Report

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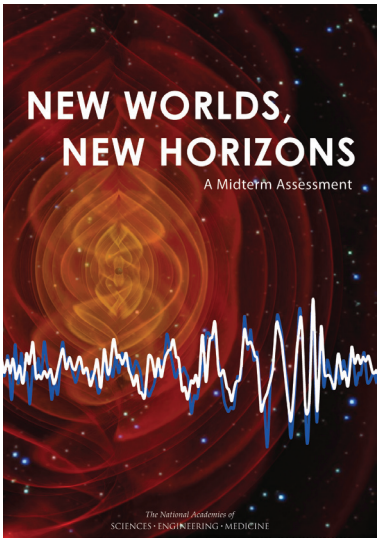
IN BRIEF

New Worlds, New Horizons

A Midterm Assessment



To carry out the Decadal Survey in Astronomy and Astrophysics, the National Academies of Sciences, Engineering, and Medicine assemble the astronomy and astrophysics community every ten years to identify science priorities for the field and provide guidance to Congress and the Administration. NASA's Astrophysics Division (NASA-APD) and the NSF's Division of Astronomical Sciences (NSF-AST) have been guided by the contents of these surveys for decades, and more recently DOE's Office of High Energy Physics has been informed by the surveys as well. The New Worlds, New Horizons Decadal Survey in Astronomy and Astrophysics (NWNH), published in 2010, recommended and prioritized a suite of innovative and powerful instruments as well as balanced, strong support for the scientific community engaged in theory, data analysis, technology development and observation. The new Academies' report, *New Worlds New Horizons: A Midterm Assessment*, evaluates the progress made by NASA, NSF, and DOE in reaching the goals set out by NWNH. In addition to the many groundbreaking scientific discoveries achieved in the first half of the decade, the development of some of the highest priority facilities identified in NWNH is underway. However, budget realities have limited progress towards the rest of the program envisioned by NWNH.

SCIENTIFIC DISCOVERIES AND TECHNICAL ADVANCES

There have been many exciting discoveries across all fields of astronomy and astrophysics since NWNH was published in 2010. Following decades of pioneering investment by the NSF in high-risk technologies for precision measurement, the Advanced Laser Interferometry Gravitational-wave Observatory (LIGO) accomplished the first direct detection of gravitational waves which will enable the study of the most extreme events in the universe across cosmological distances. The Kepler mission has enabled the discovery of extraordinarily diverse planets and planetary systems orbiting other stars and has demonstrated that there must be billions of Earth-sized worlds throughout our Galaxy. The completion of the Atacama Large Millimeter Array (ALMA) is the culmination of significant investment by NSF, and the array has already enabled transformational results on planet formation, the study of the mass loss in evolved stars, and supermassive blackholes in nearby galaxies. Using the Hubble Space Telescope (HST), astronomers are now able to study some of the earliest pe-

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riods of the universe's formation and have discovered hundreds of galaxies from the first billion years of cosmic history.

PROGRESS TOWARD NWNH GOALS – SPACE-BASED PROGRAMS

Wide Field Infrared Survey Telescope (WFIRST)

WFIRST, the highest-priority large space-based mission in NWNH, has evolved significantly from the 1.4-m telescope envisioned in NWNH to be a 2.4-meter telescope with larger infrared detectors, a coronagraph, and other instruments. These changes will make WFIRST an ambitious and powerful facility that will significantly advance the scientific program envisioned by NWNH and enable measurements ranging from the composition of exoplanet atmospheres to the physics of the accelerating universe. However, with the increase in scope, there is a significant risk that continued cost growth or delays could further distort the NASA program balance and limit options for the next decadal survey.

RECOMMENDATION: Prior to Key Decision Point B, NASA should commission an independent technical, management, and cost assessment of the Wide-Field Infrared Survey Telescope, including a quantitative assessment of the incremental cost of the coronagraph. If the mission cost estimate exceeds the point at which executing the mission would compromise the scientific priorities and the balanced astrophysics program recommended by the 2010 report *New Worlds, New Horizons in Astronomy and Astrophysics,* then NASA should descope the mission to restore the scientific priorities and program balance by reducing the mission cost.

Explorer Program

NASA's Explorer program has a distinguished history of high scientific impact through the deployment of relatively low-cost missions that can respond to opportunities on a short time scale. NWNH recommended a significant augmentation of the Explorer program, doubling or more than doubling the number of mission selections per decade. However, limited budgets have had a very large impact on the program, causing the first announcement of opportunity (AO) to be canceled before selection. Maintaining the budget profile is critical for this important program to succeed as envisioned by NWNH.

RECOMMENDATION: NASA's APD should execute its current plan as presented to the Committee of at least four Explorer AOs during the 2012-2021 decade, each with a Mission of Opportunity call, and each followed by mission selection.

Laser Interferometer Space Antenna (LISA)

The early operation of the European Space Agency (ESA)-led LISA Pathfinder mission (LPF) was successful and preliminary analysis has demonstrated the feasibility of many of the key technologies needed by LISA. However, because of JWST's cost increase and LISA's ranking behind WFIRST in the NWNH recommendations, it became clear early in the decade that NASA would not have resources to begin a gravitational wave space mission in the 2010s. This led to a termination of the U.S. LISA project and the loss of science and technology funding directed toward the mission. Also, ESA did not select LISA as its top large-class priority—a prerequisite in NWNH. The dramatic direct detection of gravitational waves by LIGO greatly strengthens the scientific case for a space-based mission by establishing gravitational wave astronomy as a revolutionary new probe of astrophysical phenomena.

RECOMMENDATION: NASA should restore support this decade for gravitational wave research that enables the U.S. community to be a strong technical and scientific partner in the European Space Agency (ESA)-led L3 mission, consistent with LISA's high priority in NWNH. One goal of U.S. participation should be the restoration of the full scientific capability of the mission as envisioned by NWNH.

International X-ray Observatory (IXO)

Recognizing it was unlikely that IXO could proceed in the 2010s, NWNH recommended an x-ray technology development program in preparation for the next decade that could be accelerated if ESA chose to give IXO top priority. Instead of IXO, ESA chose Athena, an X-ray mission that is reduced in scope but whose capabilities address many of the science goals of IXO, as its second-priority large mission.

RECOMMENDATION: NASA should proceed with its current plan to participate in Athena, with primary contributions directed toward enhancing the scientific capabilities of the mission.

Medium-scale Technology Development Programs

NWNH recommended two technology development programs, the New Worlds Technology Development (NWTD) Program and an Inflation Probe Technology Development (IPTD) Program. Important goals of NWTD include advancing the technology of starlight suppression and exploring options for studying habitable exoplanets. In addition to other smaller programs, the WFIRST coronagraph is now the main activity for the NWTD program, leading to a decadal investment larger than that envisioned by NWNH. Major goals of the IPTD program include measuring the polarization of cosmic microwave background radiation caused by gravitational waves created during the inflation of the universe as well as neutrino mass, gravitational lensing, and reionization science. IPTD activities are well aligned with NWNH recommendations and have led to vast improvements in the capabilities of detector systems and a new program that will identify science goals and instrument requirements for the next generation of experiments.

PROGRESS TOWARD NWNH GOALS – GROUND-BASED PROGRAMS

Large Synoptic Survey Telescope (LSST)

LSST, on schedule for first light in 2020, will survey the entire sky visible from its site in Chile and produce huge, unprecedented catalogs of objects and transient events. LSST planning and construction have progressed well and are within budget, successfully bringing together interagency, public, and private funding. To realize the full scientific potential of this great new facility, funding that enables individual investigators and groups of investigators to deliver the scientific results will be critical.

Mid-Scale Innovations Program (MSIP)

The recommended Mid-Scale Innovations Program (MSIP) is a program intended to fund projects and activities that fall between the funding boundaries of the NSF Major Research Instrumentation program and the Major Research Equipment and Facilities Construction (MREFC) program in a competed way. NSF-AST created a funding stream for MSIP by combining several existing programs and through divestment from older facilities. Despite this, the total funding for mid-scale initiatives has dropped by nearly a factor of two since the start of the decade, in stark contrast to the NWNH vision. The inability to fund these opportunities at the level envisioned by NWNH represents a significant loss of scientific opportunity.

FINDING: Despite limited resources for MSIP, NSF-AST has funded an exciting set of highly ranked proposals in a heavily oversubscribed competition. Some midscale programs recommended by NWNH have also moved forward with funding from DOE and from the NSF Physics and Polar Programs. The scientific promise of these projects confirms the NWNH expectation that a mid-scale program would enable major advances that respond nimbly to opportunities on a diverse range of science topics.

Giant Segmented Mirror Telescope (GSMT)

Participation in one of the U.S. Giant Segmented Mirror Telescope projects was given high priority by NWNH for ground-based astronomy. However, the highly constrained budget environment has prevented any significant involvement by NSF-AST in either of the two GSMT projects so far this decade.

FINDING: The Giant Magellan Telescope (GMT) and Thirty Meter Telescope (TMT) projects have both made major progress since 2010, and both offer technically feasible routes to achieving the GSMT science goals set forth by NWNH. However, programmatic hurdles remain, and neither project has secured the funding needed to complete construction at its full intended scope. NSF budget constraints have prevented the NSF's implementation of the NWNH recommendation that NSF-AST select one partner and participate in GSMT construction.

Cerenkov Telescope Array (CTA)

A worldwide team has assembled to construct the Cerenkov Telescope Array (CTA). Progress has been made in addressing new telescope concepts and array design, and construction could proceed as early as 2017, with completion in 2024, if sufficient funding is secured. U.S. groups have developed a plan for participation in CTA, but at a lower level than recommended in NWNH.

FINDING: U.S. participation in CTA at budget levels below those recommended by NWNH would still have a significant positive impact on the scientific productivity of the observatory and would give U.S. scientists leadership roles in the CTA program. If the U.S. CTA proposal competes successfully in the MSIP and NSF-Physics mid-scale programs, the NWNH recommendation can be implemented, albeit at a level lower than anticipated in 2010.

Cerro Chajnantor Atacama Telescope (CCAT)

The Cerro Chajnantor Atacama Telescope (CCAT), a submillimeter-wave survey telescope, was NWNH's sole medium-scale ground-based recommendation. The NSF Portfolio Review placed funding for MSIP at a higher priority than funding for the construction of CCAT. As a result, NSF-AST did not provide directed funding for CCAT.

FINDING: In the current budget climate, NSF-AST has not been able to fund CCAT beyond an initial contribution to the design. This is because the NSF-AST budget increases anticipated by NWNH did not materialize, and NSF-AST, consistent with the Porfolio Review's guidance, gave higher priority to funding the MSIP program within the constraints imposed by the budget.

PROGRAMMATIC CONTEXT AND BALANCE

NWNH emphasized the importance of a balanced decadal program, with a mix of large and medium-scale initiatives and strengthened core of research. To this end, the survey recommended a suite of small-scale activities spanning basic research, instrumentation, theory, and infrastructure. The agencies' success in implementing these activities has been mixed.

FINDING: Because the NSF-AST budget did not grow as assumed by NWNH, NSF-AST has not implemented the majority of the NWNH recommendations for small-scale projects or for expanded support for individual investigator programs. Support for the individual investigator programs has decreased during the first half of the decade.

The budgets of NASA-APD and NSF-AST since 2010 have been considerably different than the budgets assumed in NWNH, with varying consequences across the recommended programs.

FINDING: Despite a challenging budget environment, NASA-APD has maintained a balanced portfolio through the first half of the decade and, with the assumption of successful completion of an ambitious Explorer schedule, will do so during the second half of the decade as well. This stability, however, has been preceded by a decline in individual investigator funding during the last part of the previous decade.

The expected increase of operations costs for ALMA, the Daniel K. Inouye Solar Telescope (DKIST), and LSST by the beginning of the next decade will, in the presence of a flat NSF-AST budget, severely constrict the already squeezed mid-scale, small, and individual investigator programs and limit the community's ability to sustain a robust ground-based astronomy and astrophysics program. The remarkable scientific progress of the first half of the decade was made possible by capital investment in previous decades. Without funding for a balanced program that realizes the benefits of this decade's capital investment, the visionary scientific program put forward by NWNH will not be realized.

RECOMMENDATION: The NSF should proceed with divestment from ground-based facilities that have a lower scientific impact, implementing the recommendations of the NSF Portfolio Review, which is essential to sustaining the scientific vitality of the U.S. ground-based astronomy program as new facilities come into operation.

RECOMMENDATION: The NSF and the National Science Board should consider actions that would preserve the ability of the astronomical community to fully exploit the Foundation's capital investments in ALMA, DKIST, LSST, and other facilities. Without such action, the community will be unable to do so because at current budget levels the anticipated facilities operations costs are not consistent with the program balance that ensures scientific productivity.

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This Report in Brief was prepared by the Space Studies Board and the Board on Physics and Astronomy based on the report *New Worlds, New Horizons: A Midterm Assessment* (2016). The study was supported by NASA, NSF, and DOE. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the sponsors. Copies of the report are available free of charge from **http://www.nap.edu**. Learn more about the Space Studies Board at **http://nas.edu/ssb** and learn more about the Board on Physics and Astronomy at **http://nas.edu/bpa**.

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