.

Yes. The division continues to enable transformative science that expands our knowledge, technological capabilities, and trains a highly technical workforce. We commend the division for responding to the recommendations from the New Worlds New Horizons Decadal Survey, its mid-term review, the 2012 Portfolio Review, and the NRC Optimizing the U.S. Ground-Based Optical and Infrared Astronomy System. These reports detail and explore recommendations during a very difficult budgetary decade for the division. Despite this, the division has enabled world-leading facilities and research, which has touched the broadest national audience (see §3).

11) Additional comments on the quality of the projects or the balance of the portfolio:

Having AAG success rate dip below 20% is unacceptable to the community.-Without an increase in the AST budget the operations costs for new and existing facilities will continue to put pressure on the individual grants programs.

V. QUESTIONS PERTAINING TO FACILITIES

1. Questions about the process for re-competing facilities management **(Gemini and Arecibo)**.
   a. %Was the process for soliciting proposals adequate and appropriate?

   Yes. We particularly commend the NSF for finding a path (alternative #1) to support continued operations at Arecibo.

   b. Were the review methods (for example, panel, site visits, engagement with proposers, etc.) appropriate?

   Yes. Engagement with the site and site staff is of critical importance for proposers and the NSF should emphasize such interaction for these types of competitions

   c. Did the Division make use of reviewers with suitable expertise and diversity, and did AST recognize and resolve conflicts of interest appropriately?

   Yes. The panels had sufficient expertise, though it was noted that the panel for Arecibo had no expertise in maintenance. It was unclear if the Gemini panel had direct expertise in operations in Chile and Hawai'i. Both the Arecibo and Gemini panels did include expertise in Education and Public Outreach. The panels were diverse and it appears all conflicts were resolved appropriately.

   d. Do the materials in the Jacket adequately document the award and decline decision, and were the assessment criteria appropriately applied?

   Yes.

2. Questions about AST's management and oversight of operational facilities through their Cooperative Agreements **(NOAO and NRAO).**

   a. Were the reporting requirements appropriate for the assessment of facility operations and the performance of the managing organization?

   NRAO: **Yes**

   NOAO: **Yes.** The reporting structure is in flux with the transition to NCOA. The NSF should work to streamline the reporting process for the new NCOA organization so that the transition doesn't add any undue burden on the operating organizations.

   b. Does the documentation in the Jacket and on-file at NSF suggest that AST has sufficient information to assess whether the awardee is fulfilling the terms of the CA and satisfying the expectations of stakeholders within and outside of NSF?

NRAO: **Yes.** NRAO facilities have produced groundbreaking science results and the VLA performance upgrade is extremely successful. We commend NRAO for their discussion about hiring the workforce of the future and providing a number of metrics for observatory performance. Demographic information in sufficient detail wasn't provided to measure the progress in hiring and retaining women and underrepresented minorities in the scientific and engineering staff. We recommend they develop metrics by which to track their success in growing this portion of their staff.

NOAO: **Yes.** We commend AST for moving forward the reorganization aimed at providing the best support for the community in the LSST era and working to implement the transition to NCOA.

c. Did the Division make appropriate use of external experts in assessing performance in facility operations and activities related to broader impacts?

Yes.

3. Questions about the Division's oversight of MREFC projects during the construction phase **(DKIST).**

a. Were the reporting requirements set by NSF sufficient to assess the performance of the managing organization?

Yes. The reporting is extensive and comprehensive.

b. Were the levels of engagement between AST and the awardee appropriate?

Yes. AST has frequent contact at the appropriate levels throughout the NSF IPT.

c. Did the Division make appropriate use of external experts in assessing performance and progress?

Yes.

d. Were the notification and approval processes for change requests requiring the use of budget contingency appropriate for proper oversight of the MREFC project?

Yes. Change requests were well documented.

4. Questions about AST's management of the transition (reduced investment) process **(Arecibo).**

a. Was the process of reducing investment (transition) carried out with adequate community engagement throughout?

Yes.

b. Were federal regulations adequately communicated to the community?

Yes. The NSF did a commendable job dealing with the large number of federal regulations that impacted the process.

c. Was community engagement appropriate throughout the transition process; was the Division receiving suitable transition advice from the community, and was the process sufficiently transparent and satisfactorily communicated to the community?

Yes.

d. Were the schedule and duration of the process for developing new partnerships appropriate?

Yes. Once the process was formally begun the time scale was reasonable, particularly given its complexity. Parts of the process were understandably delayed to avoid carrying out simultaneous recompetitions.

We commend the NSF for managing this very difficult process to a successful conclusion and for their active efforts moving forward with hurricane repairs and implementing the ongoing transition to the new management organization. Their continued attention to the staffing issues is warranted and it is understood that the transition will take longer to accomplish than originally planned.

OTHER TOPICS

1. Please comment on any program areas in need of improvement or gaps (if any) within program areas.
2. Please provide comments as appropriate on the program's performance in meeting program-specific goals and objectives that are not covered by the above questions.
3. Please identify agency-wide issues that should be addressed by NSF to help improve the program's performance.
4. Please provide comments on any other issues the COV feels are relevant.

For topics 1-4, please see the body of the report.

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

   None.

For the 2019 NSF/MPS Division of Astronomical Sciences Committee Of Visitors
Roger Brissenden
Chair

Appendix B: Recommendations

A compilation of the COV recommendations is provided below, listed in the order of appearance in the report. **However, we emphasize that the two highest priority recommendations of the Committee are for the AST Division to: (1) implement a more rigorous approach to Broader Impacts (priority recommendation 7); and (2) take a leadership role in developing a STEM workforce that reflects the rapidly changing demographics of the U.S. (priority recommendation 8).**

Recommendation 1. AST should explore additional avenues to identify potential reviewers, in order to lighten the burden on AST staff of recruiting panelists, while simultaneously ensuring a reviewer pool that is as diverse as possible (with respect to both scientific and educational expertise, institution type, career stage, and demographics).

Recommendation 2. Strengthen the pre-meeting briefing to improve the quality of reviews by emphasizing the importance of NSF's several Merit criteria; provide examples of specific evaluative language; and encourage critical and thoughtful consideration of Broader Impacts. (See also Priority Recommendation 7, §4.9.)

Recommendation 3. For individual reviews, AST should establish a deadline of ~7 days prior to the panel meeting for panelists to deliver their evaluations.

Recommendation 4. AST should undertake a trade study to explore the potential positive impact of double-blind (anonymous) reviews for AAG, ATI, AAPF and CAREER.

Recommendation 5. The current pre-panel briefing, which initiates participants to the review process, should highlight the critical nature of the panel summary, and outline clear expectations for its contents.

Recommendation 6. Panelists should be instructed to focus their efforts to bin proposals into categories of **Highly Competitive**, **Competitive**, and **Not Competitive**; and divert attention, previously paid to detailed order ranking, toward writing thoughtful, constructive panel summaries. (See also Priority Recommendation 8, §4.10.)

Priority Recommendation 7. We recommend that AST implement a more rigorous approach to Broader Impacts in all aspects of the review process.

We recommend the following specific actions:

(a) AST should utilize the pre-panel briefing to set expectations for reviewers to consider the Broader Impacts criterion with similar rigor as for Intellectual Merit.
(b) AST should take steps to ensure that review panels have appropriate scholarly expertise associated with evaluating Broader Impact scopes of work. This might require different

recruitment sources, and accepting panel members with expertise in Broader Impacts, but less so with the principal scientific themes.

(c) AST Program Officers should reinforce the commitment to high-quality Broader Impact reviews in their proposal funding recommendations.

Priority Recommendation 8. To address NSF's strategic goals for the future, we urge that AST take a leadership role toward developing a STEM workforce that reflects the rapidly changing demographics of the United States.

We recommend the following specific actions:

(a) Program Officers should reinforce the commitment to diversify the astronomy workforce by increasing equity for underrepresented groups in the awards portfolios.

(b) To allow POs appropriate flexibility to exercise that role, reviewers should be asked to categorize proposals as "**Highly Competitive**", "**Competitive**" and "**Not Competitive**," in lieu of a detailed numerical ranking. (Recommendation 6, §4.7.)

Recommendation 9. NSF should explore competing major new Gemini instruments through MSIP, while maintaining a smaller internal fund for instrument upgrades.

Recommendation 10. AST should raise the profile of the ESM office and related NSF programs in the astronomical community, enabling a better flow of relevant information and transfer of knowledge.

Recommendation 11. Rapidly recruiting additional AST POs and replacements for key AST staff must be a high priority for NSF.

Recommendation 12. AST develop and implement plans to achieve a more representative Program Officer and Division leadership.

Recommendation 13: AST formally designate interagency liaisons for NASA and DOE.

Recommendation 14. AST, with Astronomy Community input, develop Division metrics according to Intellectual Merit and Broader Impact for use by future COVs, and others.

Recommendation 15. AST should preserve its expertise in the divestment process, including compliance with governing laws, and maintain interfaces with the key Offices within NSF.

Appendix C: Recommendations Regarding “Inclusion and Access to Power, Policy, and Leadership”

Context: An inclusive community requires inclusive leadership, with decision-making roles open and available to anyone interested in pursuing them. Informing the community of leadership opportunities, responsibilities and expectations, in addition to making leadership roles accessible, makes for both an inclusive culture and more effective leadership structures.

1. Inclusive Diversity (gender, ethnic, racial, geographical, institutional, etc.) should be made a priority (not just a goal) in all areas of policy making and leadership roles throughout the astronomy community.
2. Future decadal surveys should address concerns of diversity in participation, leadership and policy making as part of recommended actions.
3. Funding (e.g., grants) should also be tied to metrics and progress on the inclusion of underrepresented, under-resourced and disenfranchised groups.
4. Astronomical researchers should acknowledge the responsibility to be ‘good citizens’ in areas where research intersects concerns in the larger society.

Short term goals/actions	**Target stakeholders**
Increase equitable access to policy making and leadership roles; deliberately reach out to and involve individuals from across the entire astronomical community, especially under-represented and under-resourced researchers and institutions, in policy and leadership roles.	Agencies, Universities, Individuals, professional associations
Astronomy communities should consider, develop, and test policies in mentorship/apprenticeship, graduate admissions, and hires that could have a positive effect on current diversity imbalances, and can become models of action for the decadal survey.	Individuals, Universities
Funded policies that expand diversity in the field should be put in place and supported in the community.	Agencies, Universities, professional associations
Medium term goals/actions	**Target stakeholders**
Diversity (gender, ethnic, racial, geographical, institutional, etc.) is made a priority (not just a goal) on (e.g., review, policy, hiring, etc.) panels and committees.	Agencies, Universities, Individuals, professional associations
Diversity and intersectional (i.e., gender + institutional, etc.) demographic data of committee and panel makeup, as well as for the larger community, are collected and reviewed for problems and progress.	Agencies, Universities, professional associations

The decadal survey should address issues of policy making and leadership diversity imbalances as recommendations that can be acted upon by policy makers.	Universities, Individuals
Breaches of ethics, be they conflict of interest, citations, data usage, bullying or harassment, are taken seriously and addressed within the astronomy community.	Agencies, Universities, Individuals, professional associations
Long term goals/actions	**Target stakeholders**
Departments, committees and science & policy panels that are representative of the astronomical community that they represent.	Agencies, Universities, Individuals, professional associations
Astronomical researchers recognize and acknowledge responsibility to be ‘good citizens’ in areas where their research interacts with concerns in the larger society.	Individuals, agencies, Universities, professional associations
Funding of research (e.g., grants) is also tied to metrics on diversity and inclusion of underrepresented and disenfranchised groups.	Agencies, Universities, professional associations

Table B-1: Inclusion and Access to Power, Policy, and Leadership: Recommendations Summary Table from the Inclusive Astronomy 2015 Recommendations[6].

[6] https://aas.org/posts/news/2017/02/inclusive-astronomy-nashville-recommendations

Appendix D: Acronyms "

AAG	Astronomy & Astrophysics Research Grants
AAPF	Astronomy & Astrophysics Postdoctoral Fellowships
AAS	American Astronomical Society
AD	Assistant Director
AGS	Division of Atmospheric and Geospace Sciences
ALMA	Atacama Large Millimeter Array
AO	Adaptive Optics
APD	Astrophysics Division (NASA)
AST	Division of Astronomical Sciences
ATI	Advanced Technologies and Instrumentation
AUI	Associated Universities Incorporated
AURA	Association of Universities for Research in Astronomy
CAREER	Faculty Early Career Development
CDL	Central Development Laboratory
COV	Committee Of Visitors
CA	Cooperative Agreement
CORF	Committee on Radio Frequencies of the National Academies
CTIO	Cerro Tololo Inter-American Observatory
DCL	Dear Colleague Letter
DD	Division Director
DDD	Division Deputy Director
DES	Dark Energy Survey
DESI	Dark Energy Spectroscopic Instrument
DKIST	Daniel K. Inouye Solar Telescope
DOE	Department of Energy
EAGER	Early-concept Grants for Exploratory Research
EARS	Enhancing Access to the Radio Spectrum
EHT	Event Horizon Telescope
EIS	Environmental Impact Statement
ESA	Endangered Species Act
ESM	Electromagnetic Spectrum Management
ESP	Education and Special Programs
EXC	Extragalactic Astronomy and Cosmology
FCC	Federal Communications Commission
GAL	Galactic Astronomy
GEMMA	Gemini In the Era of Multi-Messenger Astronomy
GBO	Green Bank Observatory
GROWTH	Global Relay of Observatories Watching Transients Happen
GW	Gravitational Waves
HST	Hubble Space Telescope
IIP	Individual Investigator Program(s)

INSPIRE	Integrated NSF Support Promoting Interdisciplinary Research and Education
IPT	Integrated Project Team
ITU-R	World Radiocommunication Conference of the International Telecommunications Union
LFO	Large Facilities Office
LIGO	Laser Interferometer Gravitational-Wave Observatory
LSST	Large Synoptic Survey Telescope
$M_\odot$	Solar Mass
MO	Managing Organization
Mpc	Megaparsec
MPS	Mathematical and Physical Sciences
MREFC	Major Research Equipment and Facilities Construction
MRI	Major Research Instrumentation
MSIP	Mid-Scale Innovations Program
MSRI	Mid-Scale Research Infrastructure
NASA	National Aeronautics and Space Administration
ngVLA	Next Generation Very Large Array
NCOA	National Center for Optical-Infrared Astronomy
NEID	NN-EXPLORE Exoplanet Investigations with Doppler Spectroscopy
NEPA	National Environmental Policy Act
NHPA	National Historic Preservation Act
NOAO	National Optical Astronomy Observatory
NRAO	National Radio Astronomy Observatory
NSB	National Science Board
NSF	National Science Foundation
NTIA	National Telecommunications and Information Administration
OIR	Optical-Infrared
PAARE	Partnerships in Astronomy & Astrophysics Research and Education
PAPPG	Proposal and Award Policies and Procedures Guide
PI	Principal Investigator
PLA	Planetary Astronomy
PO	Program Officer
RAPID	Rapid Response Research
REU	Research Experience for Undergraduates
RFI	Radio-Frequency Interference
SAA	Stellar Astronomy and Astrophysics
SOAR	Southern
SpecEES	Spectrum Efficiency, Energy Efficiency, and Security
SPG	Solar and Planetary Grants
STEM	Science, Technology, Engineering, and Mathematics
TDA	Time Domain Astronomy
USNO	US Naval Observatory
VLA (or JVLA)	Karl G. Jansky Very Large Array
VLASS	VLA Sky Survey

VLBA	Very Long Baseline Array
VLBI	Very Long Baseline Interferometry
z	redshift