W. M. KECK OBSERVATORY
Maunakea, Island of Hawai`i

23 April, 2020

Dr. Kelvin Droegemeier, Acting Director
National Science Foundation
2415 Eisenhower Avenue, Suite 19000
Alexandria, VA 22314

Mr. James Bridenstine, Administrator
Office of the Administrator
NASA Headquarters
Washington, DC 20546-0001

Mr. Dan Brouillette, Secretary of Energy
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

The Honorable Eddie Bernice Johnson, Chairwoman
Committee on Science, Space and Technology
United States House of Representatives
Washington, DC 20515

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

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

Dear Dr. Droegemeier, Mr. Bridenstine, Secretary Brouillette, Chairwoman Johnson, Chairman Wicker, and Chairman Alexander:

I am writing to you today in my capacity as Chair of the Astronomy and Astrophysics Advisory Committee (AAAC). Please accept the attached report of the AAAC for the 2019-2020 year. I apologize for the late transmission of this year's report. It was significantly delayed due to the impacts of the COVID-19 pandemic on the Committee. Regarding COVID-19, I will be sending a separate letter on behalf of the Committee later in May to convey our opinions on the federal response to COVID-19 as it relates to this Committee's charge. On behalf of the AAAC, I hope this letter finds you all

Headquarters: 65-1120 Mamalahoa Highway, Kamuela, HI 96743
Phone (808) 885-7887 • Fax (808) 885-4464

healthy and safe, and I thank you all for your commitment and leadership during these difficult times for the nation and the world.

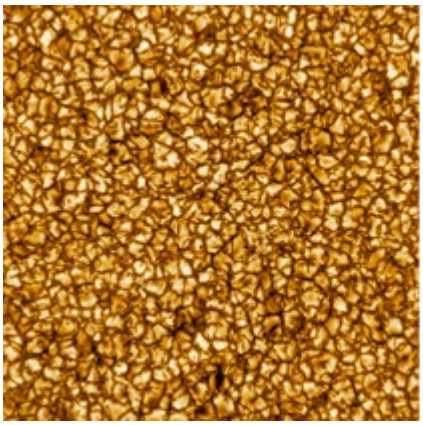
If you have any questions regarding this report, or any need for a further briefing, either as formal testimony, or in informal dialogue, please don't hesitate to contact me.

On behalf of the AAAC,

Dr. John M. O'Meara
Chair, AAAC

Report of the Astronomy and Astrophysics Advisory Committee

April 23, 2020



Committee Members:

Dr. John M. O'Meara, W.M. Keck Observatory, *Chair*
Dr. Nancy Chanover, New Mexico State University
Dr. Andrew Connolly, University of Washington
Dr. Kyle Dawson, University of Utah
Dr. Ian Dell'Antonio, Brown University
Dr. Scott Dodelson, Carnegie Mellon University
Dr. Mansi Kasliwal, California Institute of Technology
Dr. Eliza Kempton, University of Maryland
Dr. Petrus Martens, Georgia State University
Dr. Stephan Meyer, University of Chicago
Dr. Priyamvada Natarajan, Yale University
Dr. Constance Rockosi, University of California, Santa Cruz
Dr. Deidre Shoemaker, Georgia Institute of Technology

Cover Image

From left to right: A portion of the “First Sun” image from DKIST, the fully-completed fiber feed assembly for DESI, and the final science image from the *Spitzer* space telescope.

Executive Summary

We list our complete set of findings and recommendations below. The findings and recommendations are developed and supported in the body of the report. Acronyms are introduced in the text and are listed in Appendix A.

Collected Findings and Recommendations

1. Finding: NSF, NASA and DOE are continuing to work together to accomplish large research projects that were prioritized in the NWNH report and in the 2014 P5 report to DOE and NSF/PHY.

2. Finding: With the exception of CMB-S4, these projects have either completed their construction and are obtaining science results, or will complete very shortly.

3. Finding: The onset of NEID commissioning represents a significant positive milestone in NASA/NSF collaboration.

4. Recommendation: NASA and NSF should continue to collaborate on inter-agency initiatives such as NEID that have significant community impact.

5. Finding: Curation of archival datasets for use by the wider astronomical community requires resources and well-defined policies for data formats.

6. Finding: NASA's released Strategy for Data Management and Computing for Groundbreaking Science represents an important step in establishing open data, open code, data management, and data curation policies across the Science Mission Directorate, and serves as a potential starting point for inter-agency collaboration and coordination.

7. Recommendation: NASA, NSF, and DOE/Cosmic Frontier should work together to enable data discoverability across their data archives via joint adoption of standards in order to maximize science return.

8. Recommendation: All current and planned surveys supported by NSF, NASA and DOE/Cosmic Frontier should publicly release their data with suitable access tools and documentation. This is consistent with the AAAC Principles of Access recommended by the AAAC in their 2013-2014 annual report. In addition, the surveys should endeavor to use open code to create the data products in order that the community can learn how those data products were created.

9. Finding: Long term support for continued use and curation of source code can represent a significant additional cost. The AAAC recommends a cost/benefit analysis of such efforts.

10. Recommendation: NASA, NSF, and DOE/Cosmic Frontier should include funding to enable adequate public access to the data, software, and data products of these surveys.

11. Recommendation: The three agencies should coordinate on the guidelines and expectations for the public releases of data sets, data products, data access tools, and

related software used to produce future survey results, astrophysical simulations, and missions. The goal of this coordination should be to help researchers efficiently provide access to the data they produce through tools useful for the broad scientific community with minimal duplication of effort between agencies and stakeholder groups. Release and documentation of the software used to generate and analyze the data will enhance the quality of current and future science by enabling more cost effective reproducibility and extension of the scientific results from the initial studies.

12. Recommendation: The agencies and the AAAC should initiate a review of the Principles of Access after the release of the 2020 Decadal Survey recommendations.

13. Finding: The goal of detecting 90% of NEOs > 140 m diameter will not be met by 2020, and will take decades to meet at the current rate of discovery.

14. Finding: The potential contributions of ground-based astronomical surveys to the discovery of NEOs and the achievement of the goal set forth in the George E. Brown Act are significant.

15. Recommendation: The AAAC encourages ongoing NASA/NSF coordination, through the Planetary Defense Coordination Office, to clearly define the role that existing and future ground-based astrophysics surveys and facilities can play in the discovery and characterization of NEOs.

16. Finding: Radio quiet zones and the preservation of the protected regions of the radio spectrum are critical for radio astronomy.

17. Recommendation: The AAAC recommends that the NSF should continue to work with international astronomy agencies involved in radio astronomy to create and preserve geographical radio quiet zones.

18. Recommendation: We recommend that the current definition of radio quiet zones, and the federal legislation establishing them, be modernized to include radio emission from satellites and high altitude transmitters (e.g. drones and high altitude balloons) and not just terrestrial signals.

19. Finding: The emergence of mega-constellations of low earth orbit satellites represents a serious issue for astronomical observations. The reflectivity of these satellites and their radio transmissions impact the scientific returns of current and future investments in astronomical facilities across the optical and radio spectrum.

20. Recommendation: The AAAC recommends that NASA, NSF, and DOE/Cosmic Frontier develop a coordinated strategy to address the short-term impacts of the Starlink program on their facilities and missions, as well as the longer-term definition of policies to address the impact of future mega-constellations.

21. Finding: The AAAC concurs with the top-level findings of the report submitted by the NASA GW-EM task force.

22. Recommendation: Given the inter-agency response required to fully maximize the science benefits of prompt EM follow up to GW events, we recommend that NSF and NASA continue to explore ways for current and planned facilities and missions to communicate, coordinate, and optimize for prompt GW-EM follow-up.

23. Finding: The agencies are making and planning important and impactful changes to improve diversity and inclusion and to reduce implicit bias across their portfolios.

24. Finding: New initiatives at NASA to move to dual-anonymous reviews of proposals represent a potentially significant and important step in reducing implicit bias. The AAAC strongly endorses these initiatives, and encourages ongoing evaluation of their outcomes.

25. Recommendation: NASA/APD, NSF/AST, and DOE/Cosmic Frontier should learn from each others' initiatives and evaluate adopting joint priorities and policies across their Diversity and Inclusion efforts.

26. Recommendation: NASA, NSF, and DOE/Cosmic Frontier should report annually to the AAAC on their diversity and inclusion initiatives, and where possible provide quantitative evaluations of the impacts of these initiatives. The agencies should furthermore report on efforts to remove implicit bias in proposal reviews.

27. Finding: The AAAC supports NASA's recent policy to ensure that NASA-supported postdoctoral fellows have the option to be direct employees of a host institution.

28. Recommendation: The AAAC recommends that the agencies adopt or maintain policies regarding postdoctoral fellows to support the community of early-career scientists in astronomy and astrophysics.

29. Finding: Although constrained by the resources available, the MSIP program has consistently been over-subscribed and variably funded, it has proven to be an important avenue for funding the current generation of astronomy surveys, instruments and projects.

30. Recommendation: We recommend that NSF continue to offer the MSIP program within the AST division in parallel with, but separate from the NSF-wide MRI and MSRI calls. We further recommend that NSF strive to stabilize the MSIP funding level cycle-over-cycle.

31. Finding: The AAAC is gratified to see continued, significant progress by the NSF and DOE toward completion of the highest priority decadal ground-based facility, the Vera C. Rubin Observatory, which is advancing toward the start of survey science operations in 2022.

32. Finding: The AAAC expresses concern that the level of staffing within the NSF AST division is too low given the significant needs placed on the division by facilities operations.

33. Finding: Operations of the Rubin Observatory may place significant strain on the ability for NSF and DOE/Cosmic Frontier to maintain a balanced portfolio of facilities and other funding.

34. Recommendation: The AAAC urges NSF and DOE to put in place a long-term operations plan that will, while maintaining a balanced overall portfolio, ensure that the US science community can capitalize on the substantial investment in the Rubin Observatory.

35. Finding: WFIRST has successfully passed multiple reviews (including Phase C), and has now entered into final design and fabrication, consistent with the recommendations of the WIETR report.

36. Finding: The President's requested level of FY 2021 funding for NASA's Astrophysics division is not large enough to enable both a balanced portfolio of investments in Astrophysics and the funding for NASA's Wide-Field Infrared Survey Telescope

37. Finding: The proposed termination of WFIRST, as presented in the President's requested FY 2021 budget for the astrophysics division of NASA, would result in the withdrawal of federal support for the highest ranked priority for space from *NWNH.*

38. Finding: A balanced investment by NASA in astrophysical research, including a mix of major, medium, small, and individual research awards, is recognized by the AAAC as the preferred path for NASA to maximize its impact in astrophysical research.

39. Finding: The AAAC strongly supports the federal government respecting the integrity and importance of the decadal survey process for identifying the priorities for the agencies engaged in supporting astronomical and astrophysical research.

40. Recommendation: In order to maintain a balanced investment in astrophysical research while continuing to support WFIRST, the highest ranked priority for NASA by the most recent decadal survey, *NWNH,* we recommend that the NASA budget be increased above the President's request to allow a funding level for the astrophysics division that would enable the funding of WFIRST to continue in the context of a balanced portfolio of investment.

41. Finding: The AAAC commends the NASA Astrophysics Division on fulfilling the recommendation of *NWNH* and *NWNH-AMA* that at least four Announcements of Opportunity for the Explorer program be executed this decade.

42. Finding: the AAAC endorses the expansion of the SmallSat development program. In addition to providing novel science opportunities, it also provides a pathway for potential PIs of future larger missions.

43. Finding: the AAAC endorses the creation of the Pioneers mission line.

44. Finding: JWST will provide revolutionary capabilities in infrared astronomy, enabling exciting discoveries in all of NASA Astrophysics research priorities. The AAAC is heartened at the continued work and progress towards the 2021 launch date, only a year away.

45. Recommendation: NASA should continue to allocate resources to successfully launch JWST at the earliest possible date.

46. Recommendation: The AAAC recommends to Congress that SOFIA's prime mission be considered complete.

47. Finding: The proposed termination of the SOFIA mission based on an assessment of poor science return in the President's FY2021 funding request, along with the publicly available results of the SOFIA FMR indicate the continued need for SOFIA to be placed into the triannual senior review process along with other NASA missions.

48. Recommendation: The AAAC recommends that SOFIA undergo senior review including a decision on mission extension, immediately or as soon as is feasible, but no later than the next regular review cycle, in line with normal NASA review procedures.

49. Recommendation: The AAAC urges Congress to increase the proposed FY 2021 appropriation for NASA above the Administration's request to continue to provide a balanced program within astrophysics in line with the recommendations of *NWNH*.

50. Recommendation: The AAAC urges Congress to increase the proposed FY 2020 appropriation for NSF above the Administration's request to enable the Agency to properly balance research and infrastructure funding needs.

51. Recommendation: The AAAC urges Congress to increase the proposed FY 2021 appropriation for DOE High Energy Physics above the Administration's request to provide adequate funding for operations of and research and analysis of data from the numerous world-class facilities currently nearing completion.

52. Finding: The policies surrounding reporting of proposed and implemented fiscal year budgets are not uniform across the agencies the AAAC is charged with advising. In particular, the NSF budget reporting cycle lags by a year that of the other agencies, significantly hampering the AAAC's ability to meet its charge.

53. Recommendation: NSF should report their budget forecasts and implementations to the AAAC so as best to overlap with the other agency report timelines.

54. Finding: The statutory deadline, March 15th, for the submission of the AAAC annual report does not allow sufficient time for the committee to react to budget developments that typically occur in the first two months of each calendar year.

55. Recommendation: the AAAC recommends that the annual report deadline be changed from a fixed date to a deadline 45-60 days following the submission of the President's budget, so as to enable sufficient opportunity for the committee to interact with the funding agencies, understand the impact of the President's budget, and formulate recommendations. The AAAC would endeavor to still meet the current deadline of March 15th when possible.

1. Introduction

The Astronomy and Astrophysics Advisory Committee[1] (AAAC) was established in the National Science Foundation (NSF) Authorization Act of 2001. Its charge is to monitor and evaluate the performance of the NSF, National Aeronautics and Space Administration (NASA), and the Department of Energy (DOE), on issues within the field of astronomy and astrophysics, especially those requiring coordination of the agencies' efforts. The AAAC annually assesses progress in implementation of the recommendations of the most recent decadal survey, *New Worlds, New Horizons in Astronomy and Astrophysics*[2] *(NWNH),* its predecessors, and relevant reports from similarly constituted non-decadal advisory committees. The AAAC reports to the Secretary of Energy, the NASA Administrator, the NSF Director, and to relevant committees in the House and Senate. This communication represents the annual report of the 2019-2020 committee reviewing activities in 2019 and early 2020.

A few notable highlights from the past year, both in research and in engagement with the public, are outlined in Section 2. The cover photo of this report is a montage of highlights from the last year. The left-hand image is the 'first Sun' image from the Daniel K. Inouye Solar Telescope (DKIST), funded by NSF. The middle image is the fully assembled fiber feed system for the Dark Energy Spectroscopic Instrument, funded by DOE, which has completed commissioning. The right-hand image is the final science image taken by NASA's *Spitzer* space telescope before its end of mission in early 2020. The image, a composite of images from two infrared filters shows a portion of the California nebula.

Since March 15, 2019, the AAAC has had four meetings, two in-person, two via teleconference. Representatives of the three agencies have given briefings and provided input on the status of their programs. As we finalize this report, the FY 2021 budget request has been submitted by the Administration. The delivery of this report has been delayed by approximately a month due to the impacts of COVID-19.

---

[1] https://www.nsf.gov/mps/ast/aaac.jsp

[2] https://www.nap.edu/catalog/12951/new-worlds-new-horizons-in-astronomy-and-astrophysics

The AAAC notes that some sections repeat discussion, findings, and recommendations of reports from previous years. The committee continues to find these discussions of importance, and continues to support the findings and recommendations made.

Finally, the AAAC notes a slight change in format for this report relative to others. Given the proximity of this report to the findings of Astro2020 anticipated in a year's time, this report will focus on specific issues of interest and concern to the AAAC as opposed to a general discussion of the agencies' responses to *NWNH*. We will significantly shorten those pieces, or eliminate them for brevity. Nevertheless, if a finding or recommendation is listed with little discussion, it is still found to be of importance to the committee, and worth consideration by the agencies and other stakeholders.

2. Highlights of 2019-2020

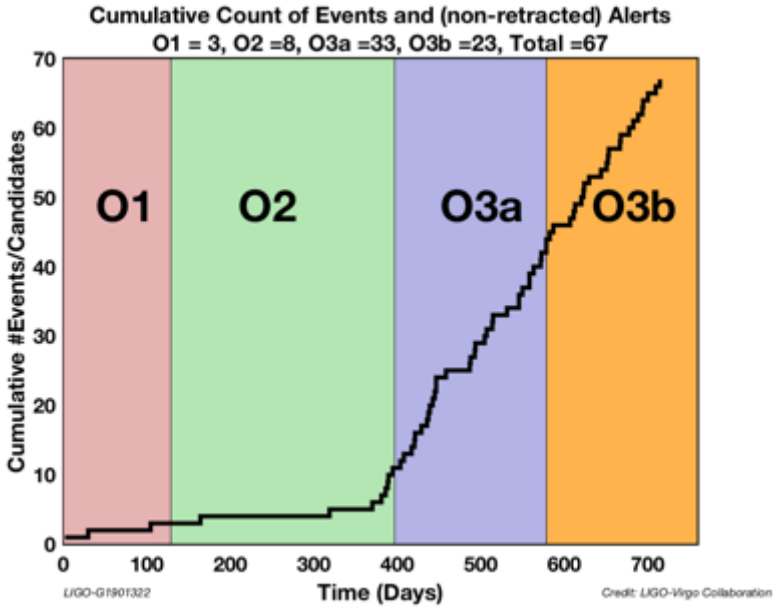
JWST nears completion of testing

JWST in the Northrop Grumman clean room in October, 2019

In August of 2019, the science payload and spacecraft components of the James Webb Space Telescope (JWST) completed integration, marking the first time the entire observatory was a single unit. In November of the same year, the sunshield underwent a test deployment. Further

environmental testing is slated for spring of 2020, and the mission is currently on track for a launch in spring, 2021.

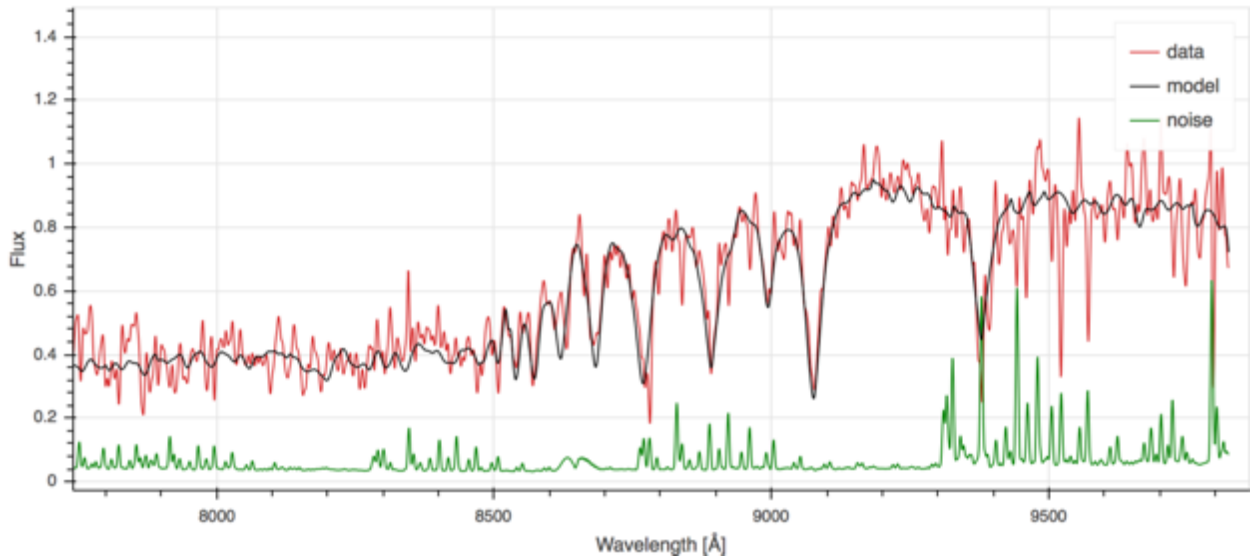
LIGO completes Observing Run Three



Total number of LIGO gravitational wave event detections (image courtesy LIGO-Virgo Collaboration)

In April 2019, the third observing run (O3) of LIGO began with a notional one year length. Although the COVID-19 pandemic caused the run to end approximately a month earlier than planned, the observing run showed a significant enhancement in detection capabilities with the inclusion of the European Virgo detector. In total, O3 measured over 50 new gravitational wave detection events, a factor of five increase over observing runs one and two combined.

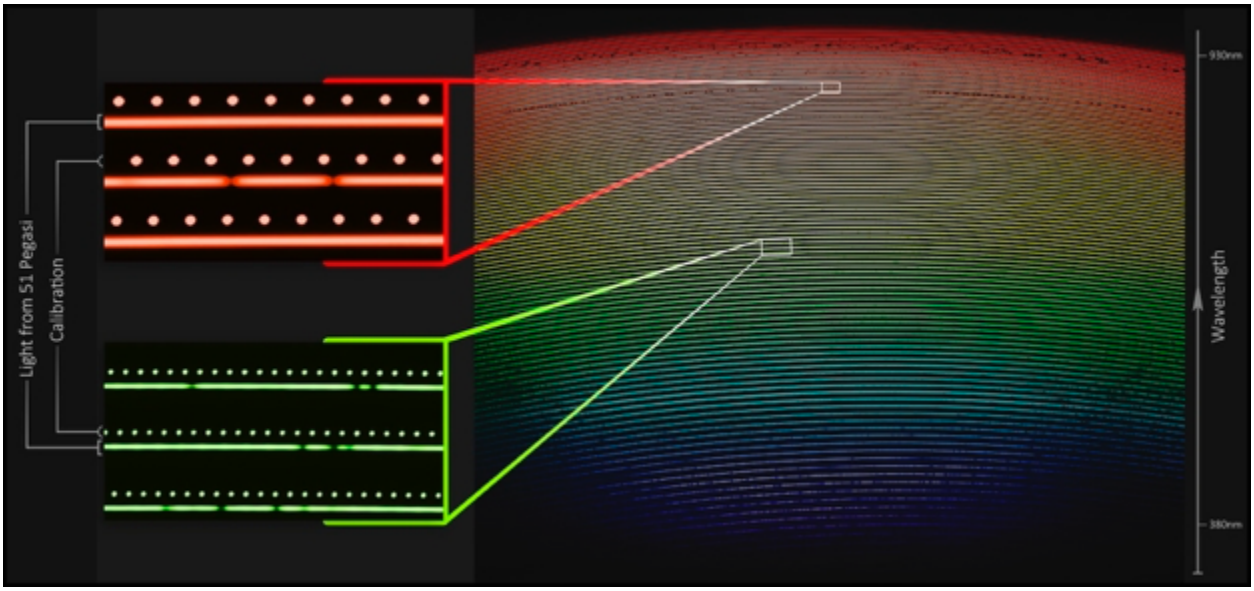
DESI Completes Commissioning



DESI commissioning spectrum of a luminous red galaxy from March, 2020 (image courtesy LBL)

DESI first light occurred in November, 2019. In March of 2020, DESI completed its commissioning demonstration program. The program tested the full DESI spectrograph system, obtaining spectra of tens of thousands of objects, and successfully demonstrated the end-to-end aspects of the instrument after installation at the telescope at Kitt Peak.

NEID arrives at Kitt Peak



NEID first light spectrum of the star 51 Pegasi (image courtesy University of Arizona)

In January, 2020, the NEID spectrograph obtained its first light spectrum, beginning its commissioning and verification at Kitt Peak National Observatory. NEID's first light spectrum was of the star 51 Pegasi, which in 1995 was the first Sun-like star identified to have at least one

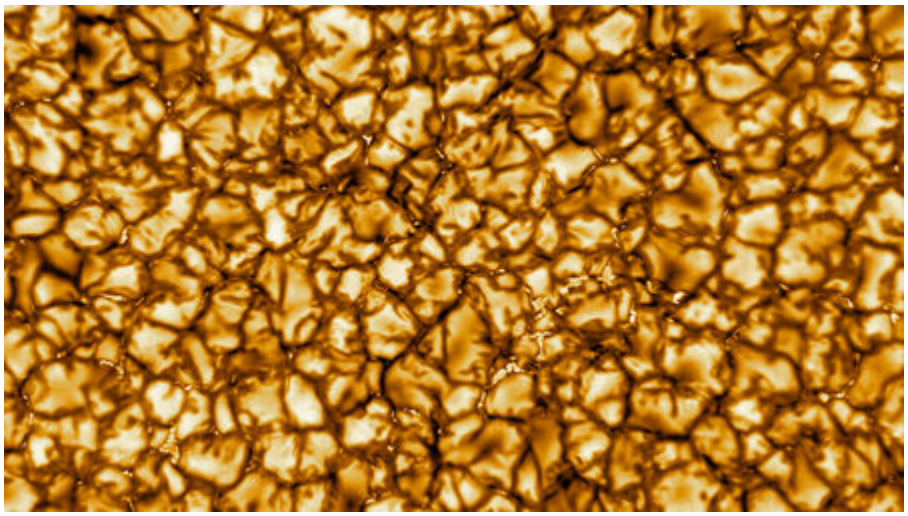
exoplanet orbiting it. NEID is funded by the joint NASA/NSF Exoplanet Exploration Program (NN-EXPLORE).

Spitzer ends its mission after 16 years

Declaration of mission's end at Mission control, NASA JPL (image courtesy NASA)

On January 30, after 16 years in operation, the NASA infrared flagship mission *Spitzer* was decommissioned, bringing to a close a mission with an immense record of scientific discovery from the Solar System to exoplanets, to distant galaxies. *Spitzer's* prime mission came to an end in 2009, but science observations continued for a decade after the helium cryogens were exhausted.

DKIST Sees "First Sun"



The Solar surface as imaged by DKIST (image courtesy DKIST)

The National Science Foundations' 4m Daniel K. Inouye Solar Telescope (DKIST) on Haleakala, Maui had its first engineering solar light in fall of 2019. The subsequent press release revealed the highest resolution solar images ever recorded to a global audience. Since first light the commissioning of the spectro-polarimeteric instruments, which will probe the solar magnetic field with the highest possible resolution and sensitivity, has commenced and first spectra have been obtained.

3. Overview of Interagency Coordination and Cooperation

NASA, NSF, and the Department of Energy continue to successfully cooperate and jointly support the construction and operation of large projects. These joint efforts are producing instruments and large surveys of great interest to the astronomical community. The largest, most visible projects are now at or nearing the beginning of observations, most notably the LSST survey at the Vera C. Rubin Observatory and DESI on the Mayall 4m telescope at Kitt Peak (DOE and NSF), but inter-agency collaboration has also led to the commissioning in 2019 of the NEID radial velocity instrument on WIYN at Kitt Peak (NASA and NSF) and the studies that will lead up to the design reviews of CMB-S4 (DOE and NSF). In addition, NSF, NASA Astrophysics and DOE Office of Science have supported the work of the Decadal Survey panels.

Finding: NSF, NASA and DOE are continuing to work together to accomplish large research projects that were prioritized in the NWNH report and in the 2014 P5 report to DOE and NSF/PHY.

Finding: With the exception of CMB-S4, these projects have either completed their construction and are obtaining science results, or will complete very shortly.

Finding: The onset of NEID commissioning represents a significant positive milestone in NASA/NSF collaboration.

Recommendation: NASA and NSF should continue to collaborate on inter-agency initiatives such as NEID that have significant community impact.

3.1 Interagency coordination and collaboration to maximize return on investments in survey datasets

Large projects such as those mentioned above will generate massive, sometimes complex datasets that will be used widely by the astronomical community. As the number of significant archival datasets grow, issues of accessibility and interoperability come to the fore.

In particular,archives that have seen the most use (SDSS, HST, *Chandra*) have a set of tools for accessing the data and processing (or provide processed data) that are simple, easy to use, and reliable Given the multitude of archive sites and the many different datasets, it is important that these access tools be accessible, and the scientific impact depends on the ability to cross-correlate data from different archives.

Finding: Curation of archival datasets for use by the wider astronomical community requires resources and well-defined policies for data formats.

The issue of Data Management at the strategic level has recently been taken up by NASA, which commissioned a study and recently released a Strategy for Data Management and Computing for Groundbreaking Science. The study was of particular interest to the AAAC, given the Committee's recommendations around data policy in recent reports. The study noted that even now archival data science results represent 50% of studies published using NASA data. Even so, both the archival datasets and required computational resources across the Science Mission Directorate are expected to grow significantly. The strategy document identified three goals for data management systems to strive for and made several recommendations for action: to implement the capabilities for open science, to evolve data and computing systems, and to harness community partnerships to enhance innovation. This led to recommendations in multiple areas.

On the open data, software and science front, the study recommends a standard NASA policy on data management for all new missions to be included in solicitations (SALMON) and award requirements, taking a lifecycle approach to data. All new software supporting these missions must be developed and released as open source, except when specific restrictions apply. For high end computing, the study recommends revisiting policies and studying the access patterns every five years to inform strategies for efficiently using NASA resources.

On data retention, it is recommended that all digital data from NASA funded research be required to be stored in NASA archives for long-term curation and public availability. To support this, the panel recommended including specific evaluation criteria in ROSES solicitations regarding the adequacy of data management plans. Recognizing that not all progress in data management is housed in NASA or indeed in astronomy, the report recommends continued effort to incorporate advances in data science methods, including machine learning and AI techniques, and software into the data archives, while at the same time reducing the bar to the use of these techniques to NASA users by making training and tutorials available. To support the increased focus on data management, the document recommended that NASA work with archive centers to increase recruitment and increase the perceived value of data stewards and developers. The report also recommended that these archives develop metadata that would allow cross-mission and cross-disciplinary investigations, even beyond NASA. For example, but not limited to this, the data archives of NASA's Heliophysics System Observatory should ideally work seamlessly with those of NSF supported ground-based observatories, such as DKIST, GONG, and SOLIS.

Finding: NASA's released Strategy for Data Management and Computing for Groundbreaking Science represents an important step in establishing open data, open code, data management, and data curation policies across the Science Mission Directorate, and serves as a potential starting point for inter-agency collaboration and coordination.

The strategies described in the document are important beyond NASA, as study of astrophysical phenomena often requires multi-mission study that crosses agency boundaries. For example, multi-messenger astrophysics is soon going to make use of NSF-funded gravitational wave and neutrino detectors, NSF and DOE-funded wide-field imaging with the Vera Rubin Observatory, and space-based imaging and spectroscopy supported by NASA.

Recommendation: NASA, NSF, and DOE/Cosmic Frontier should work together to enable data discoverability across their data archives via joint adoption of standards in order to maximize science return.

Recommendation: All current and planned surveys supported by NSF, NASA and DOE/Cosmic Frontier should publicly release their data with suitable access tools and documentation. This is consistent with the AAAC Principles of Access recommended by the AAAC in their 2013-2014 annual report. In addition, the surveys should endeavor to use open code to create the data products in order that the community can learn how those data products were created.

Finding: Long term support for continued use and curation of source code can represent a significant additional cost. The AAAC recommends a cost/benefit analysis of such efforts.

Recommendation: NASA, NSF, and DOE/Cosmic Frontier should include funding to enable adequate public access to the data, software, and data products of these surveys.

Recommendation: The three agencies should coordinate on the guidelines and expectations for the public releases of data sets, data products, data access tools, and related software used to produce future survey results, astrophysical simulations, and missions. The goal of this coordination should be to help researchers efficiently provide access to the data they produce through tools useful for the broad scientific community with minimal duplication of effort between agencies and stakeholder groups. Release and documentation of the software used to generate and analyze the data will enhance the quality of current and future science by enabling more cost effective reproducibility and extension of the scientific results from the initial studies.

Recommendation: The agencies and the AAAC should initiate a review of the Principles of Access after the release of the 2020 Decadal Survey recommendations.

3.2 Planetary Defense

The Planetary Defense Coordination Office, established in 2016 at NASA, is charged with leading national (interagency) and international efforts to detect, track, and mitigate asteroid impact hazards. The National Near-Earth Object Preparedness Strategy and Action Plan, issued by the White House in 2018, provided updated guidance concerning enhancing Near-Earth Object (NEO) detection, characterization and deflection, modeling and information integration, international cooperation, and emergency protocols. Although by 2010 NASA had successfully fulfilled the 1994 Congressional mandate to find at least 90% of the potentially hazardous NEOs larger than 1 km diameter, the population of smaller NEOs remains underdiscovered.

The George E. Brown Jr. Near-Earth Object Survey Act, a section of the 2005 NASA authorization act, directed NASA to detect at least 90 percent of NEOs at least 140 meters in diameter by the end of 2020; it will take more than 30 years to achieve this goal at the current discovery rate. While NASA is exploring the development of a dedicated space-based infrared survey telescope with the goal of finding 90% of the potentially hazardous asteroids within 10 years, it is recognized that major ground-based astronomical surveys such as the Dark Energy Survey (DES) and the Vera C. Rubin Observatory (VRO) can also play a significant role in discovering NEOs > 140 m diameter. Including the anticipated return from VRO by the end of its 10-year baseline survey, along with the existing dedicated ground-based NEO surveys, will achieve a catalog completeness of roughly 75% by 2032.

Finding: The goal of detecting 90% of NEOs > 140 m diameter will not be met by 2020, and will take decades to meet at the current rate of discovery.

Finding: The potential contributions of ground-based astronomical surveys to the discovery of NEOs and the achievement of the goal set forth in the George E. Brown Act are significant.

Recommendation: The AAAC encourages ongoing NASA/NSF coordination, through the Planetary Defense Coordination Office, to clearly define the role that existing and future ground-based astrophysics surveys and facilities can play in the discovery and characterization of NEOs.

3.3 Protecting the electromagnetic spectrum for Astronomical Research:

NSF has continued to proactively represent the US astronomical community in safeguarding the radio portion of the electromagnetic spectrum. With the rapid development of 5G technology, there is ever greater pressure on the spectrum, particularly at higher frequencies. NSF has continued to work with the national astronomy community (as well as international projects such as the SKA) to highlight the need for the protected bands. As an example, there is now a proposal for a vote at the World Radio Conference to protect bands within the 275-450 Ghz window where

there is great pressure from mobile telephony. Currently there are very few regulations for frequencies >275Ghz.

In addition to protecting frequencies, there is also a significant need to maintain the existing geographic protected regions. In addition to the region surrounding Green Bank, astronomical projects with large US involvement that cross national boundaries such as ALMA, will need additional protections.

The current protected region designation carries protection from ground-based signals, but a significant additional threat to these radio quiet zones is represented by high altitude (balloon-based) broadcast platforms and by the deployment of satellite constellations. NSF is working with international agencies towards a plan for WRC 2027 to regulate the bands satellite constellations can use to communicate to Earth--given the broad coverage of their signal and the increase of satellites, even by 2027 there is the likelihood that multiple satellites will always be "visible" in the radio sky over every radio observatory. Because the current regulations do not constrain the transmission from satellites, it is crucial that the spectrum protection conventions be modernized.

Finding: Radio quiet zones and the preservation of the protected regions of the radio spectrum are critical for radio astronomy.

Recommendation: The AAAC recommends that the NSF should continue to work with international astronomy agencies involved in radio astronomy to create and preserve geographical radio quiet zones.

Recommendation: We recommend that the current definition of radio quiet zones, and the federal legislation establishing them, be modernized to include radio emission from satellites and high-altitude transmitters (e.g. drones and high-altitude balloons) and not just terrestrial signals.

Up to now, agency activities on spectrum protection for astronomy have focused primarily on the radio. Optical spectrum management has been focused on discussion with local authorities near the sites of major ground-based observatories. In the past year, however, the development of cheap launch technology for large arrays of communications satellites has proceeded. In May, 2019, SpaceX launched the first 60 satellites (out of 1584) of a constellation of telecommunications satellites called Starlink. SpaceX's Starlink constellation is just the first of several constellations planned. Companies such as Amazon and Samsung also have announced plans for large telecommunication satellite constellations. These satellite constellations will increase the number of visible satellites by a factor of more than ten over the next ten years (up to 50,000 satellites are planned for launch). Furthermore, the reflections of sunlight from the new constellations could be brighter than 99% of the objects currently in orbit, increasing the number of man-made bright objects by factors of more than 100. The American Astronomical Society has a standing committee on Light Pollution, RFI and Space Debris, and they are carrying out studies of the effect of satellite constellations. Although the very bright and obvious streams of satellites that characterize deployment have made headlines, much of the risk to night-time astronomy is

determined by the final configurations. Satellite networks that are in lower orbits are brighter, but are in sunlight for fewer hours after sunset and before dawn. The balance on the impact on astronomical observations also depends on the saturation limit of detectors, as saturated signals can lead to persistence that damages exposures even after the satellite is no longer in the field.

The AAS working group has been meeting with SpaceX and is seeking to meet with Amazon to study ways to ameliorate the problem by reducing the reflectivity of the satellites. SpaceX deployed one of its satellites with a low-reflectivity coating, and a preliminary analysis in early 2020 shows a reduction in reflectivity, but not nearly to the level where there would be no impact on astronomical observations. One challenge with addressing the impact of satellite constellations on astronomy is the relevant set of stakeholders and regulatory bodies, with whom the astronomy community does not have established relations. For example, private companies develop the constellations, typically with no consultation with the astronomy community. Approval for satellite launches and configurations within the US are regulated by a combination of the FCC and FAA, and for constellations launched outside of the US other regulatory bodies may be involved.

Currently, the only regulations covering the optical/NIR part of the spectrum involve restrictions on lasers for adaptive optics. These new satellite constellations will impact current and future NSF and DOE observational missions, particularly the wide-field missions, and will also impact NASA ground-based support resources. Coordination, during the design and approval processes, between the companies deploying LEO satellites, the agencies, and the regulatory bodies would enable the impact of these satellites to be understood and potentially mitigated prior to launch.

Finding: The emergence of mega-constellations of low earth orbit satellites represents a serious issue for astronomical observations. The reflectivity of these satellites and their radio transmissions impact the scientific returns of current and future investments in astronomical facilities across the optical and radio spectrum.

Recommendation: The AAAC recommends that NASA, NSF, and DOE/Cosmic Frontier develop a coordinated strategy to address the short-term impacts of the Starlink program on their facilities and missions, as well as the longer-term definition of policies to address the impact of future mega-constellations.

3.4 Prompt electromagnetic follow-up to gravitational wave events

In 2019, NASA created a task force to report on how current and future NASA missions can maximize their impact with regards to prompt electromagnetic (EM) follow-up to gravitational wave (GW) events. The report found that missions can be more effective at coordination, that they can enhance Target of Opportunity capabilities, and that they can adjust their Guest Observer programs to be more impactful. The report also highlighted gaps in the existing portfolio in the immediate and future term.

Finding: The AAAC concurs with the top-level findings of the report submitted by the NASA GW-EM task force.

Recommendation: Given the inter-agency response required to fully maximize the science benefits of prompt EM follow up to GW events, we recommend that NSF and NASA continue to explore ways for current and planned facilities and missions to communicate, coordinate, and optimize for prompt GW-EM follow-up.

3.5 Ensuring a diverse and inclusive community

Far past due, the astronomical community is beginning to seriously assess and elevate the importance of diversity and inclusion on the health of the field. One example of many is the Astro2020 Decadal Survey Panel on the State of the Profession and Societal Impacts.

As major sources of funding and workforce for the astronomical community, NASA, NSF, and DOE are also engaging in multiple efforts to promote and support a culture of diversity and inclusion. Following several years of efforts within DOE and its national laboratories, in November 2019 the DOE convened an external review of the diversity, equity and inclusion efforts and initiatives ongoing at the national laboratories. The analysis of this review is currently underway. NASA has initiated a program, PI Launchpad, to train the next generation of mission principal investigators in the development of science cases, requirements, and use cases for mission concept proposals. Dual anonymous peer review that was initiated with the proposal selection process for the Hubble Space Telescope has been shown to reduce the implicit bias in the selection process. NASA plans to extend this program to Guest Observer proposals for its operating missions. The Astrophysics Data Analysis Program (ADAP), part of NASA's Research Opportunities in Space and Earth Science, will trial dual anonymous peer review for research proposals in the coming year.

Finding: The agencies are making and planning important and impactful changes to improve diversity and inclusion and to reduce implicit bias across their portfolios.

Finding: New initiatives at NASA to move to dual-anonymous reviews of proposals represent a potentially significant and important step in reducing implicit bias. The AAAC strongly endorses these initiatives, and encourages on-going evaluation of their outcomes.

Developing programs to support a diverse and inclusive workforce and the recognition across all of the agencies of the importance of promoting a culture of inclusion is critical if the US is to maintain its scientific leadership. Establishing such a culture will require sustained effort together with regular evaluation of the progress of these initiatives. We encourage all of the agencies to monitor, where allowed by law, the impact of these programs on the creation of a diverse and inclusive research community.

Recommendation: NASA/APD, NSF/AST, and DOE/Cosmic Frontier should learn from each other's initiatives and evaluate adopting joint priorities and policies across their Diversity and Inclusion efforts.

Recommendation: NASA, NSF, and DOE/Cosmic Frontier should report annually to the AAAC on their diversity and inclusion initiatives, and where possible provide quantitative evaluations of the impacts of these initiatives. The agencies should furthermore report on efforts to remove implicit bias in proposal reviews.

A change in the structure of the NASA fellowship programs (e.g. the Hubble Fellowship Program) now allows recipients to choose whether they are employees of their host institution or to take the award as a stipend. This enables early career researchers to take advantage of the health, leave, retirement and disability benefits offered by the host institution.

Finding: The AAAC supports NASA's recent policy to ensure that NASA-supported postdoctoral fellows have the option to be direct employees of a host institution.

Recommendation: The AAAC recommends that the agencies adopt or maintain policies regarding postdoctoral fellows to support the community of early-career scientists in astronomy and astrophysics.

4 Implementation of *NWNH* Recommendations

Given the impending release of the Astro2020 report, we only will devote a short space to the review of the agency responses to *NWNH* recommendations, with a focus on issues resulting from the FY2021 budget request, and those of particular interest to the AAAC.

4.1 Ground-based projects

4.1.1. The MSIP funding opportunity from NSF

In response to the 2010 decadal survey, the NSF astronomy division initiated the MSIP program specifically to fund mid-scale astronomy projects with budgets larger than the foundation-wide MRI program limits but not large enough to be funded through the MREFC program. Although highly variable in total funds allocated, the MSIP program has consistently been over-subscribed and proved to be an important avenue for funding the current generation of astronomy surveys, instruments and projects. The newly introduced NSF-wide MSRI is also a source of funding for projects of this scale.

Finding: Although constrained by the resources available, the MSIP program has consistently been over-subscribed and variably funded, it has proven to be an important avenue for funding the current generation of astronomy surveys, instruments and projects.

Recommendation: We recommend that NSF continue to offer the MSIP program within the AST division in parallel with, but separate from the NSF-wide MRI and MSRI calls. We further recommend that NSF strive to stabilize the MSIP funding level cycle-over-cycle.

4.1.2 The Vera C. Rubin Observatory

The Vera C. Rubin Observatory (formerly the Large Synoptic Survey Telescope until renamed by an act of Congress in late 2019) is a wide-field imaging optical observatory targeting all three *NWNH* science themes. Researchers will use LSST data products to probe the fundamental natures of dark energy and dark matter, study the constituents of our Solar System, map and understand the structure and contents of the Milky Way Galaxy, and survey the transient sky. The highest ranked ground-based program of *NWNH,* and the highest priority for the DOE-HEP Cosmic Frontier in the 2014 P5 strategic plan, this project moved into the construction phase and the camera received DOE Critical Decision 3 (CD-3), start of full construction, in August 2015. The project is now significantly advanced, with the DOE-funded camera making significant progress towards completion, along with the NSF-funded dome and facility at Cerro Pachon. Multiple major components have been shipped to Chile. Operations should begin in 2022.

Finding: The AAAC is gratified to see continued, significant progress by the NSF and DOE toward completion of the highest priority decadal ground-based facility, the Vera C. Rubin Observatory, which is advancing toward the start of survey science operations in 2022.

While significant progress has been made towards completion of the Rubin Observatory, significant concern remains in the AAAC regarding the operations budget, and the impact of this budget on NSF and DOE. NSF/AST in particular already has significant facilities expenditures that place stress not only on their research budgets, but also their staffing.

Finding: The AAAC expresses concern that the level of staffing within the NSF AST division is too low given the significant needs placed on the division by facilities operations.

Finding: Operations of the Rubin Observatory may place significant strain on the ability for NSF and DOE/Cosmic Frontier to maintain a balanced portfolio of facilities and other funding.

Recommendation: The AAAC urges NSF and DOE to put in place a long-term operations plan that will, while maintaining a balanced overall portfolio, ensure that the US science community can capitalize on the substantial investment in the Rubin Observatory.

4.2 Space-based Projects

4.2.1 WFIRST

WFIRST was the top space-based recommendation of *NWNH*, and is designed to address the *NWNH* themes of dark energy, exoplanets, and galaxy evolution science. Concern regarding the cost and schedule of WFIRST led the mid-decadal review[3] (*NWNH-AMA*) to recommend an independent review of the project. In 2017, the WFIRST Independent External Technical/Management/Cost Review *(WIETR)* was commissioned by NASA and their report was issued the same year. The *WIETR* reaffirmed the importance of the science goals of the mission and the team's ability to develop and execute the mission. The *WIETR* report included recommended steps to bring the mission cost back down to a cost of $3.2 billion. The *WIETR* identified options for reducing cost that included making the coronagraph instrument a technology demonstrator, making small changes to the wide field instrument, and identifying contributions to be made from international partners. Even if the coronagraph were pursued only as a technology demonstrator, a significant science capability might potentially be delivered to the community.

In 2019, WFIRST made significant progress through preliminary design, with each subsystem, and eventually the entire project passing preliminary design review. WFIRST was approved to enter Phase C in late February, 2020, with a $3.9 billion life cycle cost for development, coronagraph development, and five year prime mission support. WFIRST is working towards a launch readiness date of no earlier than October 2025, with an agency commitment of October 2026.

Finding: WFIRST has successfully passed multiple reviews (including Phase C), and has now entered into final design and fabrication, consistent with the recommendations of the WIETR report.

The President's requested budget for FY 2021 does not include funding for WFIRST. As noted in previous annual reports, the AAAC supports balanced investments by all the agencies as a method of ensuring maximal scientific impact over time. We also continue to strongly support the federal government respecting the integrity and importance of the decadal survey process for identifying the priorities for the agencies engaged in supporting astronomical and astrophysical research. Ending the funding of WFIRST is in conflict with the successful past practice of the agencies trying to realize, in partnership with the community, the aspirations of the decadal surveys. Moreover, it jeopardizes US leadership in space-based OIR astronomy.

[3] https://sites.nationalacademies.org/SSB/CurrentProjects/SSB_161177

Finding: The President's requested level of FY 2021 funding for NASA's Astrophysics division is not large enough to enable both a balanced portfolio of investments in Astrophysics and the funding for NASA's Wide-Field Infrared Survey Telescope

Finding: The proposed termination of WFIRST, as presented in the President's requested FY 2021 budget for the astrophysics division of NASA, would result in the withdrawal of federal support for the highest ranked priority for space from *NWNH.*

Finding: A balanced investment by NASA in astrophysical research, including a mix of major, medium, small, and individual research awards, is recognized by the AAAC as the preferred path for NASA to maximize its impact in astrophysical research.

Finding: The AAAC strongly supports the federal government respecting the integrity and importance of the decadal survey process for identifying the priorities for the agencies engaged in supporting astronomical and astrophysical research.

Recommendation: In order to maintain a balanced investment in astrophysical research while continuing to support WFIRST, the highest ranked priority for NASA by the most recent decadal survey, *NWNH,* we recommend that the NASA budget be increased above the President's request to allow a funding level for the astrophysics division that would enable the funding of WFIRST to continue in the context of a balanced portfolio of investment.

4.2.2 Explorers program

The NASA Explorers program of relatively low-cost missions, quickly deployed, has a history of high scientific impact, including both the Uhuru and Cosmic Background Explorer (COBE) missions leading to Nobel prizes for their investigators. A high priority of *NWNH* was a significant expansion of the existing NASA Explorer program, including at least four Explorer Announcements of Opportunity during this decade, each with Mission of Opportunity calls and mission selection. With the selection of the SPHEREx mission in 2019, NASA has fulfilled the recommendation of *NWNH*.

Finding: The AAAC commends the NASA Astrophysics Division on fulfilling the recommendation of *NWNH* and *NWNH-AMA* that at least four Announcements of Opportunity for the Explorer program be executed this decade.

4.2.2 SmallSats and the Pioneers program

The NASA Astrophysics Division is ramping up its support for SmallSAT, CubeSat and RideShare missions, with five missions in development and plan to offer opportunities yearly.

Finding: the AAAC endorses the expansion of the SmallSat development program. In addition to providing novel science opportunities, it also provides a pathway for potential PIs of future larger missions.

NASA has recognized the need to develop a new generation of mission PIs and the need to develop a class of mission between the SmallSat and regular balloon mission class and the Explorer-class missions. In response to this community need, in February, 2020 a new research announcement was made to solicit science ideas developed by PIs. These missions within the newly established *Pioneers* program, which are capped at $20 million, are roughly a factor of 4 above the typical smallSat budgets, but a similar factor below the Explorer missions, and allow missions that are more flexible both in terms of management requirements than explorers, but which allow new PIs to develop both novel science and management skills.

Finding: the AAAC endorses the creation of the Pioneers mission line.

4.2.2 The James Webb Space Telescope

The James Webb Space Telescope (JWST) remains on track for a March 2021 launch, although the impacts of the COVID-19 pandemic on this schedule are as of writing not known. Integration of the spacecraft and telescope was successfully completed in late 2019. Environmental testing will proceed through the spring of 2020, followed by vibration testing and deployment and shipping in fall 2020 in anticipation of the 2021 launch date.

Finding: JWST will provide revolutionary capabilities in infrared astronomy, enabling exciting discoveries in all of NASA Astrophysics research priorities. The AAAC is heartened at the continued work and progress towards the 2021 launch date, only a year away.

Recommendation: NASA should continue to allocate resources to successfully launch JWST at the earliest possible date.

4.2.3 SOFIA

While not strictly a space-based mission, the Stratospheric Observatory for Infrared Astronomy (SOFIA) is a 2.5 meter telescope on a Boeing 747 that is operated by NASA. SOFIA operates at mid and far-infrared wavelengths that are otherwise only accessible from space. Jointly funded by NASA and the German Aerospace Center, SOFIA's initially agreed upon 5-year prime mission was completed at the end of FY19. At the end of a prime mission, NASA usually assesses the

science performance, management of a program, and proposed future science to decide on an extension of the program through the Senior Review Process, as required by the 2005 NASA Authorization Act. The 2018 Consolidated Appropriations Act, however, redefined the prime mission length, and explicitly dismissed SOFIA from the 2019 Senior Review.

Recommendation: The AAAC recommends to Congress that SOFIA's prime mission be considered complete.

In 2019, NASA Associate Administrator Thomas Zurbuchen directed that SOFIA undergo two reviews. The first was a review of the aircraft operations and maintenance, and concluded that SOFIA should make significant changes to the management model, flight cadence, and productive time in flight. The second review, the Five Year Flagship Mission Review (FMR), was tasked with evaluating mission operations and science yield. The FMR found that the science productivity of SOFIA "falls short of that expected by the science community for a flagship mission with an annual operating cost of approximately $86M per year"[4]. The FMR then provided ten recommendations to improve science return. Only the summaries and NASA response to the reviews are publicly available.

In the President's FY2021 funding request, citing a lack of scientific productivity, the budget proposes to terminate the SOFIA mission.

Finding: The proposed termination of the SOFIA mission based on an assessment of poor science return in the President's FY2021 funding request, along with the publicly available results of the SOFIA FMR indicate the continued need for SOFIA to be placed into the triannual senior review process along with other NASA missions.

Recommendation: The AAAC recommends that SOFIA undergo senior review including a decision on mission extension, immediately or as soon as is feasible, but no later than the next regular review cycle, in line with normal NASA review procedures.

5. Additional Matters of Note

5.1 FY 2021 Budget Concerns

Examination of the President's budget request for FY2021 causes significant concern, and warrants a response nearly identical to the previous years by the AAAC.

The budget for NASA would again call for the cancelation of the WFIRST mission, the highest space mission priority of *NWNH*. A WFIRST cancellation would be a substantial departure from

[4] https://science.nasa.gov/science-pink/s3fs-public/atoms/files/NASA_Response_to_SOFIA%20Reviews_Final_TAGGED.pdf

the vision of *NWNH* and would likely jeopardize future missions of similar or larger scale that might be recommended in the 2020 Decadal Survey.

Recommendation: The AAAC urges Congress to increase the proposed FY 2021 appropriation for NASA above the Administration's request to continue to provide a balanced program within astrophysics in line with the recommendations of *NWNH*.

The Administration's FY 2021 budget request contains significant cuts to budgets at NSF, with significant impacts on the AST division. These cuts not only jeopardize the NSF's current ability to balance the need for world-class facilities and the community of researchers that use them, but also significantly threatens this balance in future years.

Recommendation: The AAAC urges Congress to increase the proposed FY 2020 appropriation for NSF above the Administration's request to enable the Agency to properly balance research and infrastructure funding needs.

The FY 2020 budget request also proposes significant cuts to the DOE High Energy Physics Program relative to the enacted FY 2020 amounts. The request will create challenges for the ability of the DOE to fund external grants and maintain future progress.

Recommendation: The AAAC urges Congress to increase the proposed FY 2021 appropriation for DOE High Energy Physics above the Administration's request to provide adequate funding for operations of and research and analysis of data from the numerous world-class facilities currently nearing completion.

5.2 Agency budget delivery

Given the AAAC's charge, particularly the focus on interagency coordination and collaboration, it is essential that the Committee have the most relevant and timely information available from the agencies. It is difficult for the Committee to properly evaluate agency efforts if adopted budgets, even at moderate levels of specificity, are not provided in a manner that allows for joint analysis. For example, the NSF budget implementation is described to the AAAC effectively a year after that from other agencies.

Finding: The policies surrounding reporting of proposed and implemented fiscal year budgets are not uniform across the agencies the AAAC is charged with advising. In particular, the NSF budget reporting cycle lags by a year that of the other agencies, significantly hampering the AAAC's ability to meet its charge.

Recommendation: NSF should report their budget forecasts and implementations to the AAAC so as best to overlap with the other agency report timelines.

5.3 AAAC report timing

The statutory date for report submission by the AAAC is March 15 (although this year, the delivery date was delayed due to the impacts of the COVID-19 pandemic). This date requires that the Committee and agency representatives meet, the Committee formulate recommendations, and the report be drafted and submitted within approximately one month of the notional delivery date of the President's annual budget request to Congress. Given rapidly shifting and uncertain budget scenarios, it is often the case that the report of the AAAC is not fully informed by important budget developments. The AAAC wishes to fully fulfill its charter and provide timely and meaningful recommendations. In order to do so, a change to the statutory due date would be extremely helpful. Generally, a due date of, for example, 45-60 days following the submission of the President's budget, would provide sufficient time for the AAAC to fully interact with the funding agencies and formulate its recommendations.

Finding: The statutory deadline, March 15th, for the submission of the AAAC annual report does not allow sufficient time for the committee to react to budget developments that typically occur in the first two months of each calendar year.

Recommendation: the AAAC recommends that the annual report deadline be changed from a fixed date to a deadline 45-60 days following the submission of the President's budget, so as to enable sufficient opportunity for the committee to interact with the funding agencies, understand the impact of the President's budget, and formulate recommendations. The AAAC would endeavor to still meet the current deadline of March 15th when possible.

5.4 Agency and Congressional response to COVID-19

The impacts of the COVID-19 pandemic on the United States and the world continue to increase and change at the time of the writing of this report. The AAAC wishes to make a number of recommendations regarding the federal response to COVID-19 as they relate to the charge of this Committee. A separate small document will be drafted by the AAAC and delivered by mid-May 2020.

Appendix A: Explanation of Abbreviations

AAAC	**Astronomy and Astrophysics Advisory Committee**
AAS	**American Astronomical Society**
ALMA	**Atacama Large Millimeter/submillimeter Array**
CMB	**Cosmic Microwave Background Radiation**
DESI	**Dark Energy Spectroscopic Instrument**
DKIST	**Daniel K. Inouye Solar Telescope**
DOE	**Department of Energy**
EM	**Electro Magnetic**
FACA	**Federal Advisory Committee Act**

FY	**Fiscal Year**
HEP	**High Energy Physics**
HST	**Hubble Space Telescope**
JWST	**James Webb Space Telescope**
KPNO	**Kitt Peak National Observatory**
LIGO	**Laser Interferometer Gravitational-Wave Observatory**
LSST	**Legacy Survey of Space and Time**
MPS	**Mathematical & Physical Sciences (NSF Directorate for …)**
MREFC	**Major Research Equipment and Facilities Construction**
MRI	**Major Research Instrumentation**
MSIP	**Mid-Scale Innovation Program**
NASA	**National Aeronautics and Space Administration**
NASA/APD	**National Aeronautics and Space Administration Astrophysics Division**
NEID	**NN-explore Exoplanet Investigations with Doppler spectroscopy**
NOAO	**National Optical Astronomy Observatory**
NRC	**National Research Council**
NSF	**National Science Foundation**
NSF/AST	**National Science Foundation Division of Astronomical Sciences**
NSF/OPP	**National Science Foundation Office of Polar Programs**
NSF/PHY	**National Science Foundation Division of Physics**
NWNH	**The 2010 NRC decadal survey report "*New Worlds, New Horizons in Astronomy and Astrophysics*"**
NWNH-AMA	**The 2016 NRC mid term assessment report, "*New Worlds, New Horizons in Astronomy and Astrophysics, A Midterm Assessment*"**
OIR	**Optical InfraRed**
OMB	**Office of Management and Budget**
P5	**Particle Physics Project Prioritization Panel**
R&D	**Research and Development**
SMD	**Science Mission Directorate, NASA**
SOFIA	**Stratospheric Observatory for Infrared Astronomy**
TESS	**Transiting Exoplanet Survey Satellite**
WFIRST	**Wide-Field Infrared Survey Telescope**