New Worlds New Horizons: Midterm Assessment

Review of Progress Toward the Decadal Survey Vision in New Worlds, New Horizons in Astronomy and Astrophysics

Jacqueline Hewitt, Committee Chair, MIT

Conducted with support from NASA-APD, NSF-AST, and DOE-HEP

Committee Membership

- Jacqueline N. Hewitt, Massachusetts Institute of Technology (Chair)
- Adam S. Burrows, Princeton University
- Neil J. Cornish, Montana State University
- Andrew W. Howard, U. Hawaii-Manoa
- Bruce Macintosh, Stanford University
- Richard F. Mushotzky, University of Maryland
- Angela V. Olinto, University of Chicago
- Steven M. Ritz, University of California Santa Cruz
- Alexey Vikhlinin, Harvard-Smithsonian Center for Astrophysics
- David H. Weinberg, Ohio State University
- Rainer Weiss, Massachusetts Institute of Technology
- Eric M. Wilcots, University of Wisconsin
- Edward L. Wright, University of California Los Angeles
- A. Thomas Young, Lockheed Martin Corp. (ret.)

Statement of Task

The National Research Council shall convene an ad hoc committee of 12-15 members to review the responses of NASA's Astrophysics program, NSF's Astronomy program, and DOE's Cosmic Frontiers program (hereafter the Agencies' programs) to previous NRC advice, primarily the 2010 NRC decadal survey, "New Worlds, New Horizons in Astronomy and Astrophysics" (NWNH).

In the context of funding circumstances that are substantially below those assumed in NWNH, the committee's review will include the following tasks:

1. Describe the most significant scientific discoveries, technical advances, and relevant programmatic changes in astronomy and astrophysics over the years since the publication of the decadal survey;
2. Assess how well the Agencies' programs address the strategies, goals, and priorities outlined in the 2010 decadal survey and other relevant NRC reports;
3. Assess the progress toward realizing these strategies, goals, and priorities; and
4. In the context of strategic advice provided for the Agencies' programs by Federal Advisory Committees, and in the context of mid-decade contingencies described in the decadal survey, recommend any actions that could be taken to maximize the science return of the Agencies' programs.

The review should not revisit or alter the scientific priorities or mission recommendations provided in the decadal survey and related NRC reports but may provide guidance on implementation of the recommended science and activities portfolio and on other potential activities in preparation for the next decadal survey.

Background on Task

- The NWNH main committee report is the document of record
  - Not all panel recommendations were adopted by NWNH
- Other advisory reports considered were
  - *Evaluation of the Implementation of WFIRST/AFTA in the Context of New Worlds, New Horizons in Astronomy and Astrophysics* (National Research Council 2014)
  - *Optimizing the U.S. Ground-Based Optical and Infrared Astronomy System* (National Research Council 2014)
  - *Panel on Implementing Recommendations from New Worlds, New Horizons Decadal Survey* (National Research Council 2012)
  - *Assessment of a Plan for U.S. Participation in Euclid (National Research Council* (National Research Council 2012)
  - *The Space Science Decadal Surveys: Lessons Learned and Best Practices* (National Academies of Sciences, Engineering, and Medicine 2015)
  - Annual reports of the Astronomy and Astrophysics Advisory Committee
  - Portfolio Review Committee Report (2012)
  - Particle Physics Project Prioritization Panel Report (2014)

Input to the Committee and Engagement with Community

- Four in-person meetings between October 2015 and February 2016, including a science symposium
- Meetings included government policymakers, researchers in the community, authors of earlier advisory reports, leaders of activities recommended by NWNH, and foreign space agency representatives
- Science symposium included leading astronomers assessing scientific progress in each of the NWNH Science Frontier Panel areas
- Splinter meeting at 2016 AAS meeting
- Many Committee telecons with presentations by members of the community
- Public email box

Scientific Discoveries and Technical Advances

Chapter 1 of the report summarizes the very significant scientific progress in the first half of the decade.
Highlights:

- The detection of gravitational waves by the Laser Interferometry Gravitational-wave Observatory, initiating a discovery area anticipated by NWNH.
- The discovery of an extraordinary diversity of extrasolar planets and the establishment that planetary systems are common in our Galaxy, both enabled by the Kepler satellite. With follow-up, some planets identified as similar to Earth in size and composition.
- The discovery of hundreds of galaxies from the first billion years of cosmic history, and IGM limits from radio measurements. The beginning of the study of the Cosmic Dawn.

And rapid progress in a broad range of other topics, capitalizing on investments made in previous decades as well as in the first half of this decade.

Technical advances are also documented in Chapter 1.

The Programmatic Context

- FINDING 2-1: The NSF-AST budget through the first half of the decade has been approximately flat in real-year dollars. This budget reality is somewhat lower than that baselined by NSF for NWNH (approximately flat in inflation-adjusted dollars) and significantly lower than that assumed by NWNH (doubling in real-year dollars)
- FINDING 2-2: For NASA-APD, NWNH assumed a flat budget in inflation-adjusted dollars. The actual combined budget for NASA-APD and JWST has roughly tracked this assumption. However, the late-breaking schedule delay and associated budget increase of JWST have delayed the availability of funding for new initiatives by about 4 to 5 years.
- FINDING 2-3: At the Department of Energy (DOE), support for astrophysics has been strong, and the budget reality has been close to the baseline plan presented in NWNH.

The Programmatic Context

- FINDING 2-4: The completion and successful operation of ALMA are a remarkable success and the culmination of significant investment by NSF through the Major Research Equipment and Facilities Construction (MREFC) program.

- Other advances in facilities, instrumentation, and programmatic areas are documented in Chapter 2 of the report.

- The committee interprets “balance” to refer to a viable mix of small, medium, and large initiatives on the ground and in space that optimizes the overall scientific return of the entire U.S. astronomy enterprise viewed collectively. It does not refer to a balance of wavelengths, nor of astronomy subtopics.

The Ground-Based Program – Key Findings

- FINDING 3-1: LSST planning and construction have progressed well and are on schedule and within budget, successfully bringing together NSF funding, DOE funding, and private funding.

- FINDING 3-2: Current projections for LSST performance and data products promise transformational scientific impact, as envisioned by NWNH. 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.

The Ground-Based Program – Key Findings (con.)

- FINDING 3-3: Implementation of the NWNH recommendation of MSIP has been possible only by subsuming previous programs into MSIP and by aggressive divestment from older facilities. The total NSF-AST 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 recommendation of MSIP as a new initiative which would expand opportunities for mid-scale projects.

- FINDING 3-4: Despite limited resources for MSIP, NSF-AST has funded an exciting set of highly ranked proposals in a heavily oversubscribed competition. Some mid-scale 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.

The Ground-Based Program – Key Findings (con.)

- FINDING 3-5: 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 NSF's implementation of the NWNH recommendation that NSF-AST select one partner and participate in GSMT construction.

A further finding points out the possibility of an NSF financial contribution to capital costs only, securing telescope time for the community in exchange.

Budget constraints have also limited support for ACTA (CTA) and CCAT. The Committee endorses NSF-AST prioritization given the budget constraints.

The Ground-Based Program – Key Findings (con.) and Recommendations

- FINDING 3-12: Even following the divestment recommended by the Portfolio Review, the operations costs of ALMA, DKIST, and LSST will compromise the ability of the U.S. community to reap the scientific return from its premier ground-based facilities. Moderate increases in the NSF-AST budget would have highly leveraged science impact as a consequence of these powerful new facilities.
- RECOMMENDATION 3-1: 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 3-2: 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.

The Space-Based Program – Key Findings and Recommendations

- FINDING 4-1: The 2.4-meter telescope, larger infrared detectors, and addition of a coronagraph make the 2016 design of WFIRST an ambitious and powerful facility that will significantly advance the scientific program envisioned by NWNH, from the atmospheres of planets around nearby stars to the physics of the accelerating universe.

"...the growth in estimated cost between 2010 and 2015 was fully attributable to the combination of the coronagraph, the Guest Observer funding, and inflation."

- FINDING 4-4: At the currently estimated cost, NASA's decision to add a coronagraph to the AFTA implementation of WFIRST is justifiable within the scientific goals of NWNH. The broader societal interest in the possibility of life beyond Earth is also compelling. However, an increase in cost much beyond the currently estimated $350 million would significantly distort the science priorities set forth by NWNH.

At KDP-A in 2016, the project reported a 25% ($550 million) cost increase over the cost reported for the WFIRST-AFTA DRM in 2015.

The Space-Based Program – Key Findings (con.)

- RECOMMENDATION 4-1: 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.

The Space-Based Program – Key Findings and Recommendations

The NWNH recommendation for the Explorer program, as written, was ambiguous. The Committee is of the opinion that the plan presented by APD falls short of the recommendation, but acknowledges that community guidance may not have been clear. With the budgets currently projected for the rest of the decade, the full augmentation recommended by NWNH is probably not executable.

- RECOMMENDATION 4-3: NASA's Astrophysics Division should execute its current plan, as presented to the committee, of at least four Explorer Announcements of Opportunity during the 2012-2021 decade, each with a Mission of Opportunity call, and each followed by mission selection.

If budgets increase, executing the full Explorer augmentation would be consistent with NWNH priorities.

The Space-Based Program – Key Findings and Recommendations

The detection of gravitational waves demonstrates the laser-interferometry technique and establishes gravitational-wave (GW) astronomy as a ground-breaking new probe, as anticipated by NWNH. LPF has demonstrated key technologies for a GW space mission, and ESA has chosen GW astronomy as its L3 theme.

- RECOMMENDATION 4-4: 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 the Laser Interferometer Space Antenna's high priority in the 2010 report New Worlds, New Horizons in Astronomy and Astrophysics (NWNH). One goal of U.S. participation should be the restoration of the full scientific capability of the mission as envisioned by NWNH.

The Space-Based Program – Key Findings and Recommendations

- RECOMMENDATION 4-5: NASA should proceed with its current plan to participate in Athena, with primary contributions directed toward enhancing the scientific capabilities of the mission.

The Space-Based Program – Key Findings and Recommendations

- FINDING 4-11: The current planned decadal investment in NWNH-recommended technology development and precursor science exceeds the level envisioned in NWNH.

Growth in exoplanet technology development (NWTD), other than modest technology development for mission design, is viewed by the Committee as lower in priority than supporting GW technology development.

- FINDING 4-12: The Inflation Probe Technology Development program is well-aligned with the recommendations of NWNH, with NASA, NSF, and DOE supporting technology development and precursor science. Third-generation ground-based efforts and a suborbital program are taking place, targeting CMB B-mode polarization. The proposed CMB-S4 program would push the limits of what can be achieved from the ground and advance understanding of the technology and science requirements for a possible future space mission.

Detection of B-mode polarization was a NWNH condition for downselecting technology development for a space mission. Will be an important topic for the next decadal survey.

Comments on the Decadal Survey Process

The Committee was not resourced to do an in-depth study

- CATE is an important part of the process. Improvements might be (1) a two-stage approach and (2) better communication between proposers and reviewers while maintaining independence.
- Facilities life-cycle costs should be considered, including in addition to operations design and development, pipeline data processing, and data curating for a "prime" mission.
- Decision rules are necessary, and the planning for the decadal survey should include consideration of their implementation.
- The Committee offers discussion of the pros and cons of the NWNH structure.
- The Committee finds considerations of the State of the Profession valuable.
- To be considered in the planning for Astro2020:
    - Engagement with the philanthropic sector
    - The international context
    - Communication of budget expectations to the entire community

THANK YOU

Complete List of F&R's

- FINDING 2-1: The NSF-AST budget through the first half of the decade has been approximately flat in real-year dollars. This budget reality is somewhat lower than that baselined by NSF for NWNH (approximately flat in inflation-adjusted dollars) and significantly lower than that assumed by NWNH (doubling in real-year dollars).
- FINDING 2-2: For NASA-APD, NWNH assumed a flat budget in inflation-adjusted dollars. The actual combined budget for NASA-APD and JWST has roughly tracked this assumption. However, the late-breaking schedule delay and associated budget increase of JWST have delayed the availability of funding for new initiatives by about 4 to 5 years.
- FINDING 2-3: At DOE, support for astrophysics has been strong, and the budget reality has been close to the baseline plan presented in NWNH.
- FINDING 2-4: The completion and successful operation of ALMA are a remarkable success and the culmination of significant investment by NSF through the Major Research Equipment and Facilities Construction (MREFC) program.

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- FINDING 3-1: LSST planning and construction have progressed well and are on schedule and within budget, successfully bringing together NSF funding, DOE funding, and private funding.
- FINDING 3-2: Current projections for LSST performance and data products promise transformational scientific impact, as envisioned by NWNH. 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.
- FINDING 3-3: Implementation of the NWNH recommendation of MSIP has been possible only by subsuming previous programs into MSIP and by aggressive divestment from older facilities. The total NSF-AST 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 recommendation of MSIP as a new initiative which would expand opportunities for mid-scale projects.

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- FINDING 3-4: Despite limited resources for MSIP, NSF-AST has funded an exciting set of highly ranked proposals in a heavily oversubscribed competition. Some mid-scale 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.
- FINDING 3-5: The GMT and 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 NSF's implementation of the NWNH recommendation that NSF-AST select one partner and participate in GSMT construction.

Complete List of F&R's

•FINDING 3-6: A selection process leading to MREFC commitment to construction of a U.S.-led GSMT project, without commitment of NSF funds to GSMT facilities operations, would partially address the NWNH recommendation of U.S. federal participation in a GSMT, while retaining flexibility in the NSF-AST budget for implementation of other priorities in the next decade.

•FINDING 3-7: 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.

Complete List of F&R's

•FINDING 3-8: 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 Portfolio Review's guidance, gave higher priority to funding the MSIP program within the constraints imposed by the budget.

•FINDING 3-9: Because the NSF-AST budget did not grow at the rate 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.

•FINDING 3-10: The core grants programs AAG and ATI have declined in real-year dollars and dropped still further in purchasing power over the first half of the decade. This reduction in funding has contributed to a substantial decline in grant funding rates, threatening the scientific productivity of the U.S. ground-based astronomy program.

Complete List of F&R's

•FINDING 3-11: The combination of a flat NSF-AST budget (in real-year dollars) with new operations costs for ALMA and DKIST, and the need to sustain the individual investigator program, have led to sharp reductions in funding for mid-scale initiatives during the first half of the decade.

•FINDING 3-12: Even following the divestment recommended by the Portfolio Review, the operations costs of ALMA, DKIST, and LSST will compromise the ability of the U.S. community to reap the scientific return from its premier ground-based facilities. Moderate increases in the NSF-AST budget would have highly leveraged science impact as a consequence of these powerful new facilities.

•RECOMMENDATION 3-1: The National Science Foundation (NSF) should proceed with divestment from ground-based facilities which have a lower scientific impact, implementing the recommendations of the NSF Portfolio Review, that is essential to sustaining the scientific vitality of the U.S. ground-based astronomy program as new facilities come into operation.

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•RECOMMENDATION 3-2: 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.

•FINDING 4-1: The 2.4-meter telescope, larger infrared detectors, and addition of a coronagraph make the 2016 design of WFIRST an ambitious and powerful facility that will significantly advance the scientific program envisioned by NWNH, from the atmospheres of planets around nearby stars to the physics of the accelerating universe.

•FINDING 4-2: Because of the risk of cost growth, the concern raised in *Evaluation of the Implementation of WFIRST/AFTA* that WFIRST could distort the NASA program balance remains a concern. In addition, the delay in the implementation of WFIRST over the schedule anticipated in NWNH means that cost growth in WFIRST would limit options for the next decadal survey.

Complete List of F&R's

•FINDING 4-3: The WFIRST coronagraph responds to an opportunity that arose after NWNH, the availability of the 2.4-m AFTA telescope. This development allows a space- borne coronagraph to carry out an exciting exoplanet science program, in addition to demonstrating technology that would be needed for a future mission capable of imaging Earth-like planets around nearby stars. The addition of the coronagraph, therefore, addresses NWNH's highest medium-scale space-based priority of a New Worlds Technology Development program.

•FINDING 4-4: At the currently estimated cost, NASA's decision to add a coronagraph to the AFTA implementation of WFIRST is justifiable within the scientific goals of NWNH. The broader societal interest in the possibility of life beyond Earth is also compelling. However, an increase in cost much beyond the currently estimated $350 million would significantly distort the science priorities set forth by NWNH.

Complete List of F&R's

•FINDING 4-5: Coronagraph technology has matured rapidly over the past 2 years, addressing one of the key recommendations of the 2014 report *Evaluation of the Implementation of WFIRST/AFTA in the Context of New Worlds, New Horizons in Astronomy and Astrophysics*. The coronagraph remains a schedule, cost, and technical risk for WFIRST.

•RECOMMENDATION 4-1: 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.

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- FINDING 4-6: The unique scientific opportunity afforded by combined WFIRST/JWST observing programs favors development and launch of WFIRST on the earliest schedule that is technically and financially feasible.
- FINDING 4-7: NASA's investment in Euclid, expected to total between $150 million and $200 million by the end of the mission, is a significant augmentation of the dark energy science program budget beyond the level envisioned by NWNH and by the NRC Committee on the Assessment of a Plan for U.S. Participation in Euclid.
- RECOMMENDATION 4-2: In the remainder of the decade, NASA should treat support of Euclid participation beyond the existing commitments to the European Space Agency as lower priority than support of the Explorer program, gravity wave technology development, and X-ray technology development.

Complete List of F&R's

- RECOMMENDATION 4-3: NASA's Astrophysics Division should execute its current plan, as presented to the committee, of at least four Explorer Announcements of Opportunity during the 2012-2021 decade, each with a Mission of Opportunity call, and each followed by mission selection.
- FINDING 4-8: The first direct detection of gravitational waves by Advanced LIGO is a ground-breaking achievement that establishes gravitational wave astronomy as a revolutionary new probe of astrophysical phenomena.
- FINDING 4-9: The dissolution of the U.S. LISA project, and the attendant loss of science and technology funding, has severely impacted preparations for a space gravitational wave mission. If this situation persists, the options for significant U.S. participation in this revolutionary discovery area will be limited.
- FINDING 4-10: Results of the LPF mission have demonstrated the feasibility of many of the key technologies needed to carry out a space gravitational wave mission, and ESA has selected a gravitational wave theme for the L3 large mission opportunity. These developments address two of the main conditions identified in NWNH for U.S. participation in a gravitational wave mission.

Complete List of F&R's

- RECOMMENDATION 4-4: 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 the 2010 report *New Worlds, New Horizons in Astronomy and Astrophysics* (NWNH). One goal of U.S. participation should be the restoration of the full scientific capability of the mission as envisioned by NWNH.
- RECOMMENDATION 4-5: NASA should proceed with its current plan to participate in Athena, with primary contributions directed toward enhancing the scientific capabilities of the mission.
- FINDING 4-11: The current planned decadal investment in NWNH-recommended technology development and precursor science exceeds the level envisioned in NWNH.

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- FINDING 4-12: The Inflation Probe Technology Development program is well aligned with the recommendations of NWNH, with NASA, NSF, and DOE supporting technology development and precursor science. Third-generation ground-based efforts and a suborbital program are taking place, targeting CMB B-mode polarization. The proposed CMB-S4 program would push the limits of what can be achieved from the ground and advance understanding of the technology and science requirements for a possible future space mission.
- FINDING 4-13: NASA's implementation of NWNH's recommended small-scale activities has been mixed. Some recommended augmentations have not occurred and there have been cuts in some programs recommended for augmentation. Other programs, in particular the suborbital and exoplanet areas, have seen increases in excess of what was recommended by NWNH.

Complete List of F&R's

•FINDING 4-14: 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.