**SUBCOMMITTEE ON SPACE AND AERONAUTICS**
**SUBCOMMITTEE ON RESEARCH AND TECHNOLOGY**
**COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY**
**U.S. HOUSE OF REPRESENTATIVES**

# HEARING CHARTER

***A Review of the Decadal Survey for Astronomy and Astrophysics in the 2020s***

Wednesday, December 1, 2021
11:00 a.m.
Online Via Zoom

## PURPOSE

The purpose of this hearing is to review the science priorities and recommendations from the decadal survey on astronomy and astrophysics, *Pathways to Discovery in Astronomy and Astrophysics for the 2020s*, recently released by the National Academies of Sciences, Engineering, and Medicine.

## WITNESSES

- **Dr. Fiona A. Harrison,** Co-Chair, Steering Committee, Committee for A Decadal Survey on Astronomy and Astrophysics 2020, National Academies of Sciences, Engineering, and Medicine; Harold A. Rosen Professor of Physics, California Institute of Technology
- **Dr. Robert C. Kennicutt, Jr.,** Co-Chair, Steering Committee, Committee for A Decadal Survey on Astronomy and Astrophysics 2020, National Academies of Sciences, Engineering, and Medicine; Laureate Professor, University of Arizona; and Professor of Physics and Astronomy, Texas A&M University
- **Mr. William Russell,** Director, Contracting and National Security Acquisitions, Government Accountability Office

## OVERARCHING QUESTIONS

- *What are the science priorities recommended by the decadal survey for the next ten years of astronomy and astrophysics?*
- *What are the decadal survey's recommendations for Federal investments in astronomy and astrophysics to pursue those priorities? What are the recommendations for ground-based and space-based telescopes and other research infrastructure? What are the recommendations for workforce development and other foundational activities to advance the science priorities?*
- *What are the potential challenges to realizing the vision of the decadal survey?*

## BACKGROUND

On November 4, 2021, the National Academies of Sciences, Engineering, and Medicine[1] issued the astronomy and astrophysics decadal survey, *Pathways to Discovery in Astronomy and Astrophysics for the 2020s* (Astro2020).[2] A decadal survey is a two-year process, conducted on approximately a ten-year cadence, culminating in the publication of a final report that aims to review the scientific progress of the previous decade in a given discipline, develop a community consensus around the scientific priorities of the next decade, and recommend a comprehensive program to best address them. The National Academies conduct decadal surveys in the Earth and space sciences (astronomy and astrophysics, planetary science, solar and space physics, and space life and physical sciences) under sponsorship by one or more federal science agencies. Astro2020 was sponsored by the National Aeronautics and Space Administration (NASA),[3] the National Science Foundation (NSF), the Department of Energy (DOE) Office of High Energy Physics, and the Air Force Office of Scientific Research, and recommends a program for implementation over the 2023-2032 decade. Agencies use the results of the decadal surveys to guide the content of their programs.

The first decadal survey produced by the National Academies was for astronomy in 1964,[4] and the National Academies has issued a new survey in astronomy and astrophysics approximately every ten years since.[5] Nearly all top-priority projects recommended by the decadal surveys have been at least initiated within the ensuing decade, with most eventually being realized, if sometimes in the following decade. It is also the case that all major federal ground-based and space-based astronomical observatories of the last half-century were, in some form, highly prioritized for implementation in one or more decadal surveys. Such examples include the Chandra X-Ray Observatory and the Very Long Baseline Array (VLBA), recommended in the 1982 survey; the Spitzer Space Telescope and Atacama Large Millimeter Array (ALMA), recommended in 1991; the James Webb Space Telescope (JWST) and Vera Rubin Observatory, recommended in 2000; and the Nancy Grace Roman Space Telescope, recommended in 2010. A consistent theme of the decadal surveys is the importance of "balance," which includes maintaining not only a diverse portfolio of small, medium, and large facilities or missions, but also a strong research grant program. Decadal surveys may also offer recommendations in areas such as technology development, research infrastructure, education, workforce, and other enabling activities.

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[1] The National Academy of Sciences was established in 1863 by an Act of Congress signed into law by President Lincoln as an independent, nongovernmental institution to advise the government. The Academies of Engineering and Medicine were established later under the charter of the National Academy of Sciences. Activities of the National Research Council are now referred to as activities of the National Academies of Sciences, Engineering, and Medicine.

[2] National Academies of Sciences, Engineering, and Medicine. 2021. *Pathways to Discovery in Astronomy and Astrophysics for the 2020s*. Washington, DC: The National Academies Press. Available at: https://doi.org/10.17226/26141.

[3] Section 18384 of Title 42, U.S. Code requires NASA to take into account the decadal surveys when submitting the President's annual budget request to Congress.

[4] National Academy of Sciences. 1964. *Ground-based Astronomy: A Ten-Year Program.* Washington, DC: The National Academies Press. Available at: https://doi.org/10.17226/13212.

[5] The National Academies went on to issue the first decadal surveys in planetary science and solar and space physics in 2003 and Earth science and applications from space in 2007.

Astro2020 Prioritized Science

The decadal survey identified three broad themes that define its scientific vision for the next decade: *World and Suns in Context*, *New Messengers and New Physics*, and *Cosmic Ecosystems*. Within each theme, the survey identifies a top priority area of study that motivates the ultimate recommended program to the agencies.

The *Worlds and Suns in Context* theme aims to understand the formation and evolution of stars beyond our own Sun and the planets that orbit them, known as exoplanets, as well as the interactions and connections between and among them. The first exoplanets were only discovered in the 1990s, and they were very different from Earth, or even any of the other planets in our own Solar System. However, driven especially by the discoveries of NASA's Kepler mission, which launched in 2009, astronomers have identified more than 4,500 exoplanets. The decadal survey identifies a priority science area within this theme as "Pathways to Habitable Worlds," which has a goal of discovering and characterizing worlds that are most like the Earth and potentially hospitable to life.

The *New Messengers and New Physics* theme encompasses the scientific inquiries enabled by the detection of particles or waves that can be "messengers" from astronomical phenomena, beyond only light waves measured with traditional telescopes, as well as the new insights offered by time-domain astrophysics, or the study of astronomical phenomena and objects that change on short timescales, such as seconds, hours, or days. The decadal survey notes that the discovery of one new messenger, gravitational waves, in 2015 by the NSF's Laser Interferometric Gravitational Observatory (LIGO) from the merger of two black holes, is "certainly one of the watershed moments in physics and astronomy of the last decades." The decadal survey identifies the priority science area within this theme as "New Windows on the Dynamic Universe," which leverages multi-messenger and time-domain observations to study some of the most extreme and energetic phenomena in the universe, including neutron stars, white dwarfs, stellar explosions, and the collisions of black holes, which may offer insights into the early formation of the Universe, as well fundamental physics questions on the nature of dark matter and dark energy.

The *Cosmic Ecosystems* theme comprises a broad array of observational and theoretical research and modeling to understand the formation and evolution of stars and galaxies. Astronomers have developed highly sophisticated simulations, informed by observations, that have revealed the interconnectedness of the Universe and all its systems, from star and planet formation to galaxy cluster evolution in a complex "cosmological web." The decadal survey identifies the priority science area within this theme as "Unveiling the Drivers of Galaxy Growth," which aims to understand the nature of the exchange of hot and cold material and energy between galaxies and their environments, and how those mechanisms might either stop or start the formation of stars in galaxies, as well as fuel the growth of supermassive black holes at the centers of galaxies.

Astro2020 Recommended Program of New Activities

The decadal survey presents a recommended program of new activities to pursue the science themes and most compelling science areas prioritized for the next decade. The report recommends near-term actions and future investments for ground- and space-based

observatories, research efforts, technology development, and human capital activities to advance science in the 2023-2032 decade and lay foundations for future ambitions. The recommended program was developed based on an assumption that missions and projects prioritized in previous surveys but not yet in scientific operation—such as the Vera Rubin Observatory,[6] JWST,[7] and the Roman Space Telescope[8]—will be completed and operate for as long as they may be scientifically productive.

The Astro2020 recommendations for federal agency projects and activities are organized into four functional categories defined in the report:[9]

- **foundational** activities, which the report defines as those that "build the people and the profession, bolster the core activities necessary for a vibrant research enterprise, and lay the technological foundations for the future;"
- programs that **sustain** and balance the science, primarily through small- and medium-scale, competed, principal-investigator-led activities;
- programs that **enable** future visions through targeted investments in development and concept maturation of major facilities prior to decadal recommendation or agency commitment; and
- large programs that forge the **frontiers,** with design and construction beginning in the coming decade of large facilities with broad capabilities, aimed at achieving the most ambitious ideas in a sustainable way.

The survey describes these categories as forming a "pathway" from the foundations of the profession out to the scientific frontiers. The report states that the primary consideration in designing its recommended program is that "the portfolio must be scientifically balanced, broad, and sustainable…[a]lso, the program must be structured to draw from the widest range of human talent." The report states that the functional categories are reflective of a "strong emphasis on balance and the need for projects on a variety of scales" and provides agencies flexibility in the face of budgetary uncertainties.

## Foundations

The survey's recommendations for the *foundations of the profession* include activities to support early-career astronomers, efforts to broaden participation and create an inclusive environment free from discrimination, community models for observatory sites, mitigation of astronomical contributions to climate change, and mitigation of radio frequency interference and light pollution, including from satellite constellations. The survey's recommendations for the *research*

[6] The Vera Rubin Observatory, formerly the Large Synoptic Survey Telescope (LSST), was the highest-priority, new, large-scale ground-based observatory recommended by the 2010 decadal survey, and the telescope is anticipated to reach full operation in 2022.
[7] The James Webb Space Telescope (JWST), formerly the Next Generation Space Telescope (NGST), was the highest-priority large-scale space mission recommended by the 2000 decadal survey, and the mission is currently scheduled to launch on December 22, 2021.
[8] The Nancy Grace Roman Space Telescope, formerly the Wide Field Infrared Survey Telescope (WFIRST), was the highest-priority large-scale space mission recommended by the 2010 decadal survey, and the mission is currently targeting launch in 2027.
[9] This organization is a departure from previous astronomy and astrophysics decadal surveys, which have presented prioritizations in categories based on budget (small, medium, and large) and platform (ground- and space-based).

*foundation* address individual-investigator grants, data management and pipeline development, and programs to support laboratory astrophysics. Recommended foundational activities related to *sustaining the operating portfolio* include addressing operations costs when establishing new ground-based facilities programs and ending operations of the Strategic Observatory for Infrared Astronomy (SOFIA) by 2023. Finally, the survey identifies recommendations to support *technological foundations*, including technology development programs at NASA and NSF.

**Sustain**

*Mid-Scale Ground-based Programs*

The survey committee found that NSF investments in mid-scale infrastructure[10] have greatly benefitted the astrophysics community and supported important research objectives, including the Event Horizon Telescope's (EHT) first ever image of a black hole at the center of the galaxy M87 in 2019. However, the survey found the available funding does not come close to meeting the demand. The survey committee's highest priority recommendation for ground-based sustaining activity is an increase in funding for mid-scale programs that support astronomy and astrophysics (up to $50 million per year) and the addition of separate funding opportunities to ensure funded projects are responsive to the survey's science priorities. The three proposal tracks are: (1) open calls, (2) strategic priorities, and (3) instrumentation upgrades and development.

*Space-based Time-Domain Program and Astrophysics Probe Missions*

The survey recommends two new sustaining programs for space: a time-domain astrophysics program (highest priority) and a competed line of medium-class missions called Astrophysics Probes. The time-domain astrophysics program is to sustain space-based capabilities to study astronomical phenomena that are short-lived or time-variable, such as gamma-ray bursts and stellar explosions or collisions, and make space-based observations of gravitational wave and other multi-messenger events. The survey recommended that NASA conduct the time-domain activity as a focused effort conducted in parallel to ongoing Explorer-class (small) missions. The new Astrophysics Probe line would be a new class of competed, principal-investigator-led missions with a cost cap of $1.5 billion to enable more powerful capabilities than can be accomplished at the Explorer mission scale (approximately $150-300 million), but with more focus than missions at the flagship scale (total budget of at least $3-5 billion).

**Enable**

*Space-based Great Observatories Mission and Technology Maturation Program*

The highest priority for enabling programs for space is the Great Observatories Mission and Technology Maturation Program, which would be a new approach for developing large space strategic missions in response to the large costs and development timescales associated with the

[10] NSF funds mid-scale ($4 million - $100 million) research infrastructure projects through the agency-wide Mid-Scale Research Infrastructure (MSRI) program and Mid-Scale Innovations Program (MSIP) within the AST and Physics (PHYS) Divisions. These programs fund a range of activities including facilities, equipment, instrumentation, or computational hardware or software.

large mission concepts submitted for consideration to the survey. The survey committee concluded that establishing a new suite of large observatories that operate concurrently is essential to address key questions in all three prioritized science themes. However, without a new approach, the survey committee also concluded that it would take many decades to realize the necessary range of observational capabilities. Under the Great Observatories Mission and Technology Maturation Program, NASA would make significant investments ($1.2 billion in the decade) in concurrently maturing technologies and mission concepts, including scope, for multiple new Great Observatories, doing so earlier in the development process and before future decadal recommendation and NASA commitment to implementing the mission. The survey recommended that the mission concept and technologies needed for a large telescope capable of making measurements in infrared, optical, and ultraviolent wavelengths enter the program first, and then the program should begin co-investing in technology development and mission maturation for both a far-infrared telescope concept and an X-ray telescope concept in the second half of the decade.

**Frontier**

*Ground-based Extremely Large Telescope Program*

The committee's highest priority for a new large-scale ground-based project is for NSF to invest in the U.S. Extremely Large Telescope (ELT) program. The ELT program is made up of three components: the Giant Magellan Telescope (GMT), the Thirty Meter Telescope (TMT), and NSF's National Optical-Infrared Astronomy Research Laboratory (NOIRLab). The GMT and TMT are already under development, with construction on each primary mirror underway. The GMT and TMT have comparable primary mirror sizes, measuring 24.5 meters and 30 meters in diameter, respectively. The combination of the two telescopes will provide coverage of both the Northern (TMT) and Southern (GMT) hemispheres. GMT will be at the Las Campanas Observatory in Chile. The TMT site will be either on Maunakea in Hawaii or on La Palma in the Canary Islands.[11] Contingent on Federal funding, both projects expect to begin operations in the 2030s. The NOIRLab would provide support to researchers, develop public data products, and foster research inclusivity. The combination of capabilities (large field of view and high-resolution imaging and spectroscopy) and full sky access provided by these telescopes will advance all three science themes prioritized by the survey committee. Advances enabled by these facilities include: the detection and characterization of rocky exoplanets; tests of relativity through observations of stars near the center of the Milky Way; measurements of the Universe's expansion rate; and imaging and spectroscopy of the oldest stars.

As part of its recommendation, the survey committee included guidance or "decision rules" to ensure that the investments in the recommended programs lead to a balanced and sustainable portfolio. To that end, the committee recommends that NSF invest a 25 percent share in each of the telescopes in the ELT program, for a total investment of $1.6 billion in construction and $32 million per year in operations. Before making this investment, the decadal committee recommended that NSF should conduct an external review of the financial and programmatic viability of each telescope. If only one is deemed viable, NSF should invest up to 50 percent in

[11] The site selection and approval process for TMT has been delayed due to intense opposition from indigenous Hawaiian activists and the recent revocation of a land agreement in the Canary Islands.

that telescope. If both telescopes are deemed viable, but budget constraints preclude a 25 percent investment in each, NSF should choose which telescope to fund based on a consideration of the following factors: complementarity with the European Southern Observatory ELT, the ability to address the survey's priority science questions, and the advantages of a larger mirror diameter versus a larger field of view.

*Cosmic Microwave Background Stage 4 and Next Generation Very Large Array*

The second priority recommendation for ground-based frontier facilities includes two equal priority projects. The first is the development and implementation of the Cosmic Microwave Background Stage 4 (CMB-S4) observatory, with joint funding from NSF and DOE. The Cosmic Microwave Background (CMB) is faint background radiation left over from the Big Bang. CMB measurements provide cosmologists with information about the history, evolution, and contents of the universe. Stage 4 will build on stage 2 and 3 CMB experiments deployed in Antarctica and Chile by significantly increasing the number of CMB detectors and expanding the range of frequency bands and probing large and small angular scales. The second second-priority ground-based recommendation is for NSF to support the design, development, and prototyping for the next-generation Very Large Array (ngVLA) radio telescope. The ngVLA includes an array of 244 reflector antennas operating at frequencies from 1.2 to 116 GHz and located at sites spanning New Mexico, west Texas, eastern Arizona, and northern Mexico, Hawaii, Washington, California, Iowa, Massachusetts, New Hampshire, Puerto Rico, the US Virgin Islands, and Canada. The improvement in sensitivity and resolution would advance multiple high-priority science questions: searching for radio emission from gravitational wave sources such as neutron star and black hole mergers and probing protoplanetary disks for signs of planet formation in action.

The survey committee imposed a key decision rule for all three ground-based frontier recommendations – new NSF Major Research Equipment and Facilities Construction (MREFC) facilities are contingent on NSF developing and implementing a sustainable plan for supporting the operations and maintenance of astronomical facilities while maintaining a balance with support for individual investigator grants and other foundational activities.

*Large, Space-based Infrared, Optical, and Ultraviolet Telescope*

The highest priority recommendation for a space-based large program that forges the frontiers is a large telescope that is optimized for observing potentially habitable, Earth-like planets orbiting other stars, as well as general astrophysics. Such a telescope would be approximately six meters in diameter, with mirrors and instruments that measure infrared, optical, and ultraviolet light, and the capability to conduct extremely high-contrast imaging and spectroscopy to detect the light from a habitable exoplanet, which would be 10 billion times fainter than the star it orbits. The decadal survey imposes a decision rule on this mission that requires the completion of a successful Great Observatories Mission and Technologies Maturation Program, described above, and a review before consideration by the next decadal survey for recommendation and ultimate commitment from NASA to develop the mission. The decadal survey estimates that this mission, could be ready to exit the Maturation Program mid- to late-decade, and that it will have a total

mission cost from that point forward, including implementation and operations (but not including the investments in the Maturation Program) of $11 billion in FY2020 dollars.

Budget Context and Input to Astro2020

In developing its priorities and recommendations, the decadal survey committee considered NSF and NASA budget guidance, which was a 2 percent annual growth in the astrophysics budget at NASA and an increase to $600 million in FY 2030 in the Major Research Equipment and Facilities Construction Line at NSF[12] The budget guidance along with several other factors (scientific ambition, timeliness, feasibility, programmatic balance) informed how the survey committee prioritized its recommended programs, and the general timeline for their implementation.

Pursuant to statute requiring independent cost estimates for decadal survey missions,[13] the NASEM contracted with the Aerospace Corporation to perform independent Technical, Risk, and Cost Evaluation (TRACE) studies on each NSF MREFC-scale project and NASA flagship concept. The current TRACE methodology builds on the foundation of the Cost and Technical Evaluation (CATE) process used in previous decadal surveys. The Aerospace Corporation used data and information provided by the relevant program panels in combination with "its proprietary models and databases, validated through multiple processes, including comparisons to historical implementations. Threats and risks were evaluated using Monte Carlo simulations." Each project was assessed independently. The output of the TRACE process is an estimated final project cost, timeline, and critical path at a 70 percent confidence level for each project, including cost and schedule reserves.

Due to limitations of the TRACE process, estimates of operations costs for ground-based facilities were produced separately by the program panels in consultation with additional expert consultants. Accurately accounting for the operations costs of future ground-based facilities is important given NSF's longstanding challenges in balancing support for facility operations with construction. Unlike budgeting for NASA missions, which includes funding for the entire mission lifecycle (development, integration, launch, and operations), NSF budgets for construction and operations through separate funding streams. Construction for facilities that cost more than $70 million is funded through the agency-wide MREFC account, while the sponsoring division for a given facility (AST for telescopes) is responsible for supporting the operations. This bifurcated process has resulted in rising operations costs that have outpaced the budget growth of the AST division. Operations costs have cut into funding for research grants. The resulting proposal pressure for individual research grants has caused concern among the research community and others about the long-term sustainability of this approach.

[12] NSF did not provide a budget forecast for AST, so the survey committee extrapolated from FY 2019 actual spending and estimated a 2.7 annual growth rate.

[13]The NASA Authorization Act of 2008, now codified in Section 20305 of Title 51, U.S. Code, directs that NASA's agreements with the National Academies for decadal surveys "shall include independent estimates of the life cycle costs and technical readiness of missions assessed in the decadal surveys whenever possible."