THE UNIVERSITY OF UTAH

**Department of Physics & Astronomy**
115 South 1400 East #201 Salt Lake City, Utah 84112-0830 (801) 581-6901 FAX (801) 581-4801

17 May, 2023

Dr. Sethuraman Panchanathan, Director
National Science Foundation
2415 Eisenhower Avenue, Suite 19000
Alexandria, VA 22314

Mr. Bill Nelson, Administrator
Office of the Administrator
NASA Headquarters
Washington, DC 20546-0001

Ms. Jennifer Granholm, Secretary of Energy
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

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

The Honorable Maria Cantwell, Chair
Committee on Commerce, Science and Transportation
United States Senate
Washington, DC 20510

The Honorable Bernard Sanders, Chairman, Committee on Health, Education, Labor & Pensions
United States Senate
Washington, DC 20510

Dear Director Panchanathan, Administrator Nelson, Secretary Granholm, Chairman Lucas, Chair Cantwell, and Chairman Sanders:

After discussion, the AAAC panel updated the AAAC 2023 annual report to more clearly convey the committee's continued and strong support for the prioritizations of the 2020 Decadal Survey, including for the US-ELT program, the highest-ranked ground-based major facility, CMB-S4, and design, cost studies, and prototyping for the ngVLA.

This version of the AAAC report supersedes the March 15 version, and should be considered the official report of record going forward.

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

(1) assess, and make recommendations regarding, the coordination of astronomy and astrophysics programs of the Foundation and the National Aeronautics and Space Administration, and the Department of Energy;
(2) assess, and make recommendations regarding, the status of the activities of the Foundation, the National Aeronautics and Space Administration, and the Department of Energy as they relate to the recommendations contained in the National Research Council's 2021 report entitled "Pathways to Discovery in Astronomy and Astrophysics for the 2020s," and the recommendations contained in subsequent National Research Council reports of a similar nature;
(3) not later than March 15 of each year, transmit a report to the NSF Director, the Administrator of the National Aeronautics and Space Administration, the Secretary of Energy, the Committee on Science of the House of Representatives, the Committee on Commerce, Science and Transportation of the United States Senate, and the Committee on Health, Labor, and Pensions of the United States Senate on the Advisory Committee's findings and recommendations under paragraphs (1) and (2).

The attached document is the twentieth such report. The executive summary is followed by the report, with findings and recommendations for NSF, NASA and DOE regarding their support of the nation's astronomy and astrophysics research enterprise, along with detailed recommendations concerning specific projects and programs. The report is also being sent to other Congressional Committees of Jurisdiction.

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

Sincerely yours, on behalf of the Committee,

Dr. Kyle Dawson
Chair, Astronomy and Astrophysics Advisory Committee

cc: The Honorable Zoe Lofgren, Ranking Member, Committee on Science, Space, and Technology, United States House of Representatives
The Honorable Ted Cruz, Ranking Member, Committee on Commerce, Science and Transportation, United States Senate
The Honorable Bill Cassidy, M.D., Ranking Member, Committee on Health, Education, Labor & Pensions, United States Senate
Dr. Karen Marrongelle, Chief Operating Officer, Office of the Director, National Science Foundation
Dr. Linnea Avallone, Chief Officer for Research Facilities, Office of the Director, National Science Foundation
Dr. Sean Jones, Assistant Director, Directorate for Mathematical and Physical Sciences, National Science Foundation
Dr. Tie Luo, Deputy Assistant Director, Directorate for Mathematical and Physical Sciences, National Science Foundation
Dr. Alexandra Isern, Assistant Director, Directorate for Geosciences, National Science Foundation

Dr. Thomas Zurbuchen, Associate Administrator, Science Mission Directorate, National Aeronautics and Space Administration
Dr. Sandra Connelly, Deputy Associate Administrator, Science Mission Directorate, National Aeronautics and Space Administration
Dr. Mark Clampin, Director, Astrophysics Division, Science Mission Directorate, National Aeronautics and Space Administration
Ms. Alicia Brown, Office of Legislative Affairs, National Aeronautics and Space Administration
Dr. Asmeret Asefaw Berhe, Deputy Director for Science Programs, Office of Science, U.S. Department of Energy
Dr. Harriet Kung, Principal Deputy Director, Office of Science, U.S. Department of Energy
Dr. Regina Rameika, Director, Office of High Energy Physics, Office of Science, U.S. Department of Energy
Dr. Glen Crawford, Division Director, Research and Technology Division, Office of High Energy Physics, Office of Science, U.S. Department of Energy
Dr. Kathleen Turner, Program Manager, Office of High Energy Physics, Office of Science, U.S. Department of Energy
Dr. Yi Pei, Program Examiner, NSF, Office of Management and Budget
Dr. Grace Hu, Program Examiner, NASA, Office of Management and Budget
Dr. Avital Bar-Shalom, Program Examiner, DOE, Office of Management and Budget
Dr. Debra Fischer, Division Director, Division of Astronomical Sciences, National Science Foundation
Dr. James Neff, Deputy Division Director, Division of Astronomical Sciences, National Science Foundation
Dr. Carrie Black, Program Director, Division of Astronomical Sciences, National Science Foundation
Dr. James Ulvestad, Acting Office Director, Office of Polar Programs, National Science Foundation
Dr. Vladimir Papitashvili, Program Director, Office of Polar Programs, National Science Foundation
Dr. Denise Caldwell, Division Director, Physics Division, National Science Foundation
Dr. Jean Cottam Allen, Deputy Division Director, Physics Division, National Science Foundation
Ms. Amanda Greenwell, Head, Office of Legislative and Public Affairs, National Science Foundation
Mr. Chris Hillesheim, Legislative Affairs Specialist, Office of Legislative and Public Affairs
Ms. Karen Pearce, Senior Legislative Affairs Specialist, Office of Legislative and Public Affairs, National Science Foundation
Mr. Robert Moller, Chief Government Affairs, Office of Legislative and Public Affairs

Astronomy and Astrophysics Advisory Committee Members:

Dr. Wenda Cao, New Jersey Institute of Technology
Dr. Kyle Dawson, University of Utah
Dr. Sarah Hörst, Johns Hopkins University
Dr. Alexie Leauthaud, University of California, Santa Cruz
Dr. Nikole Lewis, Cornell University
Dr. Britt Lundgren, University of North Carolina Asheville
Dr. Raffaella Margutti, University of California - Berkeley
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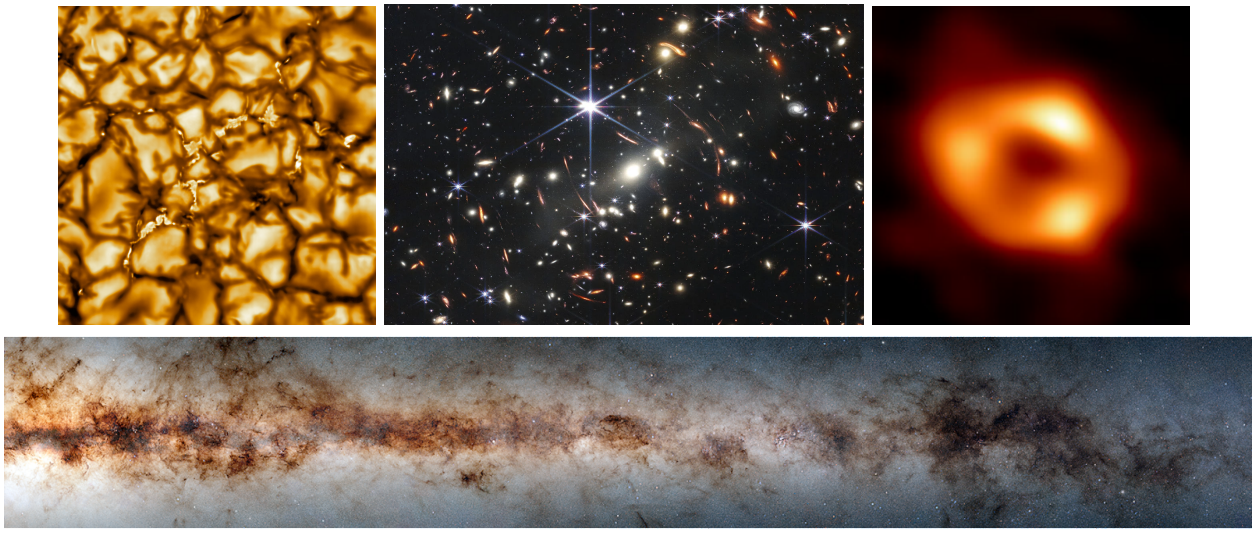
Dr. Ann Zabludoff, University of Arizona

# AAAC ANNUAL REPORT 2023



The Astronomy and Astrophysics Advisory Committee (AAAC) advises the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), and the U.S. Department of Energy (DOE) on selected issues within the fields of astronomy and astrophysics that are of mutual interest and concern to the agencies. This report represents the annual summary of findings, comments, and recommendations from the current committee. In particular, this report provides an examination of interagency coordination and appropriate recommendations as it pertains to the Astronomy & Astrophysics 2020 Decadal Survey report from the National Academy of Sciences: "Pathways to Discovery in Astronomy and Astrophysics for the 2020s." which was released in November 2021.

## Executive Summary

NSF, DOE, and NASA should be lauded for their response to the recommendations of the 2020 Decadal Survey following its long-awaited release 16 months ago. Beyond three central science themes, the Decadal report highlighted the critical role foundations of the profession, research, and technology play in achieving the overarching science objectives and emphasized the need to support these activities at a very high level in the coming decade. In this short time, the three agencies have demonstrated an active pursuit of the ambitious program of ground- and space-based initiatives and professional activities endorsed by the report.

The highest scientific priorities of the 2020 Decadal Survey require substantial future investments in new observational facilities. Doing so will ensure the US remains in a leadership position to undertake transformative science to understand the universe and our place in it. It should be emphasized that pursuit of fundamental science has benefits far beyond the

immediate science discipline of astronomy, impacting technology development, engineering, workforce development, and spurring innovation in related disciplines that can have profound societal benefit. Realizing the ambitious science goals of the Decadal, particularly for ground-based activities, however, will require careful planning and execution.

To achieve the full scope of the Decadal recommendations, it is essential the three agencies establish and maintain a coordinated framework and roadmap of implementation, as many of the recommendations are either multi-agency in nature or implicitly or explicitly depend on cooperation, collaboration, and/or consistency. During the past 12 months, agencies have had the opportunity to make substantive progress addressing many Decadal recommendations, formulating and in a number of instances, implementing new programs. Based on material presented by the agencies at public forums during the last year, the AAAC highlights three cross-agency issues of highest priority:

- **Major facilities:** The unprecedented science that will come from the highest-priority ground-based major facilities in the Decadal Survey (the US-ELTs) requires significant NSF support for construction, and thus ambitious and coordinated planning beyond the scope of historic MREFC funding levels. The CMB-S4 project, also highly ranked in the Decadal Survey, requires both DOE and NSF investment. Challenges related to Antarctic infrastructure need to be addressed through close coordination of NSF-OPP and the CMB-S4 project for DOE and NSF to complete the construction of this project. Beyond NSF-AST and DOE, those same infrastructure challenges pose a risk to completing the IceCube-Generation 2 neutrino observatory that was identified as a key future facility within NSF-PHY.
- **Dark/quiet skies:** The number of commercial satellites operating in low Earth orbit is expected to increase by an order of magnitude or more in the next decade. Reflected light from these satellites creates a potential existential threat to ground-based observations generally and to major new facilities such as the Vera Rubin Observatory, which is scheduled to commence science operations in 2024. A coordinated cross-agency effort is urgently needed to provide regulatory agencies and oversight organizations with quantifiable data and metrics to better shape policy, and ensure that new and existing astronomical facilities can achieve their full science potential.
- **Demographic data collection:** Consistency is needed in the collection of demographic data for the scientific community to track progress towards building an equitable, diverse and inclusive community. Because this need extends beyond the three agencies informed by this report, the Office of Science and Technology Policy (OSTP) and Office of Management and Budget (OMB) appear ideally positioned to establish minimal, consistent criteria for all data collection.

We conclude with other recommendations, including climate change, Time Domain and Multi-Messenger Astrophysics (TDAMM), and data archiving. These topics remain of considerable importance to the astronomical community.

## Agency and Science Highlights

**NASA:** JWST is now in full science operations with an on-orbit performance exceeding mission requirements. Cycle 1 science programs are well underway with spectacular results appearing on a nearly weekly cadence from a wide range of sub-disciplines: from the early universe and galaxy evolution to exoplanet atmospheres and young star formation. The timetable to launch the Nancy Grace Roman Space Telescope in 2027 remains on-schedule, having achieved important milestones in the construction and testing of the Coronagraph Instrument and the Element Wheel and Focal Plane Assemblies during the past year. The Roman Space Telescope is designed to measure dark energy and dark matter, search for and image exoplanets, and explore a number of topics in infrared astrophysics using a 2.4 m telescope that is the same size as the Hubble. The Wide-Field Instrument, one of two Roman will carry, however, has a field of view that is two orders of magnitude greater than the imaging capabilities of Hubble. The second instrument, a coronagraph, has the capability to image planets with a contrast that is 1000 times better than JWST. Other developments of note include efforts to refine the technical requirements, architecture options, and maturation pathway for the enabling technologies that will be required for The Habitable Worlds Observatory, whose primary science goal is to survey nearby stars for habitable planets and characterize them for evidence of biosignatures; issuance of a draft AO for the PI-led Astrophysics Probe with a target date for the final Probe AO of July 2023; and efforts to modernize and standardize the transient alert system in preparation for first light from Rubin and later Roman. Because the Rubin Observatory will look much deeper into the universe, these observations may generate on order 10 million transient alerts per night. Such estimates highlight the need for coordination between NASA, NSF, and international partners and the importance of both coordinated timing requirements and evaluation criteria so that the science potential of Time Domain and Multi-Messenger Astrophysics (TDAMM) can be realized.

**NSF:** The past year has been marked by considerable progress across multiple platforms. On August 31, 2022, the world's most powerful solar telescope, the Daniel K. Inouye Solar Telescope (DKIST), was inaugurated, heralding a new era that promises to revolutionize our understanding of the Sun, its magnetic behavior, and its influence on Earth. DKIST released the first set of publicly available datasets on December 12, 2022. The released dataset includes the observations taken in conjunction with NASA's Parker Solar Probe's (PSP) Encounter #12. The coordinated campaign between NSF's and NASA's facilities provides access to the dynamic and magnetic environment of the solar structures that give rise to the solar wind material sampled by PSP, and more generally serves to highlight the synergy and strength of inter-agency coordination. Other highlights include completion of the Telescope Mount Assembly (TMA) for the Vera C. Rubin Observatory, along with completion of an education and public outreach engagement platform that is now operational. Rubin is a next-generation, ground-based facility, providing time-lapse imaging of faint astronomical objects across half the whole sky every few nights. It is an NSF (AURA) & DOE (SLAC) partnership, with private, international contributions. NSF has also undertaken a Preliminary Design Reviews for both the ELTs, and the ngVLA prototype antenna was completed in 2022 with a Conceptual Design Phase now planned. Other highlights include plans for a Senior Review/Portfolio Review, a Committee of Visitors, and new

partnerships and centers to foster STEM education, learning, and teaching, and broaden research participation.

**DOE Office of Science, Office of High Energy Physics:** The Dark Energy Survey and the Dark Energy Spectroscopic Instrument (DESI) Experiment, joint partnerships between DOE and other agencies, primarily but not exclusively NSF, are all performing superbly, and are meeting or exceeding scheduling goals. DESI, for example, is the world's premier multi-object spectrograph with 5,000 robotically-controlled fibers. DESI is installed in the focal plane of the 4-meter Mayall Telescope at Kitt Peak National Observatory with the primary science goal to record spectra for more than 40 million galaxies to measure the effect of dark energy on the expansion of the universe. In doing so, DESI will construct a three-dimensional map that spans from the nearby universe to 11 billion years in the past. Through January 2023, its second year of operation, it had already recorded 17 million extra-galactic redshifts, more than all other previous surveys combined. Other highlights include LSST camera integration, testing, and commissioning for the Rubin Observatory, with final verification scheduled for this spring and shipment to Chile around May or June. The Commissioning Camera (ComCam) was successfully installed and is being used to exercise observatory systems. Technology development in support of CMB-S4, which includes sensor and readout electronics technologies, packing, testing, etc. is ongoing. A strategic plan to address Diversity, Equity, Inclusion, and Accessibility was released by the Office of Science, as was a requirement starting in FY23 that all proposals to this Office include a plan for Promoting Inclusive and Equitable Research (PIER) with an associated merit review metric to strengthen efforts in this area.

**Science:** The past year has been dominated by discoveries from JWST, but there was no dearth of science highlights from other facilities and research groups. Examples from JWST include the direct image of a planet orbiting a distant star (HIP 65426 b) and confirmation of a new Earth-sized rocky exoplanet (LHS 475 b); the telescope's first spectrum of the atmosphere of an exoplanet (WASP-96b) and first detection of the carbon dioxide ($CO_2$) molecule in an exoplanet atmosphere (WASP-39b); and detection of four of the most distant galaxies known. With a redshift of 13.2, the highest ever measured, the galaxies are estimated to be only 350 million years old at the time of emission, or only about 2% the current age of the universe. The Dark Energy Survey (DES) is a collaboration between NSF and DOE and funded by several U.S. and international partners. The DES mapped the broadband colors of more than 225 million galaxies over a seven year period, allowing astronomers to directly survey the distribution of dark matter on a scale never before possible. Twilight observations with the Dark Energy Camera also enabled astronomers to detect three near-Earth asteroids. Other notable science highlights include the first image of the supermassive black hole at the center of our own Milky Way galaxy, Sgr A*; unambiguous detection using the Gemini North telescope of a dormant stellar-mass black hole which is the closest black hole to Earth; and the highest resolution image ever taken of the Sun's chromosphere with the Inouye Solar Telescope.

# 2022 AAAC Annual Report and Agency Progress

The agencies have made significant progress on several of the recommendations from the 2022 AAAC Annual Report. While the associated recommendations from the 2020 Decadal Survey have not been fully realized, we do not provide additional recommendations on these topics as we wait for more information in the coming year. Instead, we briefly describe the progress and highlight those efforts that are expected to play a major role in future reports.

## Extremely Large Telescopes (Ground-based)

*Decadal recommendation: The National Science Foundation (NSF) should conduct an external review of the U.S. extremely large telescopes, with a target completion date of 2023. If only one of the Giant Magellan Telescope or the Thirty Meter Telescope can meet the conditions enumerated above by the time of NSF's review, NSF should proceed with investment in that project alone.*

**Decadal background:** The "survey's priority for a frontier ground-based observatory is a significant U.S. investment in the Giant Magellan Telescope (GMT) and Thirty Meter Telescope (TMT) projects, ideally as components of a coordinated U.S. Extremely Large Telescope Program (ELT) program."

**Status:** The goal of NSF is to provide US scientists at least 25% of the observing time on each telescope through an open peer-review process. NSF is currently preparing for a 2023 NSF Preliminary Design Review for construction to begin as early as FY25. In addition to facility design, other activities include environmental compliance and outreach to the Hawaiian community on the proposed Thirty Meter Telescope on MaunaKea. The final decision may include selection of one or two platforms. External reviewers have been solicited. In the coming year, the AAAC hopes to be informed on the composition of the review panel, whether the committee was constructed in the spirit of the decadal recommendation, and any other updates on outreach and decision points for proceeding with a U.S. investment in the ELT program.

## Laboratory Astrophysics

*Decadal recommendation: NASA and the National Science Foundation should (1) convene a broad panel of experts to identify the needs for supporting laboratory data to interpret the results from the new generation of astronomical observatories, (2) identify the national resources that can be brought to bear to satisfy those needs, and (3) consider new approaches or programs for building the requisite databases. This panel should include experts in laboratory astrophysics as well as representative users of the data, who can best identify the highest-priority applications.*

**Decadal Background:** "Laboratory astrophysics is essential to the interpretation of astrophysical data from facilities such as JWST, ALMA, and future facilities like the ELTs. Research in this area needs to be regarded as a high priority. The existing approaches are not sufficiently advancing the field."

**Status:** Representatives of NSF and NASA requested that an ad hoc taskforce be established to address the Astro2020 recommendation on laboratory astrophysics. The charge and purpose given in this request was:

> "…develop an assessment of the scientific utility and priorities in laboratory astrophysics for the US community that will enable the greatest advances in astrophysics. The purpose is to allow the agencies to devise a robust plan to make the most effective use of available resources to enable discovery science by supporting the community."

And that the task force be:

> "Comprised of laboratory astrophysicists, theorists, and database curators, as well as observational astronomers and modelers who rely on laboratory astrophysics."

In response to this recommendation, a 20 person Lab-Astro Taskforce with the requisite span of expertise was convened as of February 23rd, 2023. A chair (Prof. Lucy Ziurys, University of Arizona) has been named, and a kick-off meeting is planned for mid- to late-March, 2023. In the coming year, the Taskforce expects to meet frequently in smaller topical groups, with meetings planned on regular intervals that will include the entire group. An in-person workshop is planned for summer with the opportunity for community input. Plans are also underway to organize a splinter meeting at the Summer AAS meeting.

The Taskforce is requested to report its initial findings to the AAAC in the Fall of 2023, with a final report to be delivered by early 2024. In accordance with the Federal Advisory Committee Act (FACA), the report will be discussed, and if accepted and endorsed by the AAAC at a public meeting, the report will be formally transmitted to the agencies. The report from the Taskforce will inform recommendations in the 2024 AAAC report.

## Next Generation Very Large Array

*Decadal recommendation: The National Science Foundation (NSF) should proceed with a program to support science design, development, cost studies, and antenna prototyping for the Next Generation Very Large Array. After completion of the studies, NSF should convene a review to assess the project's readiness and available budget and proceed with construction if possible.*

**Decadal Background:** "It is of essential importance to astronomy that the JVLA and VLBA be replaced by an observatory that can achieve roughly an order of magnitude improvement in sensitivity compared to these facilities, with the ability to image radio sources on scales of arcminutes to fractions of a milliarcsecond."

**Status:** A prototype antenna design is underway with a plan for testing at the VLA in 2023. A Project Office in Albuquerque was established to coordinate the continuing design and development activities. There has also been significant outreach to the scientific community in the form of ngVLA scientific meetings and design reviews.

The ngVLA is specific to NSF and recommended to construction if allowed by the budget after construction of the US-ELT and CMB-S4 facilities. We therefore have no recommendations related to inter-agency coordination at this time. However, the AAAC would like to remain apprised of progress with ngVLA design and development.

## Findings and Recommendations

The 2020 Decadal Survey titled *Pathways to Discovery in Astronomy and Astrophysics for the 2020s* laid out a very ambitious roadmap for the next decade of astronomy in the United States. A number of the most important priorities outlined there explicitly or implicitly involve inter-agency cooperation, either in the form of direct coordination or in consistency of implementation. A cursory review of the Decadal Survey indicates that roughly 40% of the 37 key recommendations are multi-agency in nature or require coordination across agencies. Following its release in November 2021, agencies have now begun to respond to many of these recommendations, formulating, and in a number of instances implementing new programs.

It is not the intent here to provide a comprehensive status update of the many 2022 AAAC findings. Rather, in the 2023 Annual Report, we draw attention to a smaller number of high-level Decadal recommendations that this committee identified during open meetings as particularly challenging in terms of implementation.

For the topics that were identified at the highest priority in the Executive Summary, the challenges arise in large part either because of differences in the balance in agency budgets between astronomical research, facility development and operations, or because the issue extends beyond the purview of the three U.S. agencies. In some cases, consistent policies and implementation are highly desirable, while in other cases, quantifiable and comprehensive data is needed to inform Federal regulatory agencies and shape policy. Finally, to fully realize the potential of the major facilities prioritized by the Decadal Survey, a change in precedent for budgetary policy is necessary.

We conclude with other recommendations that remain of high importance to the AAAC and the larger astronomy community.

## 1. Balancing Operational Costs and Research Funding for New MREFC Facilities

*Decadal recommendation: The National Science Foundation (NSF) should develop a sustainable plan for supporting the operations and maintenance costs of its astronomical facilities, while preserving an appropriate balance with funding essential scientific foundations and the remainder of the NSF Division of Astronomical Sciences portfolio. The addition of new MREFC facilities should be contingent on implementation of this plan.*

**Finding:** The annual budget of NSF-AST is approximately $300 M, with roughly 75% percent of this amount supporting the instrumentation and facilities needed for international leadership and advances at the frontiers of observational astronomy. The remaining 25% of the AST portfolio is devoted to new research grants to individual investigators.

**Finding:** The NSF share of operations for the Extremely Large Telescope Program is expected to be roughly $32M/year, or roughly half of the current AST budget devoted to new research grants for individual investigators.

**Finding:** Current estimates suggest that a Federal investment of approximately $800 M will be required to secure a target level of at least 25 percent of the observing time on either of the two extremely large telescope projects — the Giant Magellan Telescope and the Thirty Meter Telescope — bringing the total investment to roughly $1.6 B if both projects prove to be viable.

**Finding:** The NSF MREFC funding line has historically been in the $120-200 M range per year. Of this amount, $60 M is nominally earmarked for Antarctic Infrastructure Recapitalization and $76.25 M is earmarked for Mid-Scale Research Infrastructure in future years. Notwithstanding new or competing programs outside of AST, an unprecedented increase in the MREFC budget will be needed in future years to achieve the highest-priority recommendation for ground-based astronomy through the construction of one or both extremely large telescope projects.

**Comment:** Although the US-ELT program will likely receive federal support from NSF only, it is the highest priority ground-based facility from the Decadal Survey. In addition, the significant impact of US-ELT on MREFC and on the NSF-AST R&RA budgets will affect the ability of NSF to coordinate with NASA and DOE on other facilities or programs.

**Finding:** CMB-S4 is estimated to require roughly $300 M total in construction costs from the MREFC funding line. The NSF share of CMB-S4 operations is estimated to be roughly $17 M/yr, or about 30% of the current NSF-AST budget that is devoted to new research grants to individual investigators.

**Finding:** The $300 M construction cost of CMB-S4, over six years, fits into the preliminary MREFC budget.

**Comment:** While the Decadal Survey gave the US-ELT program the highest priority among major ground-based facilities, the CMB-S4 project remains a higher priority for DOE due to the

2014 Particle Physics Project Prioritization Process (P5). As construction of CMB-S4 is a joint effort between DOE and NSF, this project demands particular attention to ensure that an appropriate balance is struck between the competing priorities of the two agencies. CMB-S4 therefore has increased significance within this report because it requires joint agency support to succeed.

**Recommendation: To enable the transformative science of the highest-ranked Decadal recommendations for ground-based astronomy (US-ELT, followed by implementation of CMB-S4, and beginning design, cost studies, and prototyping for ngVLA, in ranked order), NSF should develop and communicate a multi-year roadmap in consultation with key stakeholders (e.g. DOE) and oversight bodies. The roadmap should incorporate appropriate contingencies and breakpoints.**

**Recommendation: As recommended in the March 2021 AAAC report, Congress should provide sufficient appropriations to NSF to ensure that NSF's strategic commitments to operations and maintenance of its major facilities can be met, but not at the expense of the research and instrumentation funding portfolio within NSF-AST.**

*Decadal recommendation: The National Science Foundation should increase funding for the individual investigator Astronomy and Astrophysics Research Grants by 30 percent in real dollars (i.e., above the rate of inflation) over 5 years from 2023-2028 starting with the fiscal year 2019 budget inflated appropriately. This will have the effect of restoring success rates to a healthy competitive level.*

**Finding:** An increase to the NSF AAG program was given the highest priority of all recommendations from the research foundation component of the Decadal Survey.

**Finding:** Under current budget scenarios, the funding available to AAG will likely decrease when operations of Vera Rubin Observatory and other large facilities commence.

**Finding:** Funding opportunities beyond NSF-AST (e.g. windows on universe, AI/ML) exist within NSF that allow researchers to expand their own research portfolio while also advancing our knowledge of the cosmos.

**Comment:** While the focus in this year's report is primarily on the large facilities, facilities cannot reach their full science potential without adequate support of the researchers and the enabling measurements, calculations, and simulations that they undertake. It should be emphasized that substantial sustaining support for this enabling work represents a tiny sliver of the construction costs of a large facility, implying a significant return on investment with very modest cost.

**Recommendation: NSF-AST should communicate cross cutting and NSF-wide opportunities to potential investigators that complement the AAG program.**

**Recommendation: NSF-AST should consider how to support increased PI involvement during the planning and construction of large projects.**

**Recommendation: Continue strategic, ambitious thinking, even considering restructuring or a developing a paradigm shift for life-cycle costs, to fulfill the spirit of Decadal Survey recommendations.**

**2. The Cosmic Microwave Background Stage 4 Observatory (CMB-S4)**

*Decadal recommendation: Observations of the Cosmic Microwave Background (CMB) have been central to establishing the standard model of cosmology, and these measurements are increasingly important for science ranging from the study of galactic ecosystems to the formation of cosmic structure. NSF and DOE should jointly pursue the design and implementation of the next generation ground-based cosmic microwave background experiment (CMB-S4).*

**Finding:** In addition to the 2020 decadal recommendation, CMB-S4 was highly recommended in the 2014 Particle Physics Project Prioritization Panel (P5) process, and is thus an extremely high priority project for DOE.

**Finding:** In the 2015 NAS report titled "A Strategic Vision for NSF Investments in Antarctic and Southern Ocean Research," a next-generation Cosmic Microwave Background facility (which is now CMB-S4) was one of the three highest priorities across all fields of Antarctic science.

**Finding:** In the 2022 mid-term assessment of progress on the 2015 Strategic Vision, it was noted that "Inadequate levels of funding and planning for logistical support pose a threat to the rate of progress of ongoing Antarctic CMB research and the pace of construction of the Antarctic CMB-S4 components." The assessment encouraged effective communication between the agencies and the project to ensure that the CMB-S4 project happens in a reasonable timeframe.

**Comment:** Diminished logistics capacity directly affects the science for which the South Pole site is unique, including extremely exciting areas of astronomy, astrophysics, and cosmology. For example, the South Pole is uniquely well-suited to enable CMB-S4 to discover a signal of cosmic inflation in the first fraction of a second after the Big Bang, and to discover the sources of astrophysical neutrinos with the NSF-PHY supported IceCube experiment.

**Finding**: The ability to support major new science projects at the South Pole is diminished today compared to where it was 20 years ago. One change is due to aging LC-130 aircraft, which limits cargo and personnel movement on the ice. However, a significant fraction of this reduced air movement capability has been replaced by the development of the South Pole Traverse, which is a major new advancement by NSF that has occurred over the last 15 years, and transports significant cargo and fuel to the South Pole each year. The number of traverses each season could be increased with additional Traverse equipment investment, as suggested in the funded

NSF Antarctic Infrastructure Recapitalization (AIR) MREFC Plan, which noted, "expanded traverse capabilities can dramatically reduce risk and cost for science teams accessing deep field locations."

**Finding:** NSF has invested significantly in the Antarctic Infrastructure Recapitalization (AIR) project, which focuses mostly on infrastructure upgrades at McMurdo station. AIR also includes infrastructure upgrades and maintenance to enable science at the South Pole, as well as planning for the South Pole Master Plan for future infrastructure and logistics. NSF-OPP has indicated in a Dear Colleague Letter that critical infrastructure and maintenance activities that can no longer be deferred must go forward at the South Pole, and that support for existing projects, including CMB projects, will continue. New projects can be supported late in this decade.

**Finding:** The CMB-S4 project is in an advanced state. The CMB-S4 project has worked with the agencies (NSF and DOE) to develop a design that achieves the science goals while minimizing the logistics impact on the South Pole, and has presented this design to the agencies in December 2022. The logistics requirements for CMB-S4 are comparable to or only modestly exceed the requirements for the current CMB telescopes that are operating at the South Pole, including a power consumption of 170kW compared to the 140kW currently being used by CMB experiments currently (Slides Here).

**Finding:** A recent study from Argonne National Laboratory and NREL indicates that a renewable energy system using mature technology not only reduces the carbon footprint of the South Pole power generation by 95%, it also has a payback time of only two years (including transportation costs), and saves tens of millions of dollars over its lifetime (Slides Here). A renewable energy system would also significantly reduce overall cargo movement requirements for power generation at South Pole over its lifetime due to reduced fuel movement, opening space on existing South Pole Traverses for science cargo. Such a renewable energy system would support the entire power requirement of CMB-S4.

**Recommendation: NSF-OPP should engage directly with the CMB-S4 project to enable CMB-S4 to move forward. Coordination between NSF-OPP, NSF-AST, and DOE is critical to ensure the success of CMB-S4 and enable the world-leading science and exciting discoveries that will be achieved with the project.**

**Recommendation: NSF-OPP should actively engage with Argonne and NREL to move forward on a renewable energy plan for the South Pole.**

**Finding:** The Office of Polar Programs Advisory Committee, which provides advice and recommendations to the NSF concerning support for polar research, education, infrastructure and logistics, and related activities, currently has no members who are physicists or astronomers, and minimal representation of people who are or have been active researchers at the South Pole. Additionally, the OPP AC will be merged with the GEO (Geosciences) AC, which presents further challenges to ensure that the membership of the OPP AC reflects the

community of scientists, broadly speaking, who do science in the Polar Regions. The OPP AC has formed a subcommittee to determine a process for prioritizing science across disciplines at the South Pole.

**Recommendation: NSF-OPP should actively engage with the science community in determining science support requirements and determining how to prioritize science at the South Pole, including working directly with researchers who have experience at the South Pole, and incorporating the extremely high priority given to CMB-S4 at the South Pole by the Astronomy decadal survey, the Particle Physics Project Prioritization Panel (P5), and the 2015 Antarctic Strategic Vision NAS report.**

### 3. Protection of Dark and Quiet Skies

*Decadal recommendation: The NSF should work with the appropriate federal regulatory agencies to develop and implement a regulatory framework to control the impacts of satellite constellations on astronomy and on the human experience of the night sky. All stakeholders (U.S. astronomers, federal agencies, Congress, satellite manufacturers/operators, and citizens who care about the night sky) should be involved in this process. This is an international issue; therefore, international coordination is also vital.*

**Finding:** Since 2019 there has been an exponential expansion in the number of communications satellites launched into low Earth orbit. The negative impact of these satellites is being felt first by the professional astronomy community. Increasingly, satellite trails are contaminating expensive observations made with federally-funded and competitively accessed telescopes. These problems are exacerbated during twilight due to the angle of the Sun and when taking long-exposures and images with wide fields of view. Even some space-based telescopes are not immune to this problem; 6% of Hubble Space Telescope images are now contaminated by the trails of satellites in higher orbits. This problem is on the cusp of becoming dramatically worse as commercial satellite providers scale up the size of their fleets and new companies enter the market. Mid-2022 filings to the U.S. Federal Communications Commission and the International Telecommunication Union indicate that approximately 430,000 satellites are now planned to launch in the coming years, with one company alone, E-Space, intending to launch more than 330,000. SpaceX, whose Starlink satellites currently make up the largest orbiting fleet, is expected to soon have hundreds of satellites simultaneously visible to naked-eye observers at intermediate latitudes during astronomical twilight (within 2-3 hours of sunset and sunrise) in dark sites (McDowell 2020).

**Finding:** Recent simulations carried out by astronomers at Rubin Observatory indicate that satellites in 550 km orbits must be fainter than 7th magnitude in the G-band (centered at 464 nm, i.e. a green hue) to avoid saturating the CCDs used to collect images for the 10-year Legacy Survey of Space and Time (LSST) - a major investment of NSF and DOE. While SpaceX has made laudable efforts to reduce the reflectivity of their Starlink satellites using new coatings and adaptive orientation in orbit, recent measurements indicate that their average brightness at the

target altitude still measures 5-6 magnitudes – roughly six times brighter than LSST requirements and bright enough to be seen with the unaided eye in dark locations. During twilight hours, and during a significant fraction of the satellites' lifetime when they are below target altitudes, they are observed to be as bright as magnitude 3 (McDowell 2020).

**Finding:** As the only federal agency that represents all of ground-based astronomy in domestic and international spectrum management, the NSF is well suited to lead efforts related to preserving dark and quiet skies. The NSF has been actively working with the professional astronomy community, industry leaders, regulating bodies, and the public to mitigate the impacts of satellite constellations, which threaten investments in the many ground-based observatories under the umbrella of NSF's NOIRLab.

**Comment:** The committee applauds NSF for working with SpaceX on an agreement that was signed January 2023 to reduce the brightness of Starlink satellites and their impact on observatories operating in the optical, infrared, and radio. Similar agreements are now underway with OneWeb and Amazon's Project Kuiper. NSF's NOIRLab has also been active in hosting related community workshops (SATCON1 and SATCON2), which produced reports that have been presented to the U.S. Department of State, OSTP, DoD, and the FCC.

**Comment:** Substantial additional effort is needed to reduce the brightness of satellite constellations to levels that will preserve the night sky for both astronomers and the public. Thus, we find concerns expressed in the Decadal Survey must be treated with heightened urgency if we are to preserve professional astronomy, the public's ability to experience the night sky, and the rights of Indigenous peoples to retain traditions and knowledge systems based on the stars.

**Recommendation: NSF, NASA, and DOE should share information as broadly as possible to facilitate strong advocacy for domestic and international satellite brightness regulations.**

**Recommendation: All three agencies should provide quantifiable data and sensitivity limits for existing and soon to be completed optical/infrared facilities in a coordinated and consistent fashion to better inform regulatory agencies and shape policy. Doing so will allow policy decisions to be appropriately quantitative and data-driven.**

**Finding:** NSF's NOIRLab is working with the International Astronomical Union to co-host the newly founded IAU Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference (CPS). This group presented a conference report with detailed recommendations for international regulations to the United Nations' Committee on the Peaceful Uses of Outer Space in 2021.

**Recommendation: NSF, NASA, and DOE should work with global partners to facilitate advocacy for treaty-level cooperation that will be essential for satellite brightness regulations to be effective.**

**Comment:** While the NSF has been leading federal efforts to mitigate the impacts of satellite constellations, NASA's observatories and missions are also being affected.

**Recommendation: NASA should provide a report on how its missions are impacted by satellite contamination or confusion. The requested report should include a discussion of the effect of unmitigated satellite trails and debris on current and future Planetary Defense capabilities, including the Near Earth Object Observations Program. The committee would like to know if this critical monitoring program will be disrupted by the particularly bright reflections of these satellites during twilight – the only window to search for hazardous objects in the inner solar system. We also request reporting on the expected impacts of satellite constellations on NASA's observatories in low-Earth orbit, including the Hubble Space Telescope.**

*Decadal recommendation: To ensure that the skies remain open to radio astronomy, the National Science Foundation (NSF), in partnership with other agencies as appropriate, should support and fund a multi-faceted approach to the avoidance and mitigation of radio- frequency interference. It is critical that the astronomical community formally monitor commercial and federal uses of the spectrum managed by the Federal Communications Commission and the National Telecommunications and Information Administration and actively participate in the spectrum management process by seeking critical primary allocations to radio astronomy in the high-frequency bands above 95 GHz, by providing comments to filings for spectrum allocations, and by supporting the efforts of the Committee on Radio Frequencies, the National Radio Astronomy Observatory, and the Electromagnetic Spectrum Management division of NSF. To be most effective, international coordination is required.*

**Finding:** The NSF maintains active participation in domestic advisory committees for radio frequency regulators, including the Federal Communications Commission and the National Telecommunications and Information Administration, and works to ensure that astronomers' access to the electromagnetic spectrum is preserved and enhanced.

**Finding:** The NSF is actively involved in international spectrum regulations via the International Telecommunication Union's Radiocommunication Sector (ITU-R, a UN Specialized Agency), serving as U.S. Head of Delegation for Working Party 7D (Radio Astronomy) and participating as delegates in 25 additional working parties and study groups, as well as the CITEL regional group under the Organization of American States.

**Finding:** The NSF participates in international advocacy for electromagnetic spectrum management through its role as co-host of the newly founded International Astronomical Union's Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference (CPS), which presented spectrum regulation recommendations in its report to the United Nations' Committee on the Peaceful Uses of Outer Space in 2021.

**Comment:** The impact of commercial services and satellite constellations on radio frequency interference is becoming severe, and threatens the scientific study of cosmic microwave

background radiation, as well as detections of faint continuum sources necessitating wide bandwidths. Future large facilities especially impacted are the CMB-S4 and ngVLA; in particular, the lower frequency bands of the CMB-S4 project will be compromised and may become unusable unless action is taken.

**Recommendation: We request that NSF provide quantifiable data and sensitivity limits for existing and soon to be completed facilities operating in the radio band in a coordinated and consistent fashion to better inform regulatory agencies and shape policy. Doing so will allow future policy decisions to be appropriately quantitative and data-driven.**

**4. Time-Domain and Multi-Messenger Astrophysics**

*Decadal recommendation: NASA should establish a time-domain program to realize and sustain the necessary suite of space-based electromagnetic capabilities required to study transient and time-variable phenomena, and to follow-up multi-messenger events. This program should support the targeted development and launch of Explorer-scale or somewhat larger missions and missions of opportunity.*

**Finding:** The 2020 Astrophysics Decadal identified Time Domain and Multi-Messenger Astrophysics (TDAMM) of small and medium-scale missions as the top priority theme for space within the Sustaining Activities portfolio: "New Messengers and New Physics will exploit the new observational tools of gravitational waves and particles, along with temporal monitoring of the sky across the electromagnetic spectrum and wide-area surveys from the ultraviolet and visible to microwave and radio, to probe some of the most energetic processes in the universe…" Yet, we are currently missing capabilities (e.g., fast-turnaround UV spectroscopy or very wide field –i.e. > 10 deg2– X-ray imaging), and some of those currently available are aging (e.g., gamma-ray monitors).

**Finding:** NASA organized a workshop in August, 2022 to identify the top TDAMM science questions associated with the Decadal Survey recommendations. A summary white paper presents findings from the workshop, including a need for wide-field, fast response X-ray and gamma-ray monitors with arcminute resolution. These facilities will have maximal impact if they are launched in a time window that allows coordinated observations with other new facilities such as the Vera Rubin Observatory. The full white paper can be found here: https://pcos.gsfc.nasa.gov/TDAMM/docs/TDAMM_Report.pdf

**Finding:** NSF facilities also support a high-impact time domain program. Nearly 100 gravitational wave events have been detected since the first direct observation in 2015. The fourth run (May 2023 - end of 2024) from the LIGO-Virgo-Kagra collaboration is expected to produce around 250 new gravitational wave events. The Vera Rubin Observatory will be one of the most effective instruments to search for optical counterparts to gravitational waves, yet full observations are likely to miss O4 entirely, and the next GW observing run is not expected to start until ~2027.

**Finding:** Uncertainties in the schedule for ground-based instrumentation and observations has added significant challenges for some NASA missions that would offer key fast-turnaround electromagnetic observations of gravitational wave sources that are fundamental to realize the scientific potential of the multi-messenger revolution. In addition, there are differing opinions within the community on whether gravitational wave events are announced promptly with sufficient information.

**Finding:** Coordination of real-time observations over multiple facilities will improve the efficiency of time-domain observations. Without coordination at the time of proposals, competing observations can be approved across different facilities. There are agreements between some facilities, but those agreements do not always extend to Target of Opportunity observations.

**Comment:** Efficiency of multi-wavelength observations from NSF and NASA facilities would be improved with an expansion of proposal solicitations for observations jointly scheduled across missions/instruments. There are challenges to this approach, one important one being that the Time Allocation Committee may not be equally knowledgeable on all instruments.

**Recommendation:** NASA and NSF should coordinate construction and operations for ground-based and space-based operations to maximize the scientific return of new space-based missions. NSF should also facilitate clear communication between LIGO and the community to allow maximal impact from future space-based missions.

**5. Data**

*Decadal recommendation: NASA and NSF should explore mechanisms to improve coordination among U.S. data archive centers and to create a centralized nexus for interacting with the international archive archive communities. The goals of this effort should be informed by the broad scientific needs of the astronomical community.*

*Decadal recommendation: NSF and stakeholders should develop a plan to address how to design, build, deploy and sustain software infrastructures and pipelines for producing science-ready data across all general-purpose ground-based observatories (both federally and privately funded), providing funding in exchange for ensuring that all pipelined observation are archived in a standard format for eventual public use.*

**Finding:** TDAMM is intrinsically a multi-wavelength, multi-mission endeavor that happens on short timescales (sometimes as short as hours). There are many other science cases that require data across multiple archives. While there has been significant improvement over the last decade, it is still not unusual to have to query several separate data archives to collect the data set for a given analysis. Each archive releases the data in its own data format and conventions. Data also reach the archives in their final format on different timescales, ranging from weeks to months.

**Finding:** The Center for Computational Astrophysics (CCA) at the Flatiron Institute, in collaboration with the National Science Foundation, arranged a "Future of Astrophysical Data Infrastructure Workshop" in February, 2023. This workshop was structured to identify new strategies around implementing Decadal Survey recommendations related to ground-based astrophysical data management.

**Comment:** It is imperative to develop a path to reward and sustain the careers of those that dedicate their efforts to pipeline, software, and archiving development.

**Comment:** While the second Decadal Survey recommendation listed above was directed toward NSF and ground-based-observatories, archiving and sustainability are equally important for NASA facilities.

**Recommendation: As requested in the 2020 AAAC report, the agencies and the AAAC should initiate a review of the 2014 Principles for Access to Large Federally Funded Astrophysics Projects and Facilities. Any findings and recommendations from the Flatiron workshop should be considered in updating the Principles for Access.**

**6. State of the Profession**

*Decadal recommendation: NASA, NSF, DOE, and professional societies should ensure that their scientific integrity policies address harassment and discrimination by individuals as forms of research/scientific misconduct.*

**Finding:** The Head of NSF Office of Equity and Civil Rights (NSF OECR) has updated policies on harassment. All new NSF awards require awardee organizations to notify NSF if a PI is under investigation for violations of the organization's code of conduct. NSF will review each case using a series of criteria to ensure the continuity of science and funded project can continue.

**Finding:** DOE Office of Science has established expectations for events hosted by the Office and has new requirements for a code of conduct and broad recruitment and accessibility plans in conference proposals. DOE Office of Science also has a new requirement and assessment criteria for Promoting Inclusive and Equitable Research in any new proposals.

**Recommendation: NSF and DOE should report statistics to the AAAC on the number of instances of code of conduct investigations in award applications (NSF) or DOE-hosted conferences. NSF should also report challenges faced in implementation of the institutional reporting, for example, with regards to policies on privacy that vary from state to state.**

**Recommendation: NASA and DOE should evaluate which aspects of the NSF OECR award policy on harassment can be adopted in their own processes.**

*Decadal recommendation: NASA, NSF, and DOE should implement a cross-agency committee or working group tasked with establishing a consistent format and policy for regularly collecting,*

*evaluating, and publicly reporting demographic data and indicators pertaining at a minimum to outcomes of proposal competitions.*

**Finding:** The NIH collects demographic information from researchers in its external grants program and sets an example that other agencies can emulate.

**Finding:** The CHIPS and Science Act was released after the Decadal Survey. Sec. 10502 requires each Federal research agency to collect comprehensive demographic data on recipients of Federal awards and to report this data to NSF for summary and publication. Sec. 10502 establishes that NSF shall establish and update a policy to ensure standardization of the data collected.

**Finding:** Expectations and use of demographic data varies across agencies. Within NSF, DOE, and NASA, the astrophysics divisions are each subject to the policies on data collection established higher up within the agency.

**Finding:** Section 4 of the "Executive Order On Advancing Racial Equity and Support for Underserved Communities Through the Federal Government" can be found here: https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/20/executive-order-advancing-racial-equity-and-support-for-underserved-communities-through-the-federal-government/
This executive order requires the Director of the Office of Management and Budget (OMB) to partner with the heads of agencies to study methods for assessing equity and fairness in agency policies and actions.

**Finding:** OSTP has established a new team on science and society to broaden participation in STEM fields and strengthen the U.S. research infrastructure. While the priorities for this new initiative do not specifically include consistency in the collection of demographics data, this group may serve as a reference for such studies:
https://www.whitehouse.gov/ostp/ostps-teams/science-and-society/

**Finding:** Following advocacy from the research community, OSTP has begun working with agencies on creating uniform format for biosketches.

**Comment:** The biosketch effort may serve as an example for OSTP and agency coordination on the establishment of a minimal set of standards for demographic collection.

**Comment:** The AAAC has recommended consistent demographic collection by NSF, NASA, and DOE since the March 2021 report.

**Recommendation: Contrary to the Decadal Survey recommendation, NSF-AST, DOE Cosmic Frontier, and NASA should not set up a cross-agency task force, but should rather coordinate with the NSF Director's Office, OMB, and OSTP in establishing criteria for demographics data**

**collection. Only through a joint effort with OSTP and OMB will a minimal set of requirements be established in a holistic way that spans federal agencies.**

**7. Climate Change**

*Decadal recommendation: The astronomy community should increase the use of remote observing, hybrid conferences, and remote conferences, to decrease travel impact on carbon emissions and climate change.*

**Finding:** NSF-AST is planning to make at least one observatory completely carbon neutral in the next two years and plans to reduce emissions of all NOIRLab facilities by roughly 50% in the next few years.

**Finding:** DOE has significant ongoing programs to address climate change, reduce energy usage, enhance energy resiliency and efficiencies and develop new energy sources and technologies that include industry and academic partnerships. Many DOE Cosmic Frontier experiments now have remote data-taking, as recommended by the Decadal Survey.

**Comment:** The AAAC commends the initial efforts of NSF and DOE to mitigate greenhouse gas emissions associated with research. The Gemini Observatory has developed an ingenious model to measure carbon emissions generated by its facilities and upgraded its power system with PV arrays, under the support of NSF.

**Recommendation: NSF should share their successful experience at the Gemini Observatory with other ground-based observatories of NSF and DOE to determine if this model can be implemented on a larger scale.**

**Recommendation: NSF and DOE should develop programs specifically for supporting transitions to renewable power systems, given the operation budgets of observatories are generally not allowed for this kind of infrastructure upgrades. This specific funding should cover not only large observatories, such as the facilities in NOIRLab, but also mid-size and even small observatories.**